(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
28 February 2013 (28.02.2013)

WIPO | PCT

(10) International Publication Number
WO 2013/028720 A1

(51) International Patent Classification:
G02B 13/04 (2006.01) *G02B 9/12* (2006.01)
G02B 13/00 (2006.01) *G02B 11/18* (2006.01)

(21) International Application Number:
PCT/US2012/051795

(22) International Filing Date:
22 August 2012 (22.08.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
13/214,985 22 August 2011 (22.08.2011) US

(71) Applicant *(for all designated States except US)*: **BAE SYSTEMS INFORMATION AND ELECTRONIC SYSTEMS INTEGRATION INC.** [US/US]; PO Box 868, NHQ1-719, Nashua, NH 03061-0868 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **OSKOTSKY, Mark, L.** [US/US]; 151 Fenimore Road, #11B, Mamaroneck, NY 10543 (US). **RUSSO, Michael, J. Jr.** [US/US]; 13 Peppermill Road, Roslyn, NY 11576 (US).

(74) Agent: **LONG, Daniel, J.**; Bae Systems Information and Electronic, Systems Integration Inc., PO Box 868, NHQ1-719, Nashua, NH 03061-0868 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

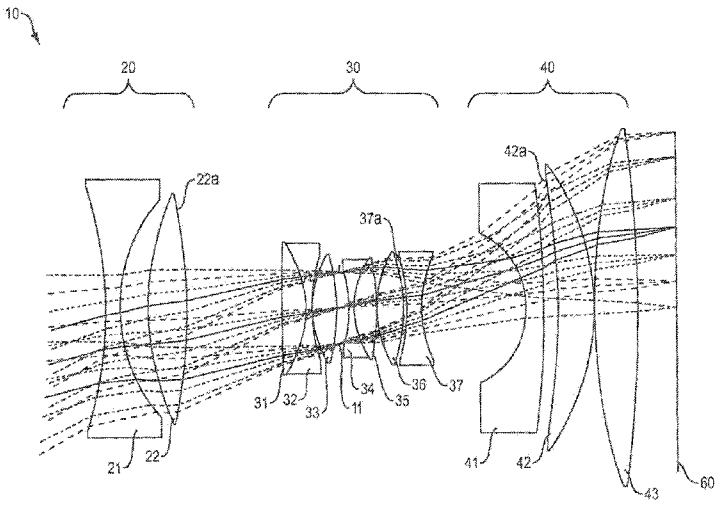
(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

(54) **Title**: LOW DISTORTION ATHERMALIZED IMAGING LENS



(57) **Abstract**: A compact, lens suitable for airborne photography and mapping has distortion less than 0.6% and is athermal from -15°C to + 40°C. The lens is near-telecentric to less than 1 1 °, apochromatic over the wavelength range 450nm - 650nm, and has a full field of view of 60° (high quality field over 53°), The lens can be secondary color corrected. In embodiments, the focal length is 101mm and the back working distance is more than 10mm. Embodiments have a focal plane diameter of 104mm and are compatible for use with a CMOS 1.8 gigapixel multiple FPA. In embodiments, the lens comprises three groups of optical elements, with an aperture located within the second optical group. In some embodiments the first group includes two elements, the second group includes six or seven elements, and the third group include three elements, in embodiments the lens (without window) is less than 180 mm long.

WO 2013/028720 A1

LOW DISTORTION ATHERMALIZED IMAGING LENS

FIELD OF THE INVENTION

The invention relates to optical lenses, and more particularly to low distortion lenses.

BACKGROUND OF THE INVENTION

Aerial mapping is a fast growing market for both military and civil applications. Aerial mapping acquires airborne image data using remote sensing and produces highly accurate topographic maps of ground regions of interest. Depending on the application, the topographic data produced by aerial mapping are used for evaluation of the dimensions and content of an observed target.

The ability of aerial mapping to provide comprehensive and detailed topographic information depends largely on the capabilities and features of the imaging lens that is used, including the distortion of the lens (whereby the image shape does not precisely reproduce the object shape, depending on the viewing angle), correction of monochromatic and polychromatic aberrations (including secondary spectrum), telecentricity, and thermal stability of the lens (ability to produce images over a required range of temperatures). Compactness and a wide field of view are also highly desirable.

U.S. Pat. No 4,333,714 (Jun. 8, 1982) discloses a reverse telephoto wide angle lens for use in interchangeable photographic cameras. The '714 lens has a wide field of view, but it is far from being telecentric, it not corrected for distortion, and its secondary spectrum is quiet large. Also this lens is not athermalized and refocus of the image plane is required to compensate for the temperature change. At least for these reasons, the '714 lens is not useable for remote aerial high resolution photography and precise mapping.

Another example of a reverse telephoto lens is disclosed in U.S. Pat. No 4,235,520 (Nov. 25, 1980). However, the '520 lens is not corrected for

distortion, and has a significant field curvature and secondary spectrum. The '520 lens is also not athermalized.

A telecentric lens is disclosed in U.S. Pat. No 6.563,650 (May 13, 2003). The '650 lens is designed to work with special beam splitters directing light onto three different LCDs. Spherical aberration is compensated in the '650 lens by the spherical aberration introduced by the beam-splitter. Distortion and secondary spectrum are not corrected.

Yet another telecentric lens is disclosed in U.S. Pat. No 6,639.653 (Oct. 28, 2003). The '653 lens has a small numerical aperture (NA) and large overall length. However, distortion and secondary spectrum are not corrected.

Still another projection lens is disclosed in U.S. Pat. No 6,038,078 (Mar. 14, 2000). The '078 lens is rather complicated, has a large overall length and a small field of view.

Yet another telecentric lens is disclosed in U.S. pat. No 5,905,596 (May 18, 1999). as with the '650 lens, spherical aberration of the '596 lens is corrected by the spherical aberration introduced by a beam-splitter, while distortion and secondary spectrum are not corrected.

Optical distortion is a function of the viewing angle. The distortion of lenses used in aerial mapping should be less than 0.5%. Such lenses should be able to operate at different altitudes, from sea level and up to 30000feet.

The index of refraction of all optical glasses varies as a function of wavelength – this is called dispersion. When the chromatic aberration is not corrected, each wavelength is focused at a different point along the optical axis. If the optical system is achromatized over a given bandwith, the outer wavelengths of the bandwidth have a common focus. The primary axial color is the difference between the focus positions of the outer wavelengths, and should be corrected to achieve good image quality by selecting glass types and lens optical powers to compensate for the axial color.

When this state of achromatization is achieved, the *primary color* is corrected. The remaining chromatic aberration is referred to as *secondary color*. Secondary color is the difference between the focus points for the outer wavelengths of the achromatized bandwidth and the central wavelength. Secondary color is the limiting axial aberration in a lens design, and may be a dominating aberration for high resolution lenses used in aerial photography and mapping.

Monochromatic and chromatic aberrations depend on the heights and angles of rays at the optical element surface and the refraction index of the material. These aberrations also depend on the shape of the optical element, and on its location with respect to the aperture stop.

The contribution of the optical element to the total axial color is proportional to the square of axial marginal ray height at the lens, its optical power, and the reciprocal of the Abbe number of the lens material.

The Abbe number V_d is given by

$$V_d = (n_d - 1) / (n_{F'} - n_{C'}) \quad (1)$$

where n_d is the index of refraction of the glass at the wavelength of the helium line d (587.6 nm), $n_{F'}$ is the index of refraction at the blue cadmium line F' (479.99 nm), and $n_{C'}$ is the index of refraction at the red cadmium line C' (643.85 nm).

Accordingly, the smaller the value of V_d, the greater the chromatic dispersion of the glass.

For the achromatic (axial color corrected) doublet, the powers and the dispersions of the elements are chosen to produce zero total dispersion by combining two elements to satisfy the following equation:

$$\Phi_1/V_1 = \Phi_2/V_2 \quad (2)$$

where

Φ_1 = the optical power of the first element,

V_1 = the Abbe number of the first element,

Φ_2 = the optical power of the second element, and

V_2 = the Abbe number of the second element.

The secondary spectrum SSdoublet for a cemented doublet of optical elements having an optical power Φ is given by:

$$SSdoublet = [(-1/\Phi)(P_1 - P_2)]/(V_1 - V_2) \quad (3)$$

where

P1 = partial dispersion of the first element, and

P2 = partial dispersion of the second element.

Partial dispersion describes dispersion for any two wavelengths with respect to the base wavelengths F′ and C′. For example, the partial dispersion P_{dF} for wavelengths d and F is defined by:

$$P_{dF} = (n_d - n_F)/(n_{F'} - n_{C'}). \quad (4)$$

Achromatic correction of a triplet is determined by the equation:

$$\Phi_1/V_1 + \Phi_2/V_2 + \Phi_3/V_3 = 0 \quad (5)$$

where

Φ_1 = the optical power of the first element,

V_1 = the Abbe number of the first element,

Φ_2 = the optical power of the second element,

V_2 = the Abbe number of the second element,

Φ_3 = the optical power of the third element, and

V_3 = the Abbe number of the third element.

The condition for the triplet apochromatic correction is:

$$P_1(\Phi_1/V_1) + P_2(\Phi_2/V_2) + P_3(\Phi_3/V_3) = 0, \quad (6)$$

Where

P_3 = partial dispersion of the third element.

As ambient temperature conditions change, the shapes and positions of optical elements in a lens will change, and the focal length and position of an image formed by the lens will change as well. This is caused by glass expansion and changes in the glass refractive index with temperature. This dependence on temperature can have a significant impact on lens performance. So as to compensate for these changes, either the focal plane array has to be adjusted along the optical axis, or some elements inside the lens have to be moved. However, this approach is highly undesirable, because additional electronics and software are needed to perform and monitor the necessary adjustments.

On the other hand, a lens does not need thermal adjustment when the change of the focus position within the required temperature range stays inside the depth of focus of the lens. The diffraction depth of focus DOF is defined by:

$$DOF = \lambda/NA^2 \qquad (7)$$

where λ is the wavelength and NA is numerical aperture at the image space

For λ = 550nm and F# 4.5 (NA = 0.111): DOF $\cong$ 0.045mm.

Therefore, in this example, if the lens design meets a requirement that all changes of the focus position over a specified range of temperature changes are inside 0.045mm, no refocusing is required.

The Opto-thermal expansion coefficient β of an optical element is a property of the glass material, and it does not depend on the focal length or shape factor of the individual optics. For a single optical element:

$$\beta = \alpha + (dn/dT)/(n-1) \qquad (8)$$

where

α = the thermal expansion coefficient of the glass

n = the refractive index of the glass at the current wavelength

T = temperature

the change of the single element optical power Φ with temperature T is given by:

$$d\Phi/dT = (\Phi)(-\beta). \quad (9)$$

For an optical system comprising more than one optical element, the total change of the optical power Φ_{system} with temperature T is:

$$d\Phi_{system}/dT = -\Phi_{systems}\Sigma(\Phi_i/\Phi_{system})(\beta_i) \quad (10)$$

where

Φ_i = optical power of a single element, and

β_i = single element Opto-thermal expansion coefficient.

Combining equations 2 and 10 allows design of an achromatic and athermalized doublet. Combining equations 2, 3 and 10 allows design of an athermalized doublet with a corrected secondary color (apochromatic correction).

Combining equations 5 and 10 allows design of an achromatic and athermalized triplet. Combining equations 5, 6 and 10 allows design of an athermalized apochromatic triplet.

Usually the partial dispersion of glasses has a linear dependence on a refractive index and Abbe number. The slope of a line connecting any two glasses determines the amount of a secondary spectrum in a doublet. The secondary spectrum can be reduced by using special glasses or materials with "abnormal" dispersion that varies non-linearly with the Abbe number, for example FK type glass (Schott) or SFPL (OHARA) or CaF_2.

What is needed, therefore, is a compact, very low distortion, near-telecentric, athermalized lens that is suitable for airborne photography and mapping.

SUMMARY OF THE INVENTION

A compact, very low distortion lens that is suitable for airborne photography and mapping has a full field of view of 60° with a high quality performance field of view of over 53°. The lens is near-telecentric to less than 11° lack of telecentricity, apochromatic over a light wavelength range of at least 450nm – 650nm, and is athermal over a temperature range from -15°C to + 40°C. Distortion of the lens is less than 0.6%. In various embodiments the focal length is 101mm and the back working distance is more than 10mm.

Embodiments have a focal plane diameter of 104mm and are compatible for use with a CMOS 1.8 gigapixel multiple FPA (focal plane array) having a 2 x 2 Bayer filter geometry and a pixel size of 2.2μm x 2.2μm, wherein each CMOS image sensor pixel includes a series of dielectric layers above the photo detector, with a micro lens on top of each pixel to focus light onto the active area of the pixel floor, thereby minimizing both the amount of light lost and the amount of light incident on adjacent photodiodes. In various embodiments, secondary color is corrected so as to take full advantage of a high resolution FPA.

In various embodiments, the lens comprises three groups of optical elements, and the aperture is located within the second optical group. In some of these embodiments, the lens has a total length of less than 180 mm (not including the optical window). In certain of these embodiments the first group includes exactly two optical elements, the second group includes at least six optical elements, and the third group includes exactly three optical elements.

In some of these embodiments, the first group of optical elements corrects the lens for pupil spherical aberration, coma, and astigmatism, the second group of optical elements corrects the lens for first order chromatic aberrations, spherical abberations, coma, and astigmatism, while also athermalizing the lens, and the third group of optical elements corrects the lens for field curvature and astigmatism.

The present invention is a low distortion lens suitable for airborne photography. The lens includes a first optical group including a plurality of optical elements, a second optical group, including a plurality of optical elements, an aperture located within the second optical group, and a third optical group, including a plurality of optical elements. The distortion of the lens is not more than 0.6%. The lens has a full field of view of at least 60°, with a quality performance field of 53°. The lens is telecentric to less than 11°. The lens is apochromatic over a range of at least 450 nm to 650 nm. And the lens is athermal over a temperature range of at least -15 °C to +40 °C.

In embodiments, the first optical group includes exactly two optical elements, and the third optical group includes exactly three optical elements. In some of these embodiments the second optical group includes exactly six optical elements. And in other of these embodiments the second optical group includes exactly seven optical elements.

In various embodiments, the lens has a focal plane of at least 104 mm. In some of these embodiments the lens is compatible for use with a CMOS 1.8 gigapixel multiple FPA (focal plane array) having a 2 x 2 Bayer filter geometry and a pixel size of 2.2μm x 2.2μm, wherein each CMOS image sensor pixel includes a series of dielectric layers above the photo detector, with a micro lens on top of each pixel to focus light onto the active area of the pixel floor, thereby minimizing both the amount of light lost and the amount of light incident on adjacent photodiodes.

In certain embodiments the lens has a length which does not exceed 180mm, an optical window not being included in the length. In some embodiments at least one surface of one of the optical elements in each of at least two of the optical groups is aspherical. And in other embodiments the first group of optical elements corrects the lens for pupil spherical aberration, coma, and astigmatism, the second group of optical elements corrects the lens for first order chromatic aberrations, spherical abberations, coma, and astigmatism, while also athermalizing the lens, and the third group of optical elements corrects the lens for field curvature and astigmatism.

In various embodiments:

the first optical group has a positive optical power;

the second optical group has a positive optical power;

the third optical group has a positive optical power;

the first optical group includes two optical elements having, in order, a negative optical power and a positive optical power respectively, the first optical group being arranged to converge light received from an object and to direct the converged light onto the second optical group;

the second optical group includes seven optical elements having, in order, a positive optical power, a negative optical power, a positive optical power, a negative optical power, a positive optical power, a positive optical power, and a negative optical power, the second optical group being arranged to converge light received from the first optical group and to direct the converged light onto the third optical group;

the third optical group includes three optical elements having, in order, a negative optical power, a positive optical power, and a positive optical power, the third optical group being arranged to focus the light from the second optical group onto an imaging surface; and

the optical groups and optical elements satisfy the relationships given in paragraph [0092] below.

In some of these embodiments both the first optical element and the second optical element of the first optical group are double concave lenses. In some of these embodiments the second surface of the second optical element of the first optical group is aspherical.

In other of these embodiments the first optical element of the second optical group is a double convex lens, the second optical element of the second optical group is a double concave lens, the third optical element of the second optical group is a double convex lens, the fourth optical element of the second optical group is a double concave lens, the fifth optical element of the second optical group is a double convex lens, the sixth optical element of the second optical group is a double convex lens, and the seventh optical element of the second

optical group is a double concave lens. In some of these embodiments the first surface of the seventh optical element of the second optical group is aspherical. In some of these embodiments the first and second optical elements of the second optical group are cemented to one another. In other of these embodiments the fourth and fifth optical elements of the second optical group are cemented to one another.

In still other of these embodiments the aperture stop is located between the third and fourth optical elements of the second optical group.

In yet other of these embodiments the first optical element of the third optical group is shaped as a negative meniscus lens whose concave surface faces toward the object, the second optical element of the third optical group is a positive meniscus lens whose concave surface faces toward the object, and the third optical element of the third optical group is a double convex lens. In some of these embodiments the first optical element of the third optical group is made from CaF2. In other of these embodiments the first surface of the second optical element of the third optical group is aspherical.

In certain embodiments:

the first optical group has a negative optical power;

the second optical group has a positive optical power;

the third optical group has a positive optical power;

the first optical group includes two optical elements having, in order, a negative optical power and a positive optical power respectively, the first optical group being arranged to converge light received from an object and to direct the converged light onto the second optical group;

the second optical group includes seven optical elements having, in order, a positive optical power, a negative optical power, a positive optical power, a negative optical power, a positive optical power, a positive optical power, and a negative optical power, the second optical group being arranged to converge light received from the first optical group and to direct the converged light onto the third optical group;

the third optical group includes three optical elements having, in order, a negative optical power, a positive optical power, and a positive optical power, the third optical group being arranged to focus the light from the second optical group onto an imaging surface; and

the optical groups and optical elements satisfy the relationships given in paragraph [00104] below.

In some of these embodiments both the first optical element and the second optical element of the first optical group are double concave lenses. In some of these embodiments the second surface of the second optical element of the first optical group is aspherical.

In other of these embodiments the first optical element of the second optical group is a double convex lens, the second optical element of the second optical group is a double concave lens, the third optical element of the second optical group is a double convex lens, the fourth optical element of the second optical group is a double concave lens, the fifth optical element of the second optical group is a double convex lens, the sixth optical element of the second optical group is a double convex lens, and the seventh optical element of the second optical group is a double concave lens.

In some of these embodiments the first surface of the seventh optical element of the second optical group is aspherical. In other of these embodiments the first and second optical elements of the second optical group are cemented to one another. And in still other of these embodiments the fourth and fifth optical elements of the second optical group are cemented to one another.

In yet other of these embodiment the aperture stop is located between the third and fourth optical elements of the second optical group.

In certain of these embodiment the first optical element of the third optical group is shaped as a negative meniscus lens whose concave surface faces toward the object, the second optical element of the third optical group is a positive meniscus lens whose concave surface faces toward the object, and the third optical element of the third optical group is a double convex lens. In

some of these embodiments the first optical element of the third optical group is made from CaF2. And in other of these embodiments the first surface of the second optical element of the third optical group is aspherical.

In various embodiments:

all three optical groups have positive optical powers;

the first optical group includes two optical elements having, in order, a negative optical power and a positive optical power respectively, the first optical group being arranged to converge light received from an object and to direct the converged light onto the second optical group;

the second optical group includes six optical elements having, in order, a negative optical power, a positive optical power, a negative optical power, a positive optical power, a positive optical power, and a negative optical power, the second optical group being arranged to converge light received from the first optical group and to direct the converged light onto the third optical group;

the third optical group includes three optical elements having, in order, a negative optical power, a positive optical power, and a positive optical power, the third optical group being arranged to focus the light from the second optical group onto an imaging surface; and

the optical groups and optical elements satisfy the relations given in paragraph [00115] below.

In some of these embodiments the first optical element of the first optical group is a double concave lens, and the second optical element of the first optical group is a double convex lens. And in some of these embodiments the second surface of the second optical element of the first optical group is aspherical.

In certain of these embodiments the first optical element of the second optical group is a double concave lens, the second optical element of the second optical group is a double convex lens, the third optical element of the second optical group is a double concave lens, the fourth optical element of the second

optical group is a double convex lens, the fifth optical element of the second optical group is a double convex lens, and the sixth optical element of the second optical group is a double concave lens. In some of these embodiments the first surface of the sixth optical element of the second optical group is aspherical. In other of these embodiments the third and fourth optical elements of the second optical group are cemented to one another.

In some of these embodiments the aperture stop is located between the second and third optical elements of the second optical group.

In other of these embodiments the first optical element of the third optical group is shaped as a negative meniscus lens whose concave surface faces toward the object, the second optical element of the third optical group is a positive meniscus lens whose concave surface faces toward the object, and the third optical element of the third optical group is a double convex lens. And in some of these embodiments the first surface of the second optical element of the third optical group is aspherical.

The features and advantages described herein are not all-inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification, and claims. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and not to limit the scope of the inventive subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a cross sectional side view illustrating a first embodiment of the present invention;

Fig. 2 presents a wave front analysis of the embodiment of Fig. 1;

Fig. 3 is a graph presenting MTF data for the embodiment of Fig. 1;

Fig. 4 includes a plurality of graphs presenting RIM RAY curves for the embodiment of Fig. 1;

Fig. 5A presents a graph of field aberration data for the embodiment of Fig. 1;

Fig. 5B presents a graph of distortion data for the embodiment of Fig. 1;

Fig. 6 is a graph presenting environmental analysis for the embodiment of Fig. 1;

Fig. 7 is a listing of properties of optical elements for the embodiment of Fig. 1;

Fig. 8 is a cross sectional side view illustrating a second embodiment of the present invention;

Fig. 9 presents a wave front analysis of the embodiment of Fig. 8;

Fig. 10 is a graph presenting MTF data for the embodiment of Fig. 8;

Fig. 11 includes a plurality of graphs presenting RIM RAY curves for the embodiment of Fig. 8;

Fig. 12A presents a graph of field aberration data for the embodiment of Fig. 8;

Fig. 12B presents a graph of distortion data for the embodiment of Fig. 8;

Fig. 13 is a graph presenting environmental analysis for the embodiment of Fig. 8;

Fig. 14 is a listing of properties of optical elements for the embodiment of Fig. 8;

Fig. 15 is a cross sectional side view illustrating a third embodiment of the present invention;

Fig. 16 presents a wave front analysis of the embodiment of Fig. 15;

Fig. 17 is a graph presenting MTF data for the embodiment of Fig. 15;

Fig. 18A includes a plurality of graphs presenting RIM RAY curves for the embodiment of Fig. 15;

Fig. 18B includes a plurality of graphs presenting additional RIM RAY curves for the embodiment of Fig. 15;

Fig. 19A presents a graph of field aberration data for the embodiment of Fig. 15;

Fig. 19B presents a graph of distortion data for the embodiment of Fig. 15;

Fig. 20 is a graph presenting environmental analysis for the embodiment of Fig. 15; and

Fig. 21 is a listing of properties of optical elements for the embodiment of Fig. 15.

DETAILED DESCRIPTION

The present invention is a compact, very low distortion lens that is suitable for airborne photography and mapping has a full field of view of 60° with a high quality performance field of view of over 53°. The lens is near-telecentric to less than 11°, apochromatic over a light wavelength range of at least 450nm – 650nm, and is athermal over a temperature range from -15°C to + 40°C. Distortion of the lens is less than 0.5%. In various embodiments the focal length is 101mm and the back working distance is more than 10mm.

Fig.1 is a cross-sectional illustration of a first embodiment of the lens 10 of the present invention. The lens 10 includes a first optical group 20, a second optical group 30 and a third optical group 40 in order from the object to the image plane. The aperture stop 11 is positioned inside the second optical group 30. An image of a distant object is formed on a focal plane array 60. In embodiments, the focal plane array incorporates CMOS with micro lenses, 2 x 2 Bayer filter geometry, and 1.8 Giga pixels. In other applications the image surface 60 may constitute CCD or a direct viewing screen.

In the embodiment of Fig. 1 the first optical group 20 has an overall positive optical power and is configured to receive light from a remote object and to direct the converged light onto the second optical group 30. The first optical

group 20 includes two optical elements 21 and 22, having negative and positive optical powers respectively. As seen in Fig. 1, the first optical element 21 of the first optical group 20 has a negative optical power and is a double concave lens. The second optical element 22 has a positive optical power and is double convex lens. The second surface 22a of the second element 22 of the first optical group may be aspherical so as to reduce the F number of the lens 10. The mutual configuration of the two optical elements 21, 22 of the first optical group 20 corrects the lens for pupil spherical aberration, spherical aberration, coma and astigmatism without introducing a distortion, while satisfying relationships required among the optical elements to achieve high resolution of the lens 10.

The second optical group 30 has a positive overall optical power and is configured to further converge light from the first optical group 20 and to direct diverged light onto the third optical group 40. The second optical group 20 includes seven optical elements 31, 32, 33, 34, 35, 36 and 37, having a positive optical power, a negative optical power, a positive optical power, a negative optical power, a positive optical power, a positive optical power and a negative optical power respectively. The aperture stop 11 is located within the second optical group 30 between optical elements 33 and 34. The position of the aperture stop inside the second optical group allows correction of the telecentricity and improves the compactness of the lens 10.Optical elements 31 and 32 and optical elements 34 and 35 may be cemented to one another as explained in more detail below.

The first optical element 31 of the second optical group 30 is a double convex lens, the second optical element 32 is a double concave lens, the third optical element 33 is a double convex lens, the fourth optical element 34 is a double concave lens, the fifth optical element 35 is a double convex lens, the sixth optical element 36 is a double convex lens, and the seventh optical element 37 is a double concave lens.

As mentioned supra, the first optical element 31 and the second optical element 32 of the second optical group 30 may be cemented to one another for the axial

and secondary color correction (apochromatic correction) in the lens 10. Optical elements 34 and 35 may be cemented to one another for the same reason. In various embodiments the first surface 37a of the seventh optical element 37 is spherical so as to compensate for residual monochromatic aberrations across the field of view.

The mutual configuration and choice of glasses of the elements in the second optical group 30 corrects the lens for first order chromatic aberrations, spherical aberration, coma, and astigmatism, while achieving athermalization of the lens 10 through the desired spectrum of 450nm – 650nm.

The third optical group 40 has a positive overall power and is configured to further converge the light from the second optical group 30 and to focus the light onto the focal plane array 60. The third optical group 30 includes optical elements 41, 42, and 43 having a negative optical power, a positive optical power, and a positive optical power respectively. The first and second optical elements 41 42 of the third optical group 40 are shaped as negative meniscus lenses whose concave surfaces faces toward the object. The third optical element 43 is a double convex lens. The mutual configuration of the third optical group elements corrects the lens 10 for field curvature and astigmatism. In some embodiments the first surface 42a of the second optical element 42 is aspherical so as to correct residual coma, astigmatism and distortion across the field of view while achieving near telecentricity.

The mutual combination of glasses refractive indices and Abbe numbers of the optical elements in the optical groups 20, 30 and 40 provides achromatic correction of the lens 10. The axial color is corrected. Moreover the combination of partial dispersions of the glasses used for the optical elements provides apochromatic correction, i.e. correction of the secondary color in the lens 10. The mutual combination of changes of refractive index with temperature of the optical elements provides athermalization of the lens 10.

In the embodiment of Figure 1, the optical groups 20, 30, 40 and their constituent optical elements satisfy the following relations.

$0.09<F'_{10}/F'_{20}<0.14$

$0.8<F'_{10}/F'_{30}<1.2$

$0.1<F'_{10}/F'_{40}<0.15$

$0.65<n_{21}/n_{22}<0.95$

$0.75<n_{21}/n_{31}=n_{21}/n_{35}=n_{21}/n_{32}=n_{21}/n_{34}<0.95$

$1.05<n_{31}/n_{33}<1.3$

$0.95<n_{31}/n_{36}<1.35$

$0.75<n_{36}/n_{37}<1.1$

$0.85<n_{21}/n_{41}<1.15$

$0.65<n_{41}/n_{42}<0.9$

$0.7<n_{43}/n_{43}<0.95$

$1.35<V_{21}/V_{22}<1.65$

$1.45<V_{21}/V_{31}=V_{21}/V_{35}<1.7$

$0.95<V_{31}/V_{32}=V_{35}/V_{34}<1.1$

$0.9<V_{21}/V_{33}<1.1$

$0.9<V_{21}/V_{36}<1.1$

$1.55<V_{21}/V_{37}<1.75$

$0.55<V_{21}/V_{41}<0.75$

$2.4<V_{21}/V_{42}<2.8$

$1.5<V_{21}/V_{43}<1.9$

$0.0025<P_{41}/V_{41}<0.0035$

$0.095<P_{42}/V_{42}<0.0135$

$0.2<dn/dT_{21}/dn/dT_{22}<0.35$

$0.35<dn/dT_{21}/dn/dT_{31}=dn/dT_{21}/dn/dT_{35}<0.55$

$0.9<dn/dT_{21}/dn/dT_{33}<1.1$

$0.9<dn/dT_{21}/dn/dT_{36}<1.1$

$0.3<dn/dT_{21}/\ dn/dT_{37}<0.4$

$-0.15<dn/dT_{21}/\ dn/dT_{41}<-0.09$

$0.9<dn/dT_{21}/\ dn/dT_{42}<1.25$

$0.18<dn/dT_{21}/\ dn/dT_{43}<0.25$

wherein:

F'_{10} is the focal length of the lens 10;

F'_{20}, F'_{30} and F'_{40} are focal lengths of the first, the second and the third optical groups 20, 30 and 40;

n_{21} and n_{22} are refractive indices for the optical elements 21 and 22 of the first optical group;

n_{31}, n_{32}, n_{33}, n_{34}, n_{35}, n_{36} and n_{37} are refractive indices for the optical elements 31, 32, 33, 34, 35, 36 and 37 of the second optical group 30;

n_{41}, n_{42} and n_{43} are refractive indices for the optical elements 41, 42 and 43 of the third optical group 40;

V_{21} and V_{22} are Abbe numbers for the optical elements 21 and 22 of the first optical group 20;

V_{31}, V_{32}, V_{33}, V_{34}, V_{35}, V_{36} and V_{37} are Abbe numbers for the optical elements 31, 32, 33, 34, 35, 36 and 37 of the second optical group 30;

V_{41}, V_{42}, and V_{43} are Abbe numbers for the optical elements 41, 42, and 43 of the third optical group 40;

P_{41} is the partial dispersion for the optical element 41 of the third optical group 40;

P_{42} is the partial dispersion for the optical element 42 of the third optical group 40;

dn/dT_{21} is the refractive index change with temperature for the first optical element 21of the first optical group 20;

dn/dT_{22} is the refractive index change with temperature for the second optical element 22of the first optical group 20;

dn/dT_{31} is the refractive index change with temperature for the first optical element 31of the second optical group 30;

dn/dT_{33} is the refractive index change with temperature for the third optical element 33of the second optical group 30;
dn/dT_{34} is the refractive index change with temperature for the fourth optical element 34 of the second optical group 30;
dn/dT_{35} is the refractive index change with temperature for the fifth optical element 35 of the second optical group 30;
dn/dT_{36} is the refractive index change with temperature for the sixth optical element 36 of the second optical group 30;
dn/dT_{37} is the refractive index change with temperature for the seventh optical element 37 of the second optical group 30;
dn/dT_{41} is the refractive index change with temperature for the first optical element 41 of the third optical group 40;
dn/dT_{42} is the refractive index change with temperature for the second optical element 42 of the third optical group 40; and
dn/dT_{43} is the refractive index change with temperature for the third optical element 43 of the third optical group 40.

The selection of the optical powers of the optical groups and elements, the selection of the refractive indices, the Abbe numbers, and the partial dispersions of the glasses as well as their dn/dT values, provides a high resolution imaging lens with chromatic and apochromatic correction while the defocusing caused by changes in temperature is less than the depth of focus of the lens.

Wave front and MTF data for the embodiment of Fig. 1 are presented in Fig. 2 and Fig.3 respectively. The wave front is well corrected over the whole spectrum.. The polychromatic MTF shows good resolution and contract over the entire field.

RIM RAY curves for the embodiment of Fig. 1 are presented in Fig. 4. They show the spherical aberration, coma and chromatic correction over the wavelength range of 450nm – 650nm. Astigmatism data is presented in Fig.5A, and distortion data is presented in Fig.5B. The field is flat and the distortion is corrected to less than 0.2% over the entire field. The change of

the focus with temperature is presented in Fig. 6. The amount of defocus over the temperature range of -15° to 45° is 0.0025mm, which is almost 20 times less than the depth of focus of 0.045mm. The lack of telecentricity is less than 10.7° across the field. A prescription of the lens 10 is presented in Fig. 7. The optical materials include optical glass and CaF2 materials that are common and widely available commercially.

Fig.8 is a cross-sectional illustration of a second embodiment of the lens 100 of the present invention. This embodiment is essentially identical to the embodiment of Fig. 1, except for the specific relations that the optical elements satisfy. In particular, the lens 100 includes a first optical group 200, a second optical group 300 and a third optical group 400 in order from the object to the image plane. The aperture stop 110 is positioned inside the second optical group 300. An image of a distant object is formed on a focal plane array 600. In embodiments, the focal plane array incorporates CMOS with micro lenses, 2 x 2 Bayer filter geometry, and 1.8 Giga pixels. In other applications the image surface 600 may constitute CCD or a direct viewing screen.

In the embodiment of Fig. 8 the first optical group 200 has an overall negative optical power and is configured to receive light from a remote object and to direct the diverged light onto the second optical group 300. The first optical group 200 includes two optical elements 210 and 220, having negative and positive optical powers respectively. As seen in Fig. 8, the first optical element 210 of the first optical group 200 has a negative optical power and is a double concave lens. The second optical element 220 has a positive optical power and is double convex lens. The second surface 220a of the second element 220 of the first optical group may be aspherical so as to reduce the F number of the lens 100. The mutual configuration of the two optical elements 210, 220 of the first optical group 200 corrects the lens for pupil spherical aberration, spherical aberration, coma and astigmatism without introducing a distortion, while satisfying relationships required among the optical elements to achieve high resolution of the lens 100.

The second optical group 300 has a positive overall optical power and is configured to further converge light from the first optical group 200 and to direct diverged light onto the third optical group 40. The second optical group 200 includes seven optical elements 310, 320, 330, 340, 350, 360, and 370, having a positive optical power, a negative optical power, a positive optical power, a negative optical power, a positive optical power, a positive optical power and a negative optical power respectively. The aperture stop 110 is located within the second optical group 300 between optical elements 330 and 340. The position of the aperture stop inside the second optical group allows correction of the telecentricity and improves the compactness of the lens 10. Optical elements 310 and 320 and optical elements 340 and 350 may be cemented to one another as explained in more detail below.

The first optical element 310 of the second optical group 300 is a double convex lens, the second optical element 320 is a double concave lens, the third optical element 330 is a double convex lens, the fourth optical element 34 is a double concave lens, the fifth optical element 350 is a double convex lens, the sixth optical element 360 is a double convex lens, and the seventh optical element 370 is a double concave lens.

As mentioned supra, the first optical element 310 and the second optical element 320 of the second optical group 300 may be cemented to one another for the axial and secondary color correction (apochromatic correction) in the lens 100. Optical elements 340 and 350 may be cemented to one another for the same reason. In various embodiments the first surface 370a of the seventh optical element 370 is spherical so as to compensate for residual monochromatic aberrations across the field of view.

The mutual configuration and choice of glasses of the elements in the second optical group 300 corrects the lens for first order chromatic aberrations, spherical aberration, coma, and astigmatism, while achieving athermalization of the lens 100 through the desired spectrum of 450nm – 650nm.

The third optical group 400 has a positive overall power and is configured to further converge the light from the second optical group 300 and to focus the light onto the focal plane array 600. The third optical group 30 includes optical elements 410, 420, and 430 having a negative optical power, a positive optical power, and a positive optical power respectively. The first and second optical elements 410 420 of the third optical group 400 are shaped as negative meniscus lenses whose concave surfaces faces toward the object. The third optical element 430 is a double convex lens. The mutual configuration of the third optical group elements corrects the lens 100 for field curvature and astigmatism. In some embodiments the first surface 420a of the second optical element 420 is aspherical so as to correct residual coma, astigmatism and distortion across the field of view while achieving near telecentricity.

The mutual combination of glasses refractive indices and Abbe numbers of the optical elements in the optical groups 200, 300, and 400 provides achromatic correction of the lens 100. The axial color is corrected. Moreover the combination of partial dispersions of the glasses used for the optical elements provides apochromatic correction, i.e. correction of the secondary color in the lens 100. The mutual combination of changes of refractive index with temperature of the optical elements provides athermalization of the lens 100.

In the embodiment of Fig. 8, the optical groups 200, 300, 400 and their constituent optical elements satisfy the following relations.

$-0.1<F'_{100}/ F'_{200}<-0.07$

$1.35<F'_{100}/ F'_{300}<1.55$

$0.17<F'_{100}/ F'_{400}<0.19$

$0.70<n_{210}/ n_{220}<0.90$

$0.80<n_{210}/ n_{310}=n_{210}/ n_{350}=n_{210}/ n_{320}=n_{210}/ n_{340}<1$

$1<n_{310}/ n_{330}<1.25$

$0.9<n_{310}/ n_{360}<1.3$

$0.65<n_{360}/ n_{370}<1.05$

$0.80<n_{210}/\ n_{410}<1.1$

$0.7<n_{410}/\ n_{420}<0.85$

$0.8<n_{410}/\ n_{430}<0.95$

$1.55<V_{210}/V_{220}<1.85$

$1.4<V_{210}/V_{310}=V_{210}/V_{350}<1.65$

$0.85<V_{310}/V_{320}=V_{350}/V_{340}<1.15$

$0.85<V_{210}/V_{330}<1$

$0.95<V_{210}0V_{360}<1.1$

$1.6<V_{210}/V_{370}<1.8$

$0.85<V_{210}/V_{410}<1.2$

$2.2<V_{210}/V_{420}<2.6$

$1.45<V_{210}/V_{430}<1.75$

$0.0035<P_{410}/V_{410}<0.0055$

$0.1<P_{420}/V_{420}<0.015$

$0.15<dn/dT_{210}/\ dn/dT_{220}<0.3$

$0.4<dn/dT_{210}/\ dn/dT_{310}=\ dn/dT_{210}/\ dn/dT_{305}<0.6$

$0.85<dn/dT_{210}/dn/dT_{330}<1.05$

$0.8<dn/dT_{210}/\ dn/dT_{360}<1.1$

$0.35<dn/dT_{210}/\ dn/dT_{370}<0.5$

$0.9<dn/dT_{210}/\ dn/dT_{410}<1.2$

$0.85<dn/dT_{210}/\ dn/dT_{420}<1.3$

$0.15<dn/dT_{210}/\ dn/dT_{430}<0.3$

where:

F'_{100} is the focal length of the lens 100;

F'_{200}, F'_{300} and F'_{400} are focal lengths of the first, the second and the third optical groups 200, 300 and 400;

n_{210} and n_{220} are refractive indices for the optical elements 210 and 220 of the first optical group;

n_{310}, n_{320}, n_{330}, n_{340}, n_{350}, n_{360} and n_{370} are refractive indices for the optical elements 310, 320, 330, 340, 350, 360 and 370 of the second optical group 300;

n_{410}, n_{420} and $n_{430}$are refractive indices for the optical elements 410, 420 and 430 of the third optical group 400;

V_{210} and V_{220} are Abbe numbers for the optical elements 410 and 420 of the first optical group 200;

V_{310}, V_{320}, V_{330}, V_{340}, V_{350}, V_{360} and V_{370} are Abbe numbers for the optical elements 310, 320, 330, 340, 35, 360 and 370 of the second optical group 300;

P_{410} is the partial dispersion for the optical element 410of the third optical group 400;

P_{420} is the partial dispersion for the optical element 420of the third optical group 400;

dn/dT_{210} is the refractive index change with temperature for the first optical element 210of the first optical group 200;

dn/dT_{220} is the refractive index change with temperature for the second optical element 220 of the first optical group 200;

dn/dT_{310} is the refractive index change with temperature for the first optical element 310of the second optical group 300;

dn/dT_{330} is the refractive index change with temperature for the third optical element 330 of the second optical group 300;

dn/dT_{350} is the refractive index change with temperature for the fifth optical element 350 of the second optical group 300;

dn/dT_{360} is the refractive index change with temperature for the sixth optical element 360 of the second optical group 300;

dn/dT_{370} is the refractive index change with temperature for the seventh optical element 370 of the second optical group 300;

dn/dT_{410} is the refractive index change with temperature for the first optical element 410 of the third optical group 400;

dn/dT_{420} is the refractive index change with temperature for the second optical element 420 of the third optical group 400; and

dn/dT_{430} is the refractive index change with temperature for the third optical element 430 of the third optical group 400.

The selection of the optical powers of the optical groups and elements, the selection of the refractive indices, the Abbe numbers, and the partial dispersions, of the glasses as well as their dn/dT values, provides a high resolution imaging lens with chromatic and apochromatic correction while the defocusing caused by changes in temperature is less than the depth of focus of the lens.

Wave front and MTF data for the embodiment of Fig. 8 is presented in Fig. 9 and Fig.10 respectively. The wave front is well corrected over the whole spectrum and is polychromatic. The MTF shows good resolution and contract over the entire field. The RIM RAY curves in Fig. 11 show the spherical aberration, coma and chromatic correction over the wavelength range of 450nm – 650nm. Astigmatism data is presented in Fig.12A, and distortion data is presented in Fig.12B. The field is flat and distortion is corrected to less than 0.3% over the entire field of view.

The change of the focus with temperature is presented in Fig. 13. The defocus over the temperature range of -15° to 45° is 0.028mm, which is 1.6 times less than depth of focus of 0.045mm. Lack of telecentricity is less than 9.2° across the field of view. A prescription of the lens 100 is presented in Fig. 14. The optical materials used include optical glasses that are common and widely available commercially.

Fig.15 is a cross-sectional illustration of a third embodiment of the lens 1000 of the present invention. The lens 1000 includes a first optical group 700, a second optical group 800 and a third optical group 900 in the stated order from the object to the image plane. Aperture stop 80 is positioned inside the second optical group 800. An image of a distant object is formed on a focal plane array 90. In some embodiments, the focal plane array incorporates CMOS with micro lenses, 2 x 2 Bayer filter geometry, and 1.8 Giga pixels. In other

embodiments the image surface 60 incorporates CCD or a direct viewing screen.

The first optical group 700 has an overall positive optical power and is configured to receive light from the remote object and to direct the converged light onto the second optical group 800. The first optical group 700 includes two optical elements 701 and 702, having negative and positive optical powers respectively. As shown in Fig. 15, the first optical element 701 of the first optical group 700 has a negative optical power and is a double concave lens. The second optical element 702 of the first optical group 700 has a positive optical power and is a double convex lens. In various embodiments, the second surface 702a of the second optical element 702 is aspherical so as to reduce the F number of the lens 1000. The mutual configuration of the two optical elements 701, 702 of the first optical group 700 provides correction of pupil spherical aberration, coma, and astigmatism without introducing a distortion, while satisfying relationships required among the optical elements that provide the required performance of the lens 700.

The second optical group 800 has a positive overall optical power and is configured to further converge light from the first optical group 700 and to direct the converged light onto the third optical group 900. The second optical group 800 includes six optical elements 801, 802, 803, 804, 805 and 806 having a negative optical power, a positive optical power, a negative optical power, a positive optical power, a positive optical power, and a negative optical power respectively. The aperture stop 80 is located between the optical elements 802 and 803. Elements 803 and 804 can be cemented to one another as described in more detail below. The first optical element 801 of the second optical group 800 is a single concave lens, the second optical element 802 is a double convex lens, the third optical element 803 is a double concave lens, the fourth and fifth optical elements 804 805 are double convex lenses, and the sixth optical element 806 is a double concave lens. The location of the aperture stop 80 inside the second optical group provides correction of telecentricity and compactness of the lens 1000.

Further, as mentioned supra, the third optical element 803 and the fourth optical element 804 of the second optical group 800 can be cemented to one another for axial and secondary color correction (apochromatic correction) of the lens 1000. In embodiments, the first surface 806a of the sixth optical element 806 is aspherical so as to compensate residual monochromatic aberrations across the field of view.

The mutual configuration and choices of glasses for the optical elements in the second optical group 800 provides correction of chromatic aberrations, spherical aberration and coma, and astigmatism through the desired wavelength range of 450nm – 650nm, while achieving athermalization of the lens 1000.

The third optical group 900 has a positive overall power and is configured to further converge the light from the second optical group 800 and to focus the light onto the focal plane array 90. The third optical group includes optical elements 901, 902 and 903 having a negative optical power, a positive optical power, and a positive optical power respectively. The first optical element 901 of the third optical group 400 is shaped as a negative meniscus lens whose concave surface faces toward the object. The second optical element 902 of the third optical group is shaped as a positive meniscus lens whose concave surface faces toward the object. The third optical element 903 is a double convex lens. The mutual configuration of the third optical group elements provides correction of field curvature, distortion, and astigmatism across the field of view. In embodiments, the first surface 902a of the second optical element 902 is aspherical so as to correct residual coma, astigmatism and distortion while achieving near-telecentricity in the lens 1000.

The mutual combination of refractive indices and Abbe numbers of the optical elements in the optical groups 700, 800 and 900 provides achromatic and apochromatic correction of the lens 1000. The mutual combination of changes of refractive index with temperature provides athermalization of the lens 1000.

In the embodiment of Fig. 15, the optical groups 700, 800, 900 and their constituent optical elements satisfy the following relations.

$2.6<F'_{1000}/ F'_{700}<3.4$

$2<F'_{1000}/ F'_{800}<2.6$

$2.2<F'_{1000}/ F'_{900}<2.7$

$0.65<n_{701}/ n_{702}<0.95$

$0.75<n_{701}/ n_{801} = n_{701}/ n_{803} = n_{701}/ n_{804} = n_{701}/ n_{806}<1$

$0.95<n_{801}/ n_{802} = n_{801}/ n_{805}<1.25$

$0.90<n_{701}/ n_{901}<1.15$

$0.7<n_{901}/ n_{902}<0.9$

$0.75<n_{801}/ n_{903}<0.95$

$1.35<V_{701}/V_{702}<1.7$

$1.4<V_{701}/V_{801} = V_{701}/V_{803} = V_{701}/V_{806}<1.8$

$0.45<V_{801}/V_{802} = V_{801}/V_{805} = <0.75$

$0.85<V_{803}/V_{804}<1.15$

$0.85<V_{701}/V_{901}<1.15$

$2.4<V_{701}/V_{902}<2.8$

$1.55<V_{701}/V_{903}<1.85$

$0.004<P_{901}/V_{901}<0.006$

$0.95<P_{902}/V_{902}<0.015$

$0.2<dn/dT_{701}/ dn/dT_{702}<0.35$

$0.25<dn/dT_{701}/ dn/dT_{801} = dn/dT_{701}/ dn/dT_{803} = dn/dT_{701}/ dn/dT_{806}<0.45$

$0.85<dn/dT_{701}/dn/dT_{802} = dn/dT_{701}/dn/dT_{805}<<1.15$

$0.4<dn/dT_{701}/ dn/dT_{804}<0.6$

$0.8<dn/dT_{701}/ dn/dT_{901}<1.2$

$1<dn/dT_{701}/ dn/dT_{902}<1.25$

$0.1<dn/dT_{701}/ dn/dT_{903}<0.35$

where:

F'_{1000} is the focal length of the lens 1000;

F'_{700}, F'_{800} and F'_{900} are focal lengths of the first, the second and the third optical groups 700, 800 and 900;

n_{701} and n_{702} are refractive indices for the optical elements 701 and 702 of the first optical group 700;

n_{801}, n_{802}, n_{803}, n_{804}, n_{805} and n_{806} are refractive indices for the optical elements 801, 802, 803, 804, 805 and 806 of the second optical group 800;

n_{901}, n_{902} and n_{903} are refractive indices for the optical elements 901, 902 and 903 of the third optical group 900;

V_{701} and V_{702} are Abbe numbers for the optical elements 701 and 702 of the first optical group 700;

V_{801}, V_{802}, V_{803}, V_{804}, V_{805} and V_{806} are Abbe numbers for the optical elements 801, 802, 803, 804, 805 and 806 of the second optical group 800;

P_{901} is the partial dispersion for the optical element 901 of the third optical group 900;

P_{902} is the partial dispersion for the optical element 902 of the third optical group 900;

dn/dT_{701} is the refractive index change with temperature for the first optical element 701 of the first optical group 700;

dn/dT_{702} is the refractive index change with temperature for the second optical element 702 of the first optical group 700;

dn/dT_{801} is the refractive index change with temperature for the first optical element 801of the second optical group 800;

dn/dT_{802} is the refractive index change with temperature for the second optical element 802 of the second optical group 800;

dn/dT_{803} is the refractive index change with temperature for the third optical element 803 of the second optical group 800;

dn/dT_{804} is the refractive index change with temperature for the fourth optical element 804 of the second optical group 800;

dn/dT_{805} is the refractive index change with temperature for the fifth optical element 805 of the second optical group 800;

dn/dT_{806v} is the refractive index change with temperature for the sixth optical element 806 of the second optical group 800;
dn/dT_{901} is the refractive index change with temperature for the first optical element 901 of the third optical group 900;
dn/dT_{902} is the refractive index change with temperature for the second optical element 902 of the third optical group 900; and
dn/dT_{9031} is the refractive index change with temperature for the third optical element 903 of the third optical group 900.

The selection of the optical powers of the optical groups and elements, the selection of the refractive indices, the Abbe numbers, and the partial dispersions, of the glasses as well as their dn/dT values, provides a high resolution imaging lens with chromatic and apochromatic correction while the defocusing caused by changes in temperature is less than the depth of focus of the lens.

Wave front and MTF data for the embodiment of Fig. 15 are presented in Fig. 16 and Fig.17 respectively. The wave front is well corrected over the whole spectrum and is polychromatic. The MTF shows good resolution and contract over the entire field of view. The RIM RAY curves presented in Fig. 18A and Figure 18B show the spherical aberration, coma, and chromatic corrections over the wavelength range of 450nm – 650nm. Astigmatism graphs are presented in Fig.19A, and distortion graphs are presented in Fig.19B. The field is flat and the distortion is corrected to less than 0.55% over the entire field of view. Data regarding the change of the focus with temperature is presented in Fig. 20. The amount of defocus over the temperature range of -15° to 45° is 0.02mm, which is 2.25 times less than depth of focus of 0.045mm. The lack of telecentricity is less than 8.5° across the field of view. A prescription of the lens is presented in Fig. 21. The optical materials used in the embodiment of Fig. 15 include optical glasses that are common and widely available commercially.

The foregoing description of the embodiments of the invention has been presented for the purposes of illustration and description. It is not intended to

be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of this disclosure. It is intended that the scope of the invention be limited not by this detailed description, but rather by the claims appended hereto.

CLAIMS

What is claimed is:

1. A low distortion lens suitable for airborne photography, comprising:
a first optical group including a plurality of optical elements;
a second optical group, including a plurality of optical elements;
an aperture located within the second optical group; and
a third optical group, including a plurality of optical elements,
the distortion of the lens being not more than 0.6%,
the lens having a full field of view of at least 60°, with a quality performance field of 53°,
the lens being telecentric to less than 11°,
the lens being apochromatic over a range of at least 450 nm to 650 nm, and
the lens being athermal over a temperature range of at least -15 °C to +40 °C.

2. The lens of claim 1, wherein the first optical group includes exactly two optical elements, and the third optical group includes exactly three optical elements.

3. The lens of claim 2, wherein the second optical group includes exactly six optical elements.

4. The lens of claim 2, wherein the second optical group includes exactly seven optical elements.

5. The lens of claim 1, wherein the lens has a focal plane of at least 104 mm.

6. The lens of claim 6, wherein the lens is compatible for use with a CMOS 1.8 gigapixel multiple FPA (focal plane array) having a 2 x 2 Bayer filter geometry and a pixel size of 2.2μm x 2.2μm, wherein each CMOS image sensor pixel includes a series of dielectric layers above the photo detector, with a micro

lens on top of each pixel to focus light onto the active area of the pixel floor, thereby minimizing both the amount of light lost and the amount of light incident on adjacent photodiodes.

7. The lens of claim 1, wherein the lens has a length which does not exceed 180mm, an optical window not being included in the length.

8. The lens of claim 1, wherein at least one surface of one of the optical elements in each of at least two of the optical groups is aspherical.

9. The lens of claim 1, wherein the first group of optical elements corrects the lens for pupil spherical aberration, coma, and astigmatism, the second group of optical elements corrects the lens for first order chromatic aberrations, spherical abberations, coma, and astigmatism, while also athermalizing the lens, and the third group of optical elements corrects the lens for field curvature and astigmatism.

10. The lens of claim 1, wherein:

the first optical group has a positive optical power;

the second optical group has a positive optical power;

the third optical group has a positive optical power;

the first optical group includes two optical elements having, in order, a negative optical power and a positive optical power respectively, the first optical group being arranged to converge light received from an object and to direct the converged light onto the second optical group;

the second optical group includes seven optical elements having, in order, a positive optical power, a negative optical power, a positive optical power, a negative optical power, a positive optical power, a positive optical power, and a negative optical power, the second optical group being arranged to converge light received from the first optical group and to direct the converged light onto the third optical group;

the third optical group includes three optical elements having, in order, a negative optical power, a positive optical power, and a positive optical power, the third optical group being arranged to focus the light from the second optical group onto an imaging surface;

the focal lengths of the lens and of the optical groups satisfy the relationships

$0.09<F'_{10}/ F'_{20}<0.14$,

$0.8<F'_{10}/ F'_{30}<1.2$, and

$0.1<F'_{10}/ F'_{40}<0.15$,

where

F'_{10} is the focal length of the lens, and

F'_{20}, F'_{30} and F'_{40} are focal lengths of the first, the second and the third optical groups respectively;

the indexes of refraction of the optical elements satisfy the relationships

$0.65<n_{21}/ n_{22}<0.95$,

$0.75<n_{21}/ n_{31} = n_{21}/ n_{35}<0.95$,

$1.05<n_{31}/ n_{33}<1.3$,

$0.95<n_{31}/ n_{36}<1.35$,

$0.75<n_{36}/ n_{37}<1.1$,

$0.85<n_{21}/ n_{41}<1.15$,

$0.65<n_{41}/ n_{42}<0.9$, and

$0.7<n_{41}/ n_{43}<0.95$,

where

n_{21}, and n_{22} are the refractive indices of the first and second optical elements of the first optical group, respectively,

n_{31}, n_{33}, n_{35}, n_{36}, and n_{37} are the refractive indices of the first, third, fifth, sixth, and seventh optical elements of the second optical group, respectively, and

n_{41}, n_{42} and n_{43} are the refractive indices of the first, second, and third optical elements of the third optical group, respectively;

the Abbe numbers for the optical elements satisfy the relationships

$1.35<V_{21}/V_{22}<1.65$,

$1.45<V_{21}/V_{31}=V_{21}/V_{35}<1.7$,

$0.95<V_{31}/V_{32}=V_{35}/V_{34}<1.1$,

$0.9<V_{21}/V_{33}<1.1$,

$0.9<V_{21}/V_{36}<1.1$,

$1.55<V_{21}/V_{37}<1.75$,

$0.55<V_{21}/V_{41}<0.75$,

$2.4<V_{21}/V_{42}<2.8$, and

$1.5<V_{21}/V_{43}<1.9$,

where

V_{21}, and V_{22} are the Abbe numbers for the first, and second optical elements of the first optical group, respectively,

V_{31}, V_{32}, V_{33}, V_{34}, V_{35}, V_{36}, and V_{37} are the Abbe numbers for the first, second, third, fourt, fifth, sixth, and seventh optical elements of the second optical group, respectively, and

V_{41}, V_{42}, and V_{43} are the Abbe numbers for the first, second, and third optical elements of the third optical group, respectively;

the partial dispersions of the optical elements satisfy the relationships

$0.0025<P_{41}/V_{41}<0.0035$, and

$0.095<P_{42}/V_{42}<0.0135$,

where

P_{41} is the partial dispersion for the first optical element of the third optical group, and

P_{42} is the partial dispersion for the second optical element of the third optical group; and

the changes of refractive index with temperature satisfy the relationships

$0.2<dn/dT_{21}/\ dn/dT_{22}<0.35$,

$0.35<dn/dT_{21}/\ dn/dT_{31}=\ dn/dT_{21}/\ dn/dT_{35}<0.55$,

$0.9<dn/dT_{21}/dn/dT_{33}<1.1$,

$0.9<dn/dT_{21}/\ dn/dT_{36}<1.1$,

$0.3<dn/dT_{21}/\ dn/dT_{37}<0.4$,

$-0.15<dn/dT_{21}/\ dn/dT_{41}<-0.09$,

$0.9<dn/dT_{21}/\ dn/dT_{42}<1.25$, and

$0.18<dn/dT_{21}/\ dn/dT_{43}<0.25$,

where

dn/dT_{21} is the refractive index change with temperature for the first optical element of the first optical group,

dn/dT_{22} is the refractive index change with temperature for the second optical element of the first optical group,

dn/dT_{31} is the refractive index change with temperature for the first optical element of the second optical group,

dn/dT_{33} is the refractive index change with temperature for the third optical element of the second optical group,

dn/dT_{34} is the refractive index change with temperature for the fourth optical element of the second optical group,

dn/dT_{35} is the refractive index change with temperature for the fifth optical element of the second optical group,

dn/dT_{36} is the refractive index change with temperature for the sixth optical element of the second optical group,

dn/dT_{37} is the refractive index change with temperature for the seventh optical element of the second optical group,

dn/dT_{41} is the refractive index change with temperature for the first optical element of the third optical group,

dn/dT_{42} is the refractive index change with temperature for the second optical element of the third optical group, and

dn/dT_{43} is the refractive index change with temperature for the third optical element of the third optical group.

11. The lens of claim 10, wherein the both the first optical element and the second optical element of the first optical group are double concave lenses.

12. The lens of claim 11, wherein the second surface of the second optical element of the first optical group is aspherical.

13. The lens of claim 10, wherein:

the first optical element of the second optical group is a double convex lens;

the second optical element of the second optical group is a double concave lens;

the third optical element of the second optical group is a double convex lens;

the fourth optical element of the second optical group is a double concave lens;

the fifth optical element of the second optical group is a double convex lens;

the sixth optical element of the second optical group is a double convex lens; and

the seventh optical element of the second optical group is a double concave lens.

14. The lens of claim 12, wherein the first surface of the seventh optical element of the second optical group is aspherical.

15. The lens of claim 13, wherein the first and second optical elements of the second optical group are cemented to one another.

16. The lens of claim 13, wherein the fourth and fifth optical elements of the second optical group are cemented to one another.

17. The lens of claim 10, wherein the aperture stop is located between the third and fourth optical elements of the second optical group.

18. The lens of claim 10, wherein:

the first optical element of the third optical group is shaped as a negative meniscus lens whose concave surface faces toward the object;

the second optical element of the third optical group is a positive meniscus lens whose concave surface faces toward the object; and

the third optical element of the third optical group is a double convex lens.

19. The lens of claim 18, wherein the first optical element of the third optical group is made from CaF2.

20. The lens of claim 18, wherein the first surface of the second optical element of the third optical group is aspherical.

21. The lens of claim 1, wherein:

the first optical group has a negative optical power;

the second optical group has a positive optical power;

the third optical group has a positive optical power;

the first optical group includes two optical elements having, in order, a negative optical power and a positive optical power respectively, the first optical group being arranged to converge light received from an object and to direct the converged light onto the second optical group;

the second optical group includes seven optical elements having, in order, a positive optical power, a negative optical power, a positive optical power, a negative optical power, a positive optical power, a positive optical power, and a negative optical power, the second optical group being arranged to converge light received from the first optical group and to direct the converged light onto the third optical group;

the third optical group includes three optical elements having, in order, a negative optical power, a positive optical power, and a positive optical power, the third optical group being arranged to focus the light from the second optical group onto an imaging surface;

the focal lengths of the lens and of the optical groups satisfy the relationships

$$-0.1<F'_{100}/F'_{200}<-0.07,$$

$1.35<F'_{100}/F'_{300}<1.55$, and

$0.17<F'_{100}/F'_{400}<0.19$,

where

F'_{100} is the focal length of the lens, and

F'_{200}, F'_{300} and F'_{400} are focal lengths of the first, the second and the third optical groups respectively;

the indexes of refraction of the optical elements satisfy the relationships

$0.70<n_{210}/n_{220}<0.90$,

$0.80<n_{210}/n_{310}=n_{210}/n_{350}<1$,

$1<n_{310}/n_{330}<1.25$,

$0.9<n_{310}/n_{360}<1.3$,

$0.65<n_{360}/n_{370}<1.05$,

$0.80<n_{210}/n_{410}<1.1$,

$0.7<n_{410}/n_{420}<0.85$, and

$0.8<n_{410}/n_{430}<0.95$,

where

n_{210}, and n_{220} are the refractive indices of the first and second optical elements of the first optical group, respectively,

n_{310}, n_{330}, n_{350}, n_{360}, and n_{370} are the refractive indices of the first, third, fifth, sixth, and seventh optical elements of the second optical group, respectively, and

n_{410}, n_{420}, and n_{430} are the refractive indices of the first, second, and third optical elements of the third optical group, respectively;

the Abbe numbers for the optical elements satisfy the relationships

$1.55<V_{210}/V_{220}<1.85$,

$1.4<V_{210}/V_{310}=V_{210}/V_{350}<1.65$,

$0.85<V_{310}/V_{320}=V_{350}/V_{340}<1.15$,

$0.85<V_{210}/V_{330}<1$,

$0.95<V_{210}0V_{360}<1.1$,

$1.6<V_{210}/V_{370}<1.8$,

$0.85<V_{210}/V_{410}<1.2$,

$2.2<V_{210}/V_{420}<2.6$, and

$1.45<V_{210}/V_{430}<1.75$,

where

V_{210}, and V_{220} are the Abbe numbers for the first, and second optical elements of the first optical group, respectively,

V_{310}, V_{320}, V_{330}, V_{340}, V_{350}, V_{360}, and V_{370} are the Abbe numbers for the first, second, third, fourth, fifth, sixth, and seventh optical elements of the second optical group, respectively, and

V_{410}, V_{420}, and V_{430} are the Abbe numbers for the first, second, and third optical elements of the third optical group, respectively;

the partial dispersions of the optical elements satisfy the relationships

$0.0035<P_{410}/V_{410}<0.0055$, and

$0.1<P_{420}/V_{420}<0.015$,

where

P_{410} is the partial dispersion for the first optical element of the third optical group, and

P_{420} is the partial dispersion for the second optical element of the third optical group; and

the changes of refractive index with temperature satisfy the relationships

$0.15<dn/dT_{210}/\ dn/dT_{220}<0.3$,

$0.4<dn/dT_{210}/\ dn/dT_{310}= dn/dT_{210}/\ dn/dT_{305}<0.6$,

$0.85<dn/dT_{210}/dn/dT_{330}<1.05$,

$0.8<dn/dT_{210}/\ dn/dT_{360}<1.1$,

$0.35<dn/dT_{210}/\ dn/dT_{370}<0.5$,

$0.9<dn/dT_{210}/\ dn/dT_{410}<1.2$,

$0.85<dn/dT_{210}/\ dn/dT_{420}<1.3$, and

$0.15<dn/dT_{210}/\ dn/dT_{430}<0.3$,

where

dn/dT_{210} is the refractive index change with temperature for the first optical element of the first optical group,
dn/dT_{220} is the refractive index change with temperature for the second optical element of the first optical group,
dn/dT_{310} is the refractive index change with temperature for the first optical element of the second optical group,
dn/dT_{330} is the refractive index change with temperature for the third optical element of the second optical group,
dn/dT_{340} is the refractive index change with temperature for the fourth optical element of the second optical group,
dn/dT_{350} is the refractive index change with temperature for the fifth optical element of the second optical group,
dn/dT_{360} is the refractive index change with temperature for the sixth optical element of the second optical group,
dn/dT_{370} is the refractive index change with temperature for the seventh optical element of the second optical group,
dn/dT_{410} is the refractive index change with temperature for the first optical element of the third optical group,
dn/dT_{420} is the refractive index change with temperature for the second optical element of the third optical group, and
dn/dT_{430} is the refractive index change with temperature for the third optical element of the third optical group.

22. The lens of claim 21, wherein both the first optical element and the second optical element of the first optical group are double concave lenses.

23. The lens of claim 22, wherein the second surface of the second optical element of the first optical group is aspherical.

24. The lens of claim 21, wherein:

the first optical element of the second optical group is a double convex lens;

the second optical element of the second optical group is a double concave lens;

the third optical element of the second optical group is a double convex lens;

the fourth optical element of the second optical group is a double concave lens;

the fifth optical element of the second optical group is a double convex lens;

the sixth optical element of the second optical group is a double convex lens; and

the seventh optical element of the second optical group is a double concave lens.

25. The lens of claim 24, wherein the first surface of the seventh optical element of the second optical group is aspherical.

26. The lens of claim 24, wherein the first and second optical elements of the second optical group are cemented to one another.

27. The lens of claim 24, wherein the fourth and fifth optical elements of the second optical group are cemented to one another.

28. The lens of claim 21, wherein the aperture stop is located between the third and fourth optical elements of the second optical group.

29. The lens of claim 21, wherein:

the first optical element of the third optical group is shaped as a negative meniscus lens whose concave surface faces toward the object;

the second optical element of the third optical group is a positive meniscus lens whose concave surface faces toward the object; and

the third optical element of the third optical group is a double convex lens.

30. The lens of claim 29, wherein the first optical element of the third optical group is made from CaF2.

31. The lens of claim 29, wherein the first surface of the second optical element of the third optical group is aspherical.

32. The lens of claim 1, wherein:

all three optical groups have positive optical powers;

the first optical group includes two optical elements having, in order, a negative optical power and a positive optical power respectively, the first optical group being arranged to converge light received from an object and to direct the converged light onto the second optical group;

the second optical group includes six optical elements having, in order, a negative optical power, a positive optical power, a negative optical power, a positive optical power, a positive optical power, and a negative optical power, the second optical group being arranged to converge light received from the first optical group and to direct the converged light onto the third optical group;

the third optical group includes three optical elements having, in order, a negative optical power, a positive optical power, and a positive optical power, the third optical group being arranged to focus the light from the second optical group onto an imaging surface;

the focal lengths of the lens and of the optical groups satisfy the relationships

$2.6<F'_{1000}/ F'_{700}<3.4$

$2<F'_{1000}/ F'_{800}<2.6$

$2.2<F'_{1000}/ F'_{900}<2.7$

where

F'_{1000} is the focal length of the lens, and

F'_{700}, F'_{800} and F'_{900} are focal lengths of the first, the second and the third optical groups respectively;

the indexes of refraction of the optical elements satisfy the relationships

$0.65<n_{701}/ n_{702}<0.95$

$0.75<n_{701}/ n_{801} = n_{701}/ n_{803}= n_{701}/ n_{804}= n_{701}/ n_{806}<1$

$0.95<n_{801}/ n_{802}=n_{801}/ n_{805}<1.25$

$0.90<n_{701}/ n_{901}<1.15$

$0.7<n_{901}/ n_{902}<0.9$

$0.75<n_{801}/ n_{903}<0.95$

where

n_{701}, and n_{702} are the refractive indices of the first and second optical elements of the first optical group, respectively,

n_{801}, n_{802}, n_{803}, n_{804}, n_{805}, and n_{806} are the refractive indices of the first, second, third, fourth, fifth, and sixth optical elements of the second optical group, respectively, and

n_{901}, n_{902}, and n_{903} are the refractive indices of the first, second, and third optical elements of the third optical group, respectively;

the Abbe numbers for the optical elements satisfy the relationships

$1.35<V_{701}/V_{702}<1.7$

$1.4<V_{701}/V_{801}=V_{701}/V_{803}=V_{701}/V_{806}<1.8$

$0.45<V_{801}/V_{802}=V_{801}/V_{805}= <0.75$

$0.85<V_{803}/V_{804} <1.15$

$0.85<V_{701}/V_{901}<1.15$

$2.4<V_{701}/V_{902}<2.8$

$1.55<V_{701}/V_{903}<1.85$

where

V_{701}, and V_{702} are the Abbe numbers for the first, and second optical elements of the first optical group, respectively,

V_{801}, V_{802}, V_{803}, V_{804}, V_{805}, and V_{806} are the Abbe numbers for the first, second, third, fourth, fifth, and sixth optical elements of the second optical group, respectively, and

V_{901}, V_{902}, and V_{903} are the Abbe numbers for the first, second, and third optical elements of the third optical group, respectively;

the partial dispersions of the optical elements satisfy the relationships

$0.004<P_{901}/V_{901}<0.006$

$0.95<P_{902}/V_{902}<0.015$

where

P_{901} is the partial dispersion for the first optical element of the third optical group, and

P_{902} is the partial dispersion for the second optical element of the third optical group; and

the changes of refractive index with temperature satisfy the relationships

$0.2<dn/dT_{701}/\ dn/dT_{702}<0.35$

$0.25<dn/dT_{701}/\ dn/dT_{801}= dn/dT_{701}/\ dn/dT_{803}= dn/dT_{701}/\ dn/dT_{806}<0.45$

$0.85<dn/dT_{701}/dn/dT_{802}=dn/dT_{701}/dn/dT_{805}<<1.15$

$0.4<dn/dT_{701}/\ dn/dT_{804}<0.6$

$0.8<dn/dT_{701}/\ dn/dT_{901}<1.2$

$1<dn/dT_{701}/\ dn/dT_{902}<1.25$

$0.1<dn/dT_{701}/\ dn/dT_{903}<0.35$

where

dn/dT_{701} is the refractive index change with temperature for the first optical element of the first optical group,

dn/dT_{702} is the refractive index change with temperature for the second optical element of the first optical group,

dn/dT_{801} is the refractive index change with temperature for the first optical element of the second optical group,

dn/dT_{802} is the refractive index change with temperature for the third optical element of the second optical group,
dn/dT_{803} is the refractive index change with temperature for the fourth optical element of the second optical group,
dn/dT_{804} is the refractive index change with temperature for the fifth optical element of the second optical group,
dn/dT_{805} is the refractive index change with temperature for the sixth optical element of the second optical group,
dn/dT_{806} is the refractive index change with temperature for the seventh optical element of the second optical group,
dn/dT_{901} is the refractive index change with temperature for the first optical element of the third optical group,
dn/dT_{902} is the refractive index change with temperature for the second optical element of the third optical group, and
dn/dT_{903} is the refractive index change with temperature for the third optical element of the third optical group.

33. The lens of claim 32, wherein the first optical element of the first optical group is a double concave lens, and the second optical element of the first optical group is a double convex lens.

34. The lens of claim 33, wherein the second surface of the second optical element of the first optical group is aspherical.

35. The lens of claim 32, wherein:

the first optical element of the second optical group is a double concave lens;

the second optical element of the second optical group is a double convex lens;

the third optical element of the second optical group is a double concave lens;

the fourth optical element of the second optical group is a double convex lens;

the fifth optical element of the second optical group is a double convex lens; and

the sixth optical element of the second optical group is a double concave lens.

36. The lens of claim 35, wherein the first surface of the sixth optical element of the second optical group is aspherical.

37. The lens of claim 35, wherein the third and fourth optical elements of the second optical group are cemented to one another.

38. The lens of claim 32, wherein the aperture stop is located between the second and third optical elements of the second optical group.

39. The lens of claim 32, wherein:

the first optical element of the third optical group is shaped as a negative meniscus lens whose concave surface faces toward the object;

the second optical element of the third optical group is a positive meniscus lens whose concave surface faces toward the object; and

the third optical element of the third optical group is a double convex lens.

40. The lens of claim 39, wherein the first surface of the second optical element of the third optical group is aspherical.

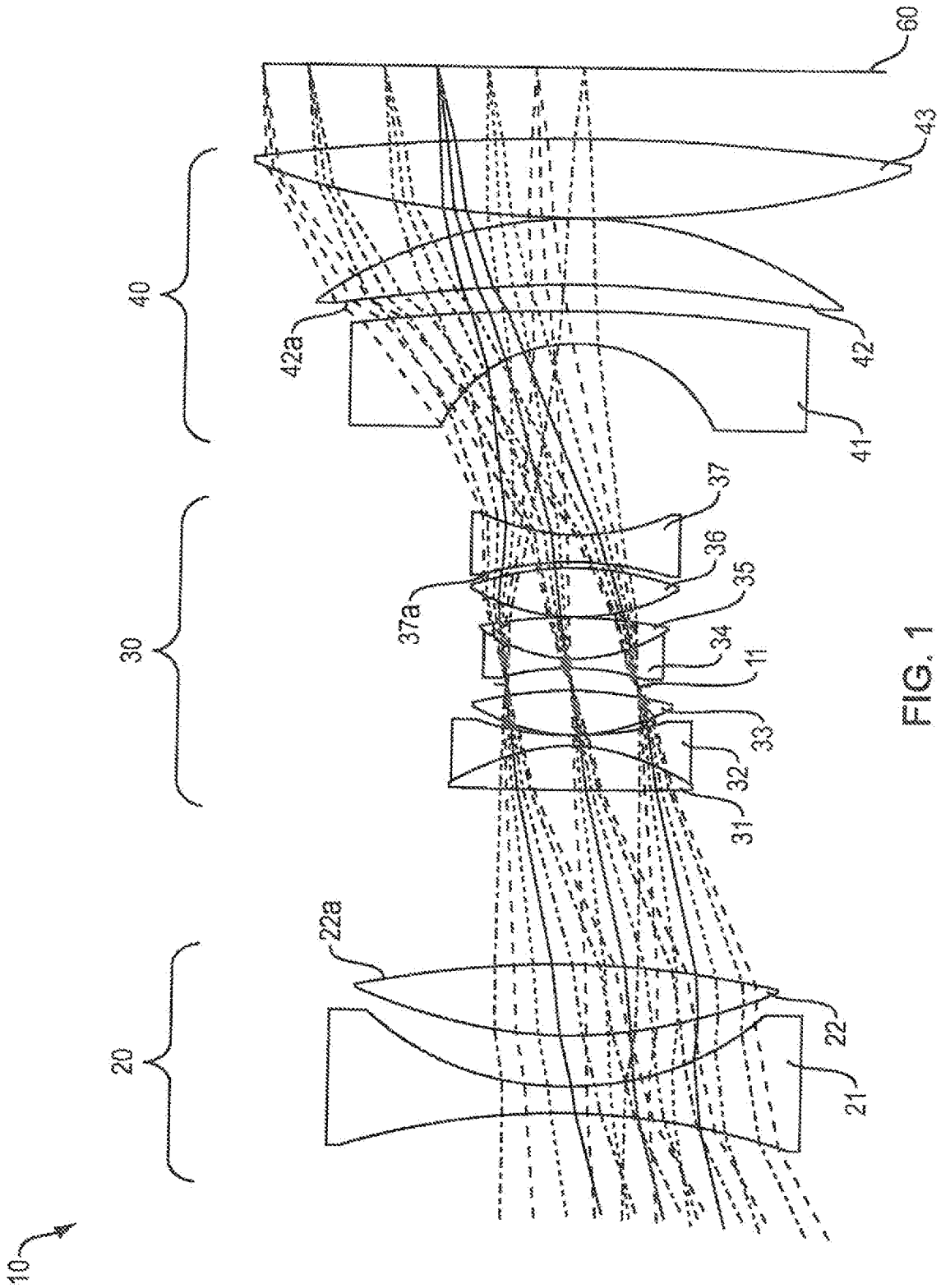


FIG. 1

WAVEFRONT ANALYSIS

X REL. FIELD	0.00	0.00	0.00	0.00	0.00
Y REL. FIELD	0.00	0.18	0.54	0.73	1.00
WEIGHTS	1.00	1.00	1.00	1.00	1.00
NUMBER OF RAYS	1580	1556	1340	1182	902

WAVELENGTHS	650.0	600.0	550.0	500.0	450.0
WEIGHTS	55	75	100	95	89

FIELD			BEST INDIVIDUAL FOCUS				BEST COMPOSITE FOCUS			
	FRACT	DEG	SHIFT (MM.)	FOCUS (MM.)	RMS (WAVES)	STREHL	SHIFT (MM.)	FOCUS (MM.)	RMS (WAVES)	STREHL
X	0.00	0.00	0.000000	0.002406	0.0517	0.900	0.000000	0.001204	0.0519	0.899
Y	0.00	0.00	0.000000			0.000000				
X	0.00	0.00	0.000000	0.000818	0.0552	0.887	0.000000	0.001204	0.0552	0.887
Y	0.18	5.00	-0.000258			-0.000234				
X	0.00	0.00	0.000000	-0.002489	0.0762	0.795	0.000000	0.001204	0.0771	0.791
Y	0.54	15.00	-0.000761			-0.000174				
X	0.00	0.00	0.000000	-0.003664	0.0868	0.743	0.000000	0.001204	0.0879	0.737
Y	0.73	20.00	-0.000978			-0.000097				
X	0.00	0.00	0.000000	0.015963	0.0796	0.779	0.000000	0.001204	0.0872	0.741
Y	1.00	26.50	0.002674			0.000307				

FIG. 2

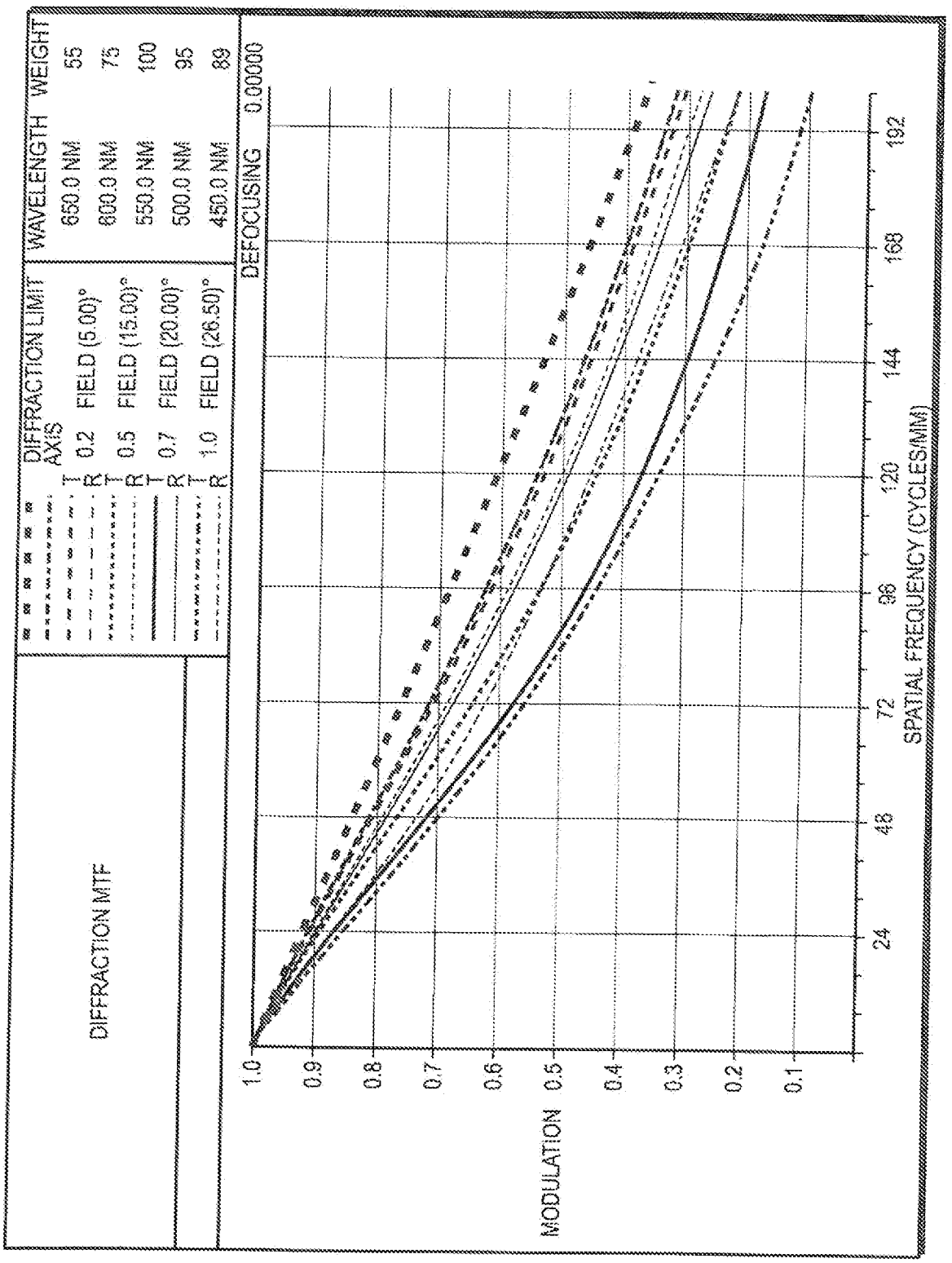

DIFFRACTION MTF
DIFFRACTION LIMIT
AXIS
T 0.2 FIELD (5.00)°
R
T 0.5 FIELD (15.00)°
R
T 0.7 FIELD (20.00)°
R
T 1.0 FIELD (26.50)°
R
WAVELENGTH WEIGHT
650.0 NM 55
600.0 NM 75
550.0 NM 100
500.0 NM 95
450.0 NM 89
DEFOCUSING 0.00000
MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
24
48
72
96
120
144
168
192
SPATIAL FREQUENCY (CYCLES/MM)

FIG. 3

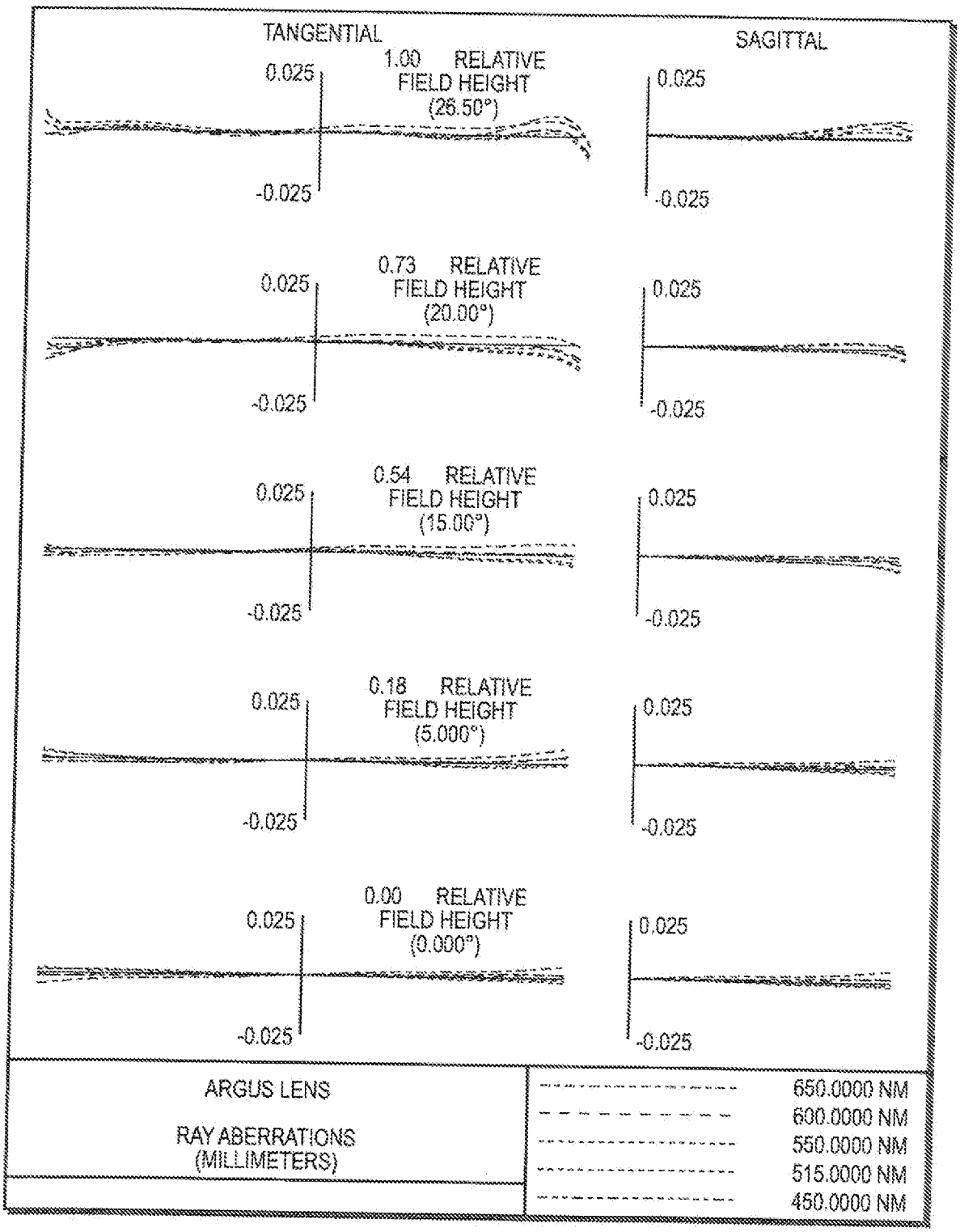

TANGENTIAL
SAGITTAL
1.00 RELATIVE FIELD HEIGHT (26.50°)
0.73 RELATIVE FIELD HEIGHT (20.00°)
0.54 RELATIVE FIELD HEIGHT (15.00°)
0.18 RELATIVE FIELD HEIGHT (5.000°)
0.00 RELATIVE FIELD HEIGHT (0.000°)
0.025
-0.025
ARGUS LENS
RAY ABERRATIONS (MILLIMETERS)
650.0000 NM
600.0000 NM
550.0000 NM
515.0000 NM
450.0000 NM

FIG. 4

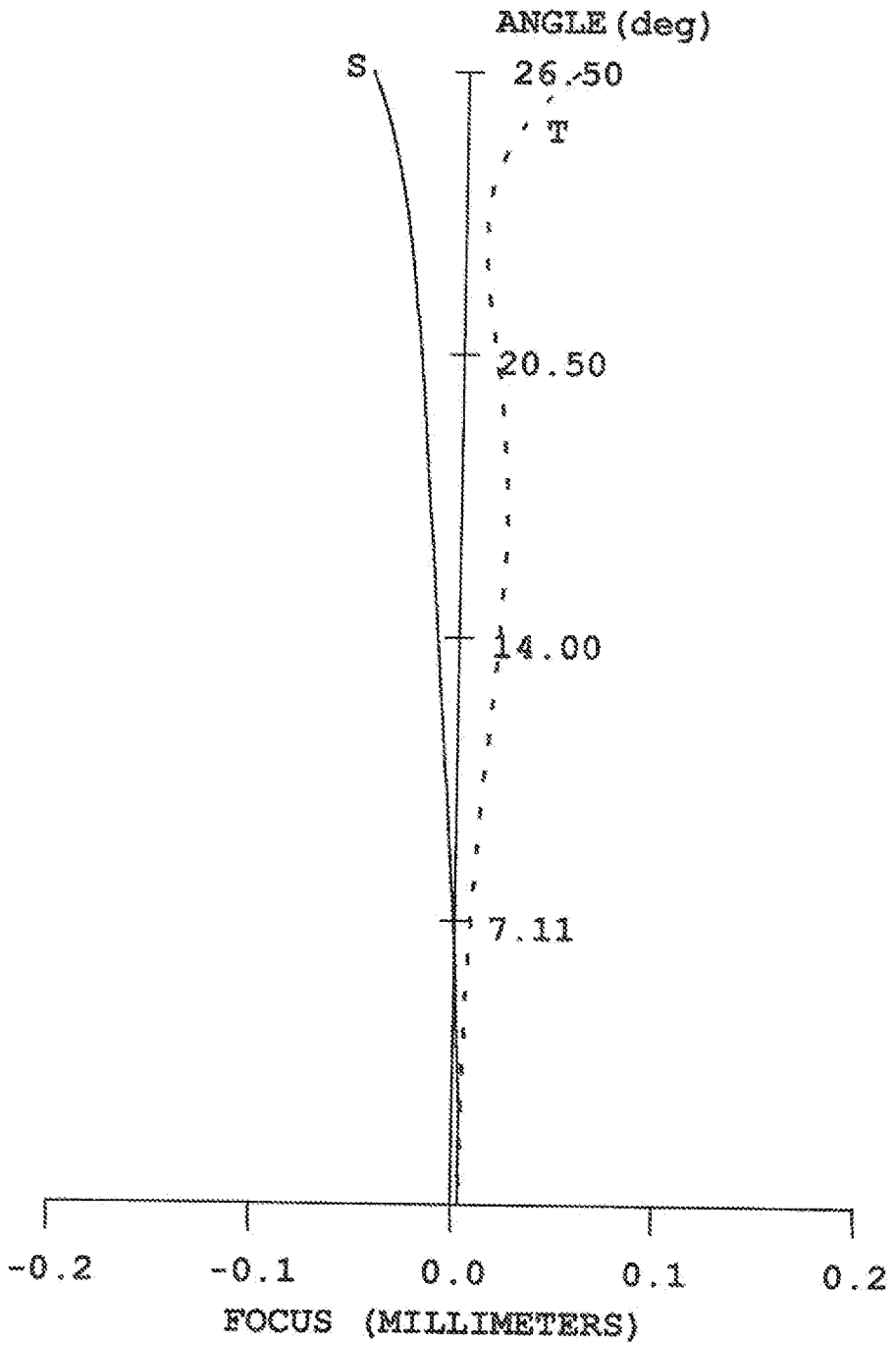

ASTIGMATIC
FIELD CURVES
ANGLE (deg)
S
T
26.50
20.50
14.00
7.11
-0.2
-0.1
0.0
0.1
0.2
FOCUS (MILLIMETERS)

FIG. 5A

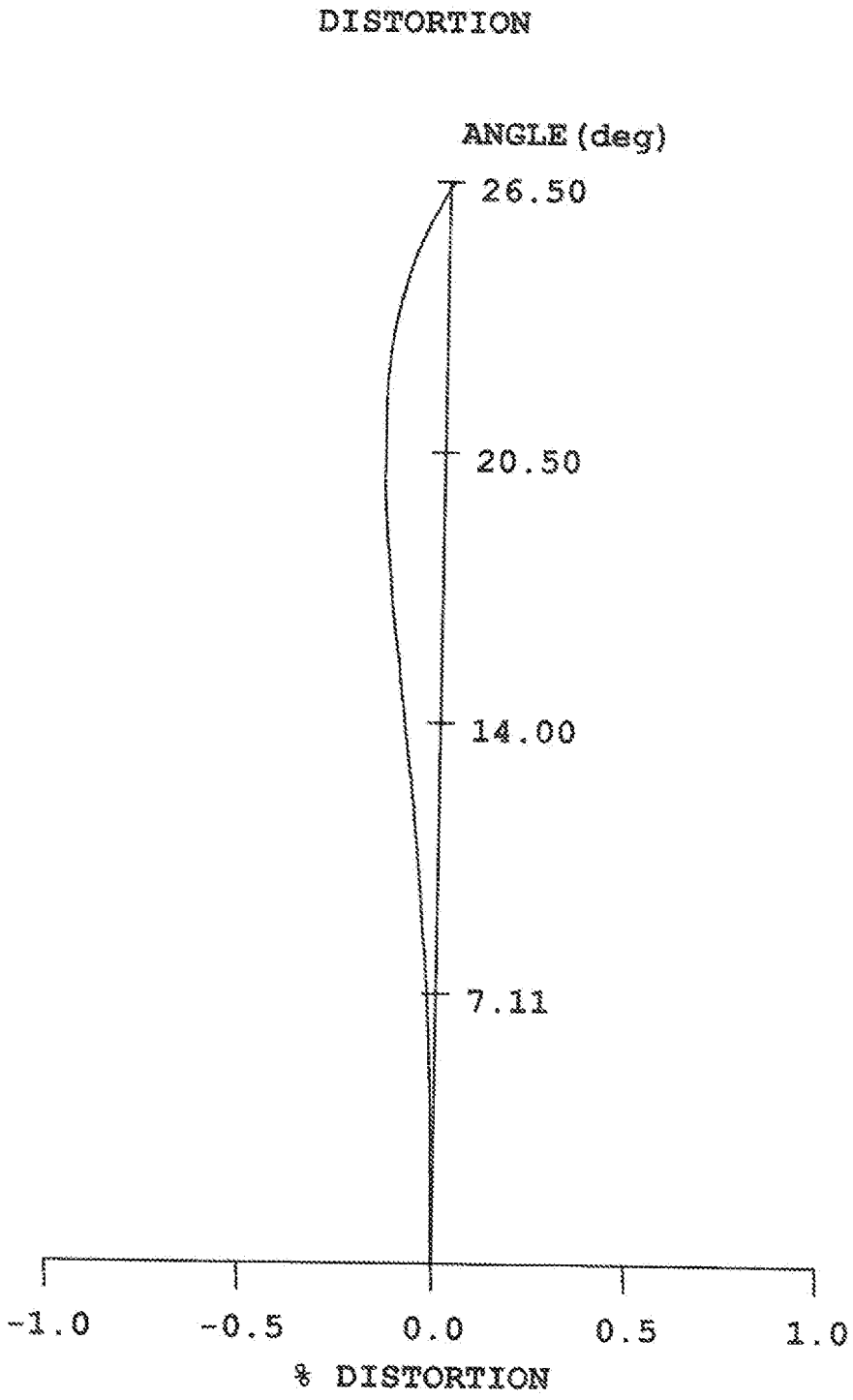

DISTORTION
ANGLE (deg)
26.50
20.50
14.00
7.11
-1.0
-0.5
0.0
0.5
1.0
% DISTORTION

FIG. 5B

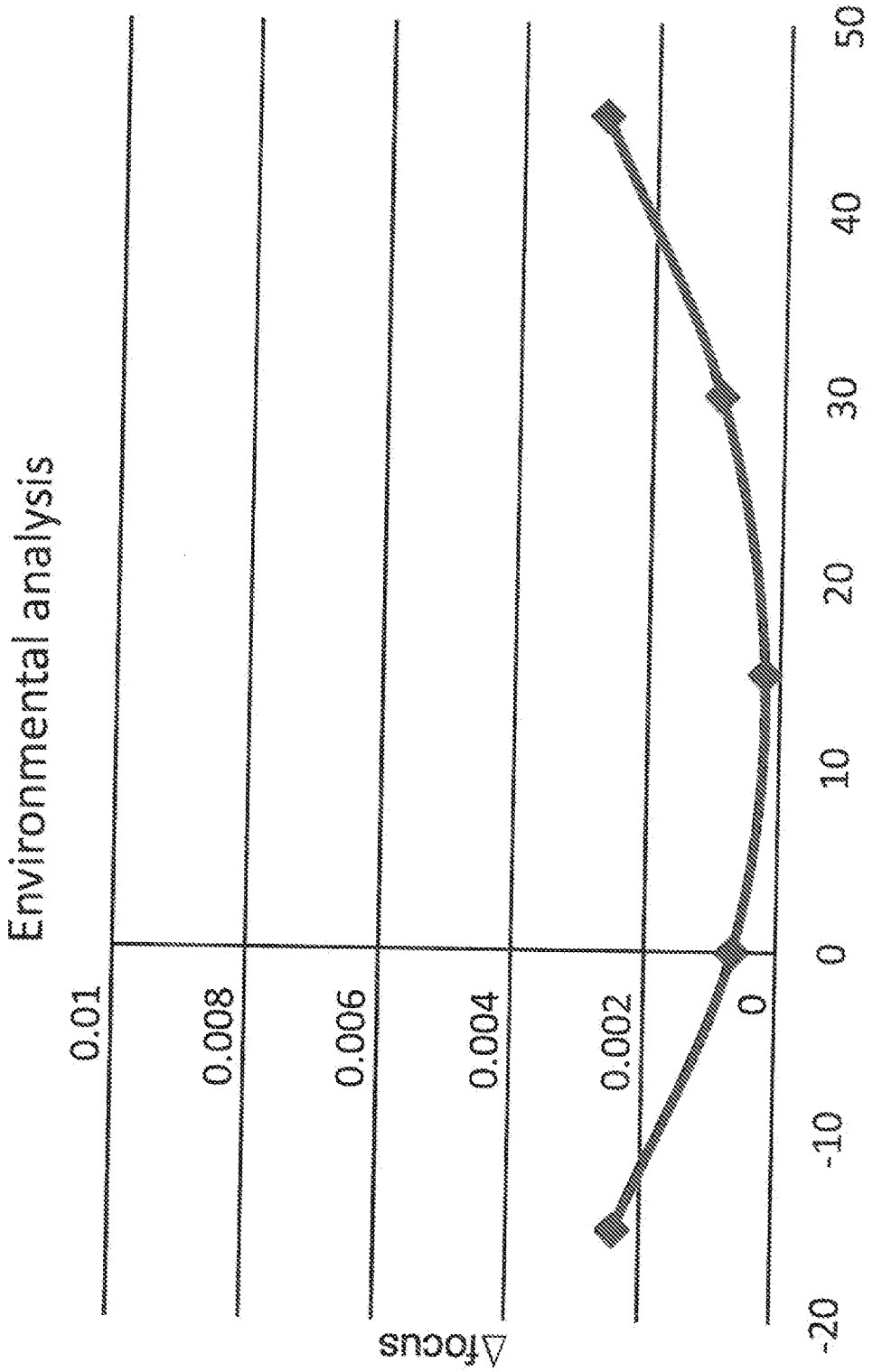

Environmental analysis
0.01
0.008
0.006
0.004
0.002
0
Δfocus
50
40
30
20
10
0
-10
-20
T°

FIG. 6

```
          RDY          THI    RMD     GLA        CCY  THC  GLC
 > OBJ:     INFINITY     INFINITY                  100  100
   1:    -129.86590     5.000000    SBSL7_OHARA      0  100
   2:     55.47164      9.620229                     0    0
   3:     93.12743     13.282758    SLAH52_OHARA     0    0
   4:   -193.63723     32.315958                     0    0
    ASP:
    K :  0.000000  KC :   100
    CUF:  0.000000  CCF:   100
    A :0.294932E-07  B :-.881134E-10  C :0.165359E-13  D :-.108485E-16
    AC :    0     BC :    0     CC :    0     DC :    0

   5:    702.56232     8.349251    SBAH27_OHARA     0    0
   6:    -37.83706     1.900000    KZFSN5_SCHOTT    0    0
   7:     54.85115     0.100000                     0    0
   8:     34.63852     8.289475    SBSL7_OHARA      0    0
   9:    -72.12363     1.000000                     0    0
 STO:     INFINITY     3.023834                     0    0
  11:    -44.07919     1.900000    KZFSN5_SCHOTT    0    0
  12:     30.88559     7.590710    SBAH27_OHARA     0    0
  13:    -83.73314     0.100000                     0    0
  14:     38.41752     9.165871    SBSL7_OHARA      0    0
  15:    -54.45233     0.884839                     0    0
  16:    -83.50069     5.000000    KZFSN5_SCHOTT    0  100
    ASP:
    K :  0.000000  KC :   100
    CUF:  0.000000  CCF:   100
    A :-.606497E-05  B :-.228387E-08  C :0.126695E-11  D :-.227964E-15
    AC :    0     BC :    0     CC :    0     DC :    0

  17:     40.22135    34.836882                     0    0
  18:    -27.75720     6.000000    CAF2_SCHOTT      0  100
  19:   -291.01113     5.672332                     0    0
  20:   -173.59692    11.958626    STIH53_OHARA     0    0
    ASP:
    K :  0.000000  KC :   100
    CUF:  0.000000  CCF:   100
    A :0.575554E-06  B :-.350877E-10  C :-.266881E-13  D :0.589549E-17
    AC :    0     BC :    0     CC :    0     DC :    0

  21:    -81.45265     0.100000                     0    0
  22:    198.18460    13.909236    SLAH60_OHARA     0    0
  23:   -467.43992    13.934321                     0    0
 IMG:     INFINITY     0.000000                   100  100

SPECIFICATION DATA
 FNO      4.50000
 DIM        MM
 WL       650.00   600.00   550.00   500.00   450.00
 REF         3
 WTW        55       75      100       95       89
 INI       ORA
 XAN     0.00000   0.00000   0.00000   0.00000   0.00000
 YAN     0.00000   5.00000  15.00000  20.00000  26.50000
 WTF     1.00000   1.00000   1.00000   1.00000   1.00000
 VUX     0.00000   0.00056   0.00230   0.00548   0.01051
 VLX     0.00000   0.00056   0.00230   0.00548   0.01051
 VUY     0.00000  -0.00216  -0.00103   0.00449   0.01655
 VLY     0.00000   0.00522   0.01415   0.02835   0.05035
 POL         N
```

FIG. 7

APERTURE DATA/EDGE DEFINITIONS

CA APE	
CIR S0	**********
CIR S1	41.467341
CIR S2	36.508662
CIR S3	37.049008
CIR S4	36.837049
CIR S5	21.130901
CIR S6	20.649323
CIR S7	17.515834
CIR S8	17.074260
CIR S9	16.398263
CIR S10	11.978442
CIR S11	13.203107
CIR S12	15.475868
CIR S13	15.952802
CIR S14	17.691174
CIR S15	17.679787
CIR S16	17.405657
CIR S17	17.746305
CIR S18	24.804522
CIR S19	39.113539
CIR S20	44.757539
CIR S21	45.863828
CIR S22	57.296397
CIR S23	57.469116
CIR S24	58.624836

REFRACTIVE INDICES

GLASS CODE	650.00	600.00	550.00	500.00	450.00
KZFSN5_SCHOTT	1.649587	1.653101	1.657624	1.663660	1.672092
SLAH60_OHARA	1.827894	1.832626	1.838763	1.847011	1.858606
SBAH27_OHARA	1.696897	1.700493	1.705147	1.711390	1.720162
STIH53_OHARA	1.837273	1.844526	1.854151	1.867463	1.886939
SBSL7_OHARA	1.514053	1.515825	1.518051	1.520943	1.524849
CAF2_SCHOTT	1.432570	1.433563	1.434822	1.436467	1.438693
SLAH52_OHARA	1.794322	1.798350	1.803543	1.810469	1.820110

No solves defined in system

No pickups defined in system

INFINITE CONJUGATES

EFL	101.0000
BFL	13.9381
FFL	-20.9459
FNO	4.5000
IMG DIS	13.9343
OAL	180.0000
PARAXIAL IMAGE	
HT	50.3567
ANG	26.5000
ENTRANCE PUPIL	
DIA	22.4444
THI	51.9099
EXIT PUPIL	

FIG. 7 (continued)

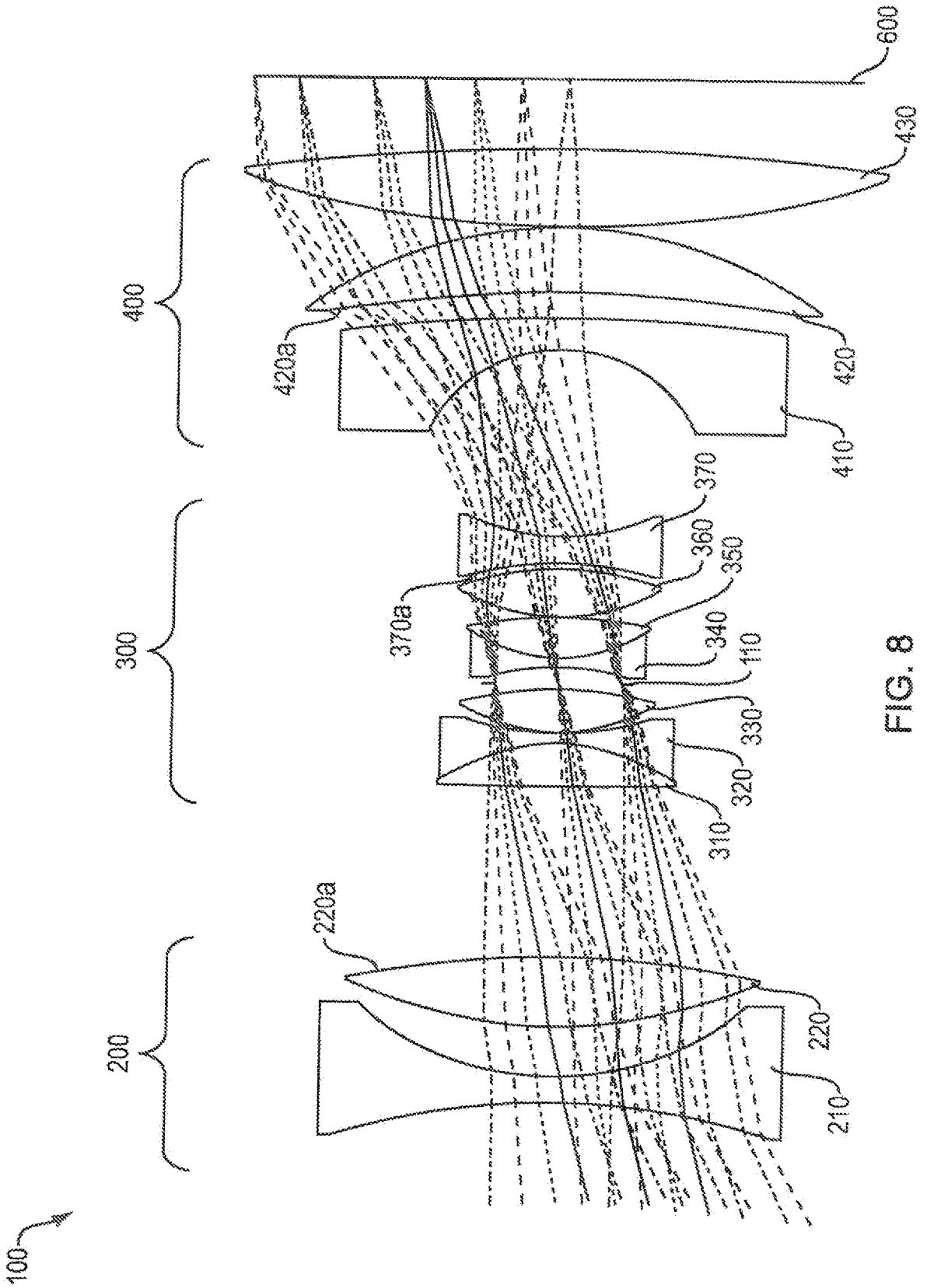

100
200
300
400
600
430
420a
420
410
370
360
350
370a
340
110
330
320
310
220a
220
210

FIG. 8

WAVEFRONT ANALYSIS

X REL. FIELD	0.00	0.00	0.00	0.00	0.00
Y REL. FIELD	0.00	0.18	0.54	0.73	1.00
WEIGHTS	1.00	1.00	1.00	1.00	1.00
NUMBER OF RAYS	1580	1558	1372	1202	946

WAVELENGTHS	650.0	600.0	550.0	500.0	450.0
WEIGHTS	55	75	100	95	89

FIELD			BEST INDIVIDUAL FOCUS				BEST COMPOSITE FOCUS			
	FRACT	DEG	SHIFT (MM.)	FOCUS (MM.)	RMS (WAVES)	STREHL	SHIFT (MM.)	FOCUS (MM.)	RMS (WAVES)	STREHL
X	0.00	0.00	0.000000	0.003214	0.0397	0.940	0.000000	0.001521	0.0401	0.939
Y	0.00	0.00	0.000000		0.000000					
X	0.00	0.00	0.000000	0.000130	0.0435	0.928	0.000000	0.001521	0.0438	0.927
Y	0.18	5.00	-0.000044		0.000034					
X	0.00	0.00	0.000000	-0.004451	0.0792	0.781	0.000000	0.001521	0.0814	0.770
Y	0.54	15.00	-0.001158		-0.000305					
X	0.00	0.00	0.000000	-0.000026	0.0843	0.755	0.000000	0.001521	0.0844	0.755
Y	0.73	20.00	-0.000724		-0.000480					
X	0.00	0.00	0.000000	0.017425	0.0772	0.791	0.000000	0.001521	0.0864	0.745
Y	1.00	26.50	0.002566		0.000507					

COMPOSITE RMS FOR
POSITION 1: 0.06740

Units of RMS are waves at 512.4 nm.

FIG. 9

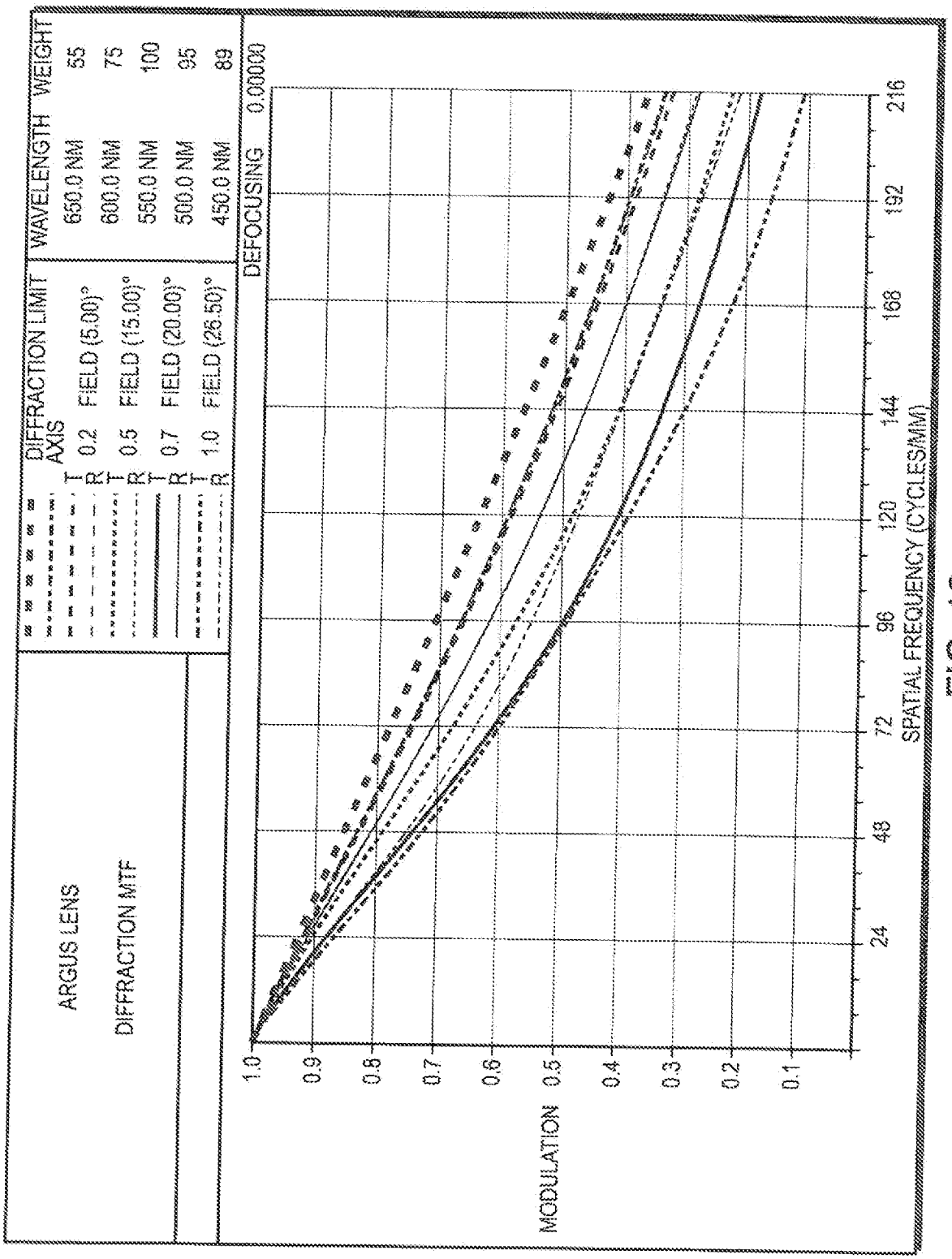

ARGUS LENS
DIFFRACTION MTF
DIFFRACTION LIMIT
AXIS
T
R
0.2 FIELD (5.00)°
0.5 FIELD (15.00)°
0.7 FIELD (20.00)°
1.0 FIELD (26.50)°
WAVELENGTH WEIGHT
650.0 NM 55
600.0 NM 75
550.0 NM 100
500.0 NM 95
450.0 NM 89
DEFOCUSING 0.00000
MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
24
48
72
96
120
144
168
192
216
SPATIAL FREQUENCY (CYCLES/MM)

FIG. 10

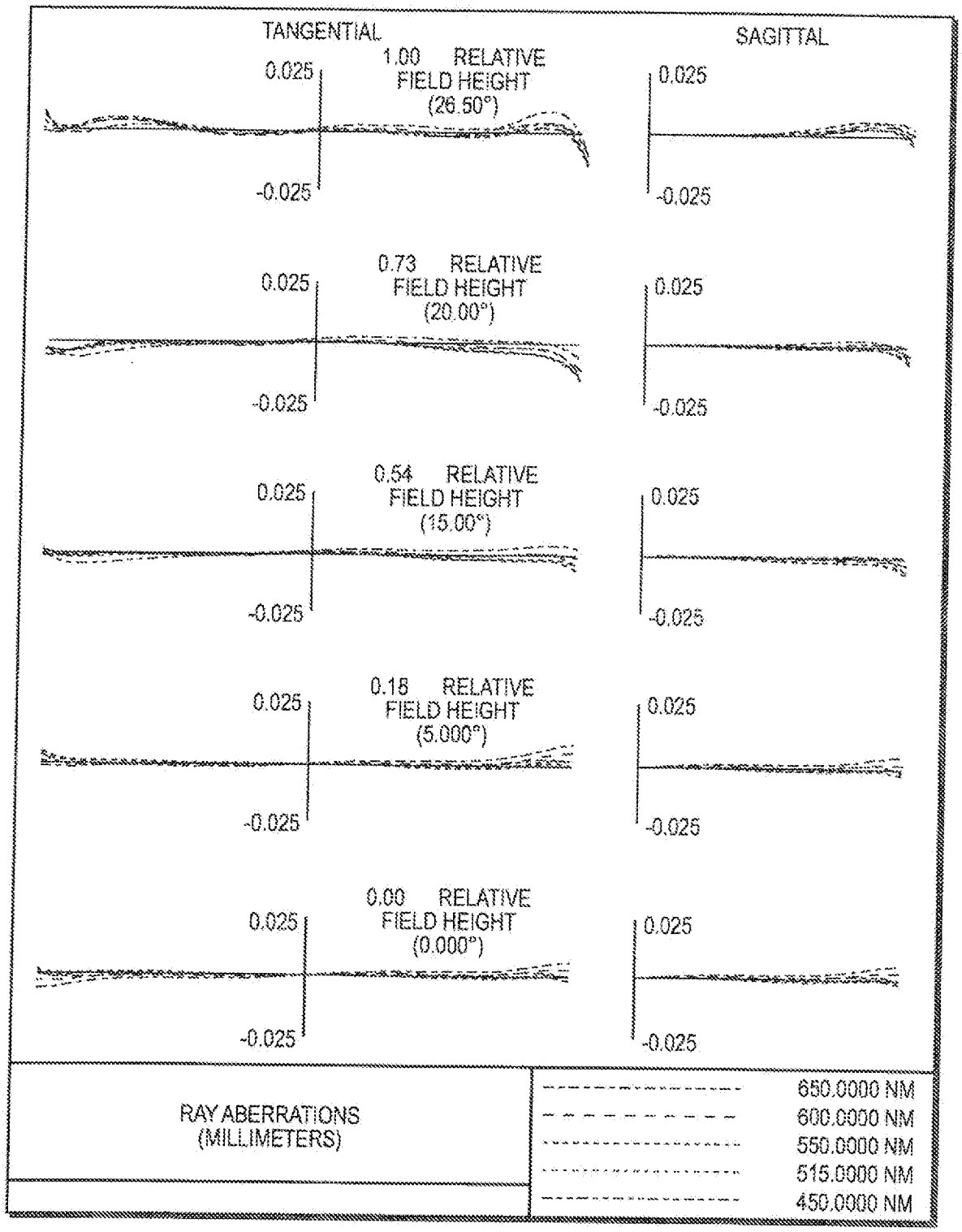

TANGENTIAL
SAGITTAL
1.00 RELATIVE FIELD HEIGHT (26.50°)
0.73 RELATIVE FIELD HEIGHT (20.00°)
0.54 RELATIVE FIELD HEIGHT (15.00°)
0.18 RELATIVE FIELD HEIGHT (5.000°)
0.00 RELATIVE FIELD HEIGHT (0.000°)
0.025
-0.025
RAY ABERRATIONS (MILLIMETERS)
650.0000 NM
600.0000 NM
550.0000 NM
515.0000 NM
450.0000 NM

FIG. 11

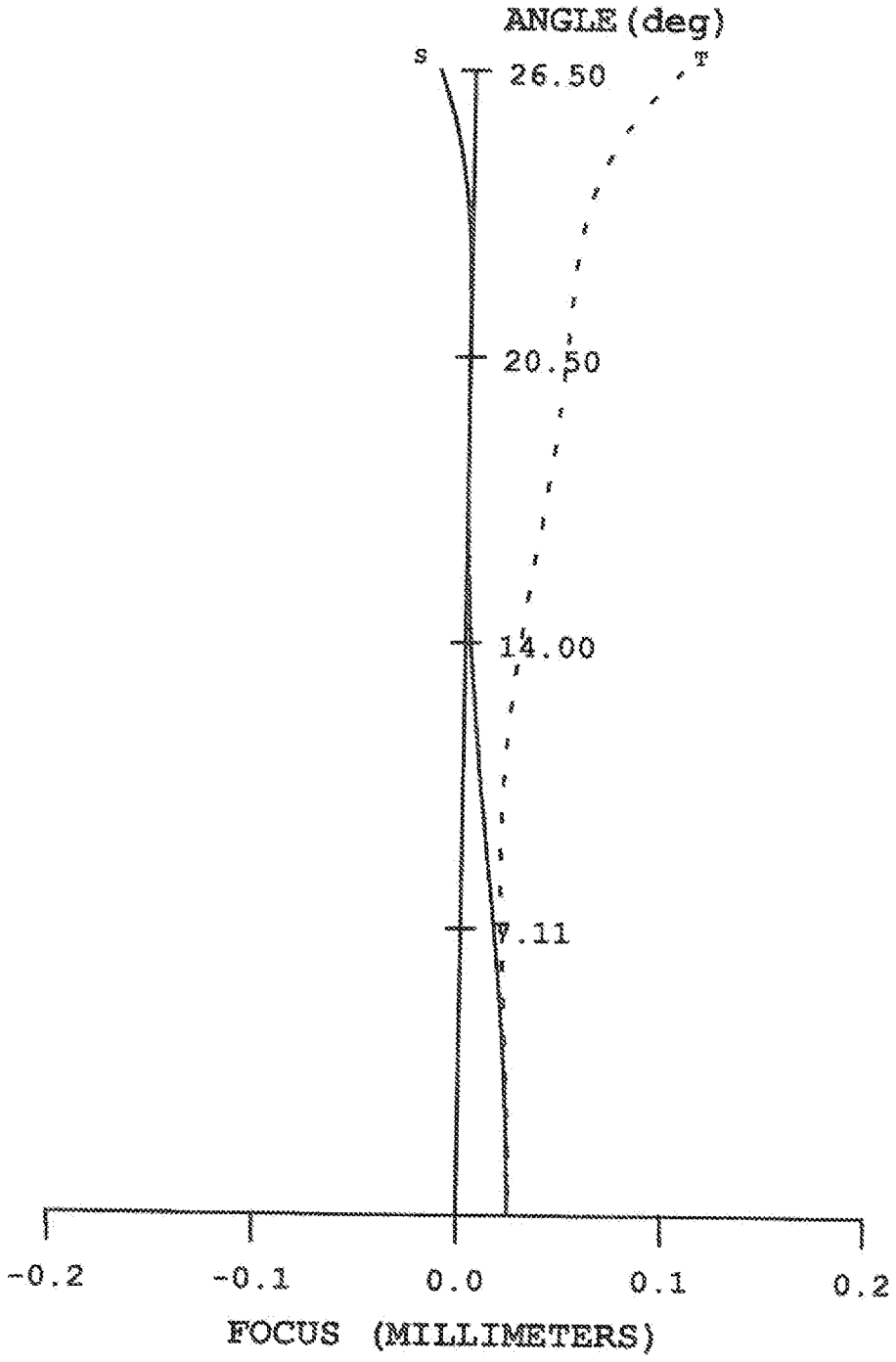

ASTIGMATIC
FIELD CURVES
ANGLE (deg)
S
T
26.50
20.50
14.00
7.11
-0.2
-0.1
0.0
0.1
0.2
FOCUS (MILLIMETERS)

FIG. 12A

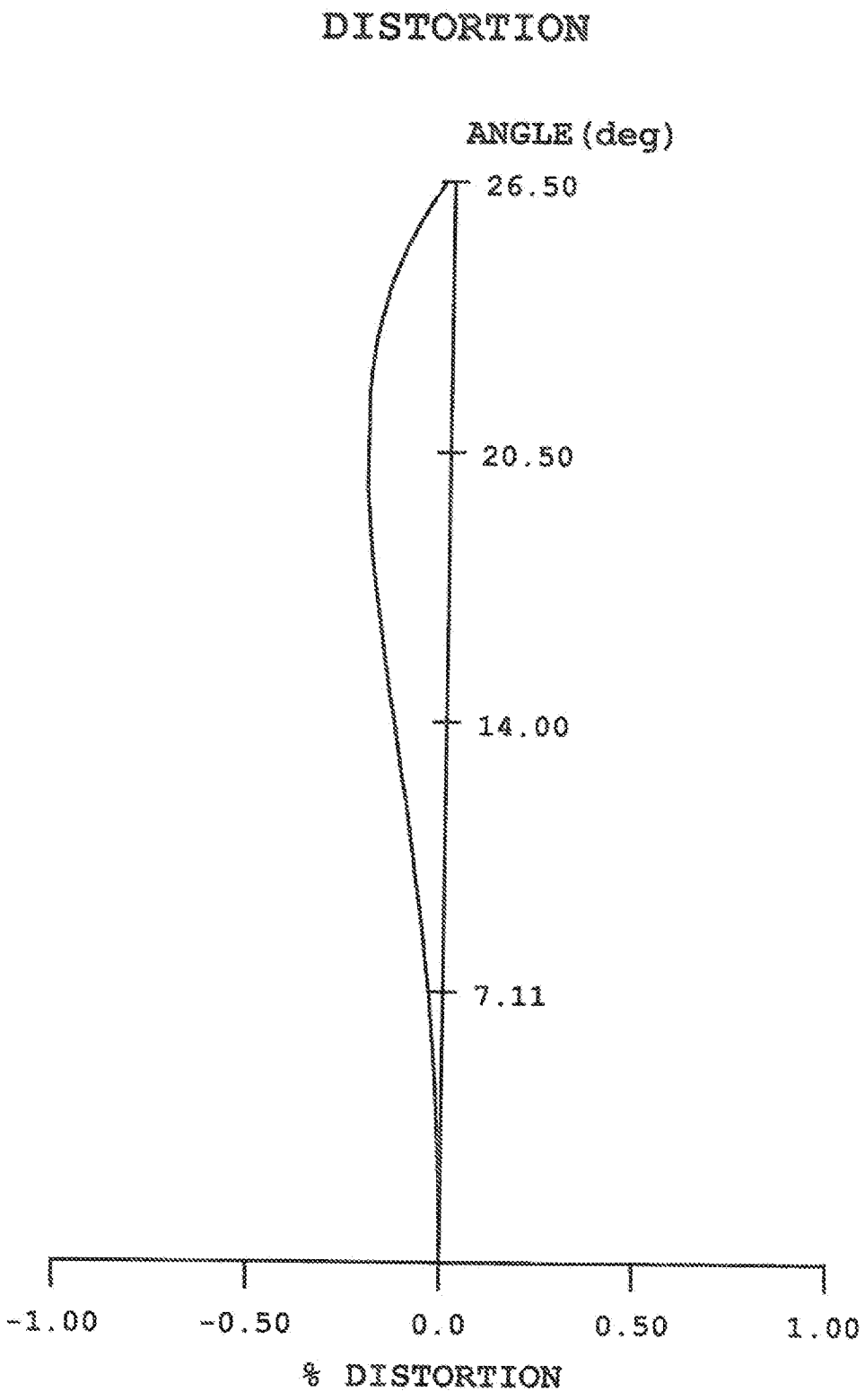

DISTORTION
ANGLE (deg)
26.50
20.50
14.00
7.11
-1.00
-0.50
0.0
0.50
1.00
% DISTORTION

FIG. 12B

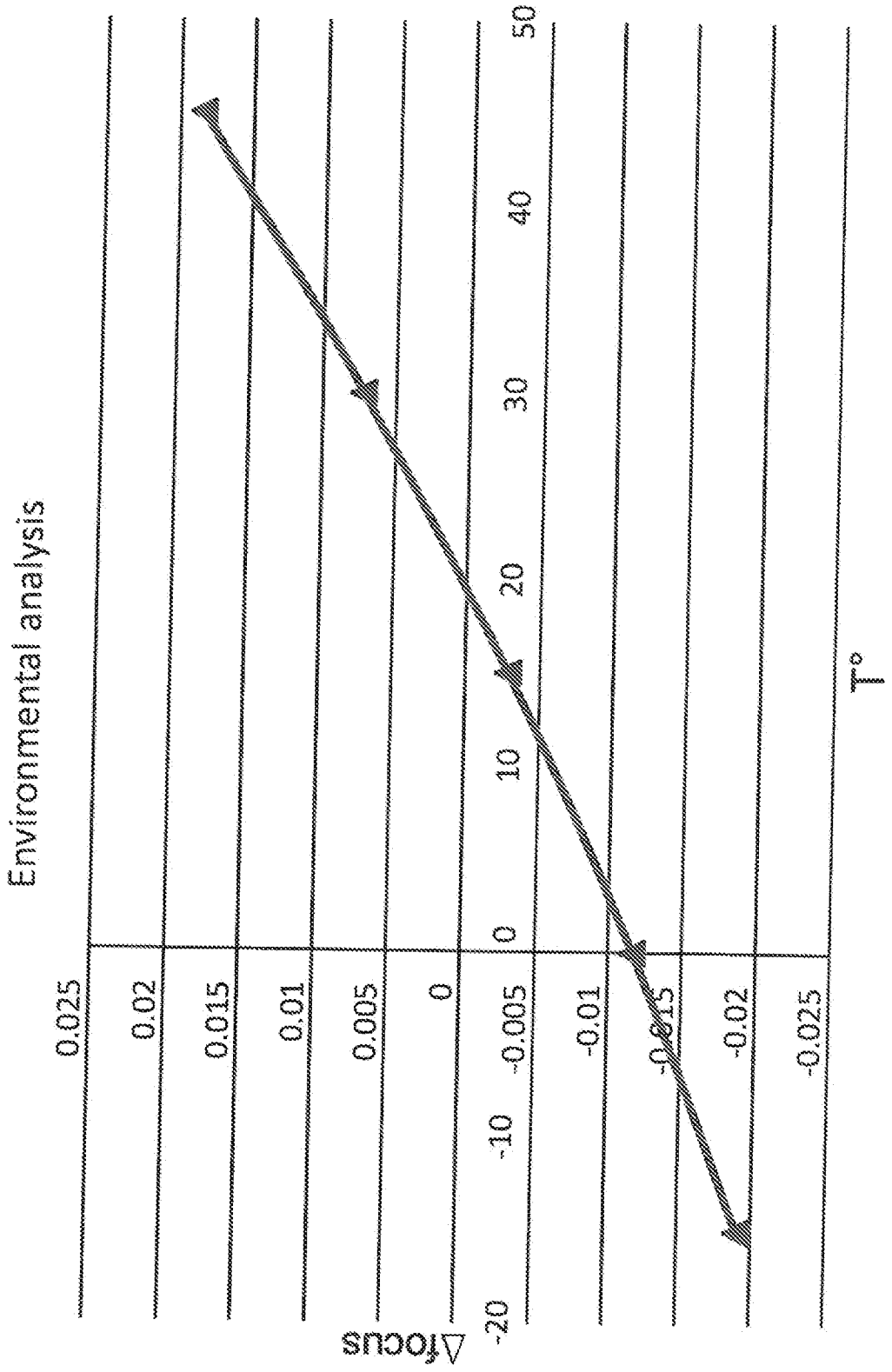

Environmental analysis
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
Δfocus
-20
-10
0
10
20
30
40
50
T°

FIG. 13

```
          RDY          THI    RMD      GLA        CCY  THC  GLC
 > OBJ:     INFINITY     INFINITY                  100  100
   1:    -124.09345     4.000000    SBSL7_OHARA      0  100
   2:     58.99244      8.203417                     0    0
   3:    138.40019      9.896213    SLAH60_OHARA     0    0
   4:   -175.94654     31.935685                     0    0
    ASP:
    K :  0.000000  KC :   100
    CUF:  0.000000  CCF:   100
    A :-.207041E-07  B :-.737550E-10  C :0.243370E-14  D :-.381992E-17
    AC :     0     BC :     0     CC :     0     DC :     0

   5:   1358.73428     7.982708    SBAH27_OHARA     0    0
   6:    -37.59348     2.000000    KZFSN5_SCHOTT    0    0
   7:     63.57500     0.100000                     0    0
   8:     35.77401     8.231694    SBSL7_OHARA      0    0
   9:    -70.96972     1.000000                     0    0
 STO:     INFINITY     3.317454                     0    0
  11:    -42.42568     2.000000    KZFSN5_SCHOTT    0    0
  12:     32.24658     8.268874    SBAH27_OHARA     0    0
  13:    -73.40921     0.100000                     0    0
  14:     38.33026     9.823331    SBSL7_OHARA      0    0
  15:    -54.12046     1.307844                     0    0
  16:    -72.12253     5.000000    KZFSN5_SCHOTT    0  100
    ASP:
    K :  0.000000  KC :   100
    CUF:  0.000000  CCF:   100
    A :-.601752E-05  B :-.211229E-08  C :0.226564E-11  D :-.338452E-15
    AC :     0     BC :     0     CC :     0     DC :     0

  17:     40.61398    39.294617                     0    0
  18:    -29.36558     6.000000    SBSL7_OHARA      0  100
  19:   -145.98224     4.403097                     0    0
  20:   -220.06103    13.517821    STIH53_OHARA     0    0
    ASP:
    K :  0.000000  KC :   100
    CUF:  0.000000  CCF:   100
    A :0.499358E-06  B :-.729937E-10  C :-.671110E-14  D :0.255542E-17
    AC :     0     BC :     0     CC :     0     DC :     0

  21:    -83.87297     0.100000                     0    0
  22:    191.34283    13.517245    SLAH60_OHARA     0    0
  23:   -672.31427    14.816059                     0    0
 IMG:     INFINITY     0.000000                   100  100

SPECIFICATION DATA
 FNO     4.50000
 DIM       MM
 WL      650.00   600.00   550.00   500.00   450.00
 REF        3
 WTW       55       75      100       95       89
 INI       ORA
 XAN    0.00000   0.00000   0.00000   0.00000   0.00000
 YAN    0.00000   5.00000  15.00000  20.00000  26.50000
 WTF    1.00000   1.00000   1.00000   1.00000   1.00000
 VUX    0.00000   0.00032   0.00133   0.00326   0.00645
 VLX    0.00000   0.00032   0.00133   0.00326   0.00645
 VUY    0.00000   0.00033   0.00240   0.00704   0.01592
 VLY    0.00000   0.00133   0.00493   0.01217   0.02541
 POL        N
```

FIG. 14

APERTURE DATA/EDGE DEFINITIONS

CA	
CIR S0	**********
CIR S1	38.621696
CIR S2	34.400673
CIR S3	34.484914
CIR S4	34.312010
CIR S5	20.550567
CIR S6	20.104198
CIR S7	17.494308
CIR S8	17.037290
CIR S9	16.371689
CIR S10	12.783974
CIR S11	13.829988
CIR S12	16.179645
CIR S13	16.662486
CIR S14	18.313126
CIR S15	18.238007
CIR S16	17.822566
CIR S17	18.007475
CIR S18	26.111244
CIR S19	39.007781
CIR S20	46.691892
CIR S21	47.775622
CIR S22	57.997683
CIR S23	58.106654
CIR S24	58.646516

REFRACTIVE INDICES

GLASS CODE	650.00	600.00	550.00	500.00	450.00
KZFSN5_SCHOTT	1.649587	1.653101	1.657624	1.663660	1.672092
SLAH60_OHARA	1.827894	1.832626	1.838763	1.847011	1.858606
SBAH27_OHARA	1.696897	1.700493	1.705147	1.711390	1.720162
STIH53_OHARA	1.837273	1.844526	1.854151	1.867463	1.886939
SBSL7_OHARA	1.514053	1.515825	1.518051	1.520943	1.524849

No solves defined in system

No pickups defined in system

INFINITE CONJUGATES

EFL	101.0000
BFL	14.8412
FFL	-19.8032
FNO	4.5000
IMG DIS	14.8161
OAL	180.0000
PARAXIAL IMAGE	
HT	50.3567
ANG	26.5000
ENTRANCE PUPIL	
DIA	22.4444
THI	46.7214
EXIT PUPIL	
DIA	34.0759
THI	-138.5006

FIG. 14 (continued)

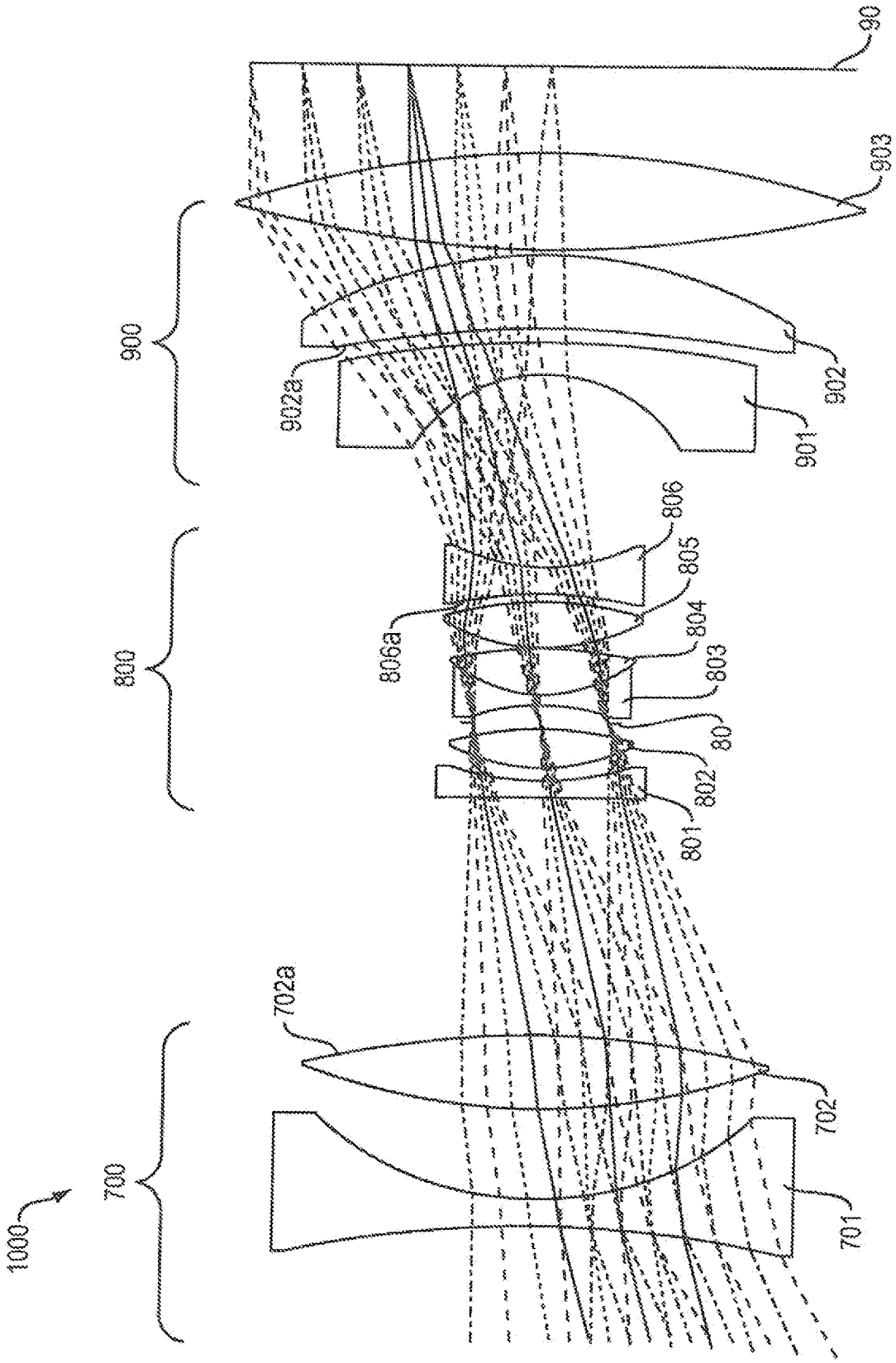

1000
700
800
900
90
903
902
902a
901
806
805
804
803
80
802
801
806a
702a
702
701

FIG. 15

WAVEFRONT ANALYSIS

ARGUS lens POSITION 1

X REL. FIELD 0.00 0.00 0.00 0.00 0.00
0.00 0.00
Y REL. FIELD 0.00 0.16 0.31 0.48 0.65
0.83 1.00
WEIGHTS 1.00 1.00 1.00 1.00 1.00
1.00 1.00
NUMBER OF RAYS 1580 1566 1510 1404 1220
1044 844

WAVELENGTHS 650.0 600.0 550.0 500.0 450.0
WEIGHTS 55 75 100 95 89

FIELD		BEST INDIVIDUAL FOCUS				BEST COMPOSITE FOCUS			
FRACT	DEG	SHIFT (MM.)	FOCUS (MM.)	RMS (WAVES)	STREHL	SHIFT (MM.)	FOCUS (MM.)	RMS (WAVES)	STREHL
X 0.00	0.00	0.000000	0.004144	0.0786	0.783	0.000000	0.002373	0.0789	0.782
Y 0.00	0.00	0.000000			0.000000				
X 0.00	0.00	0.000000	0.003754	0.0813	0.770	0.000000	0.002373	0.0814	0.770
Y 0.16	5.00	-0.000155			-0.000226				
X 0.00	0.00	0.000000	0.001675	0.0910	0.721	0.000000	0.002373	0.0910	0.721
Y 0.31	10.00	-0.000357			-0.000290				
X 0.00	0.00	0.000000	-0.004831	0.0957	0.697	0.000000	0.002373	0.0985	0.682
Y 0.48	15.00	-0.001184			-0.000239				
X 0.00	0.00	0.000000	-0.006674	0.1068	0.638	0.000000	0.002373	0.1098	

FIG. 16

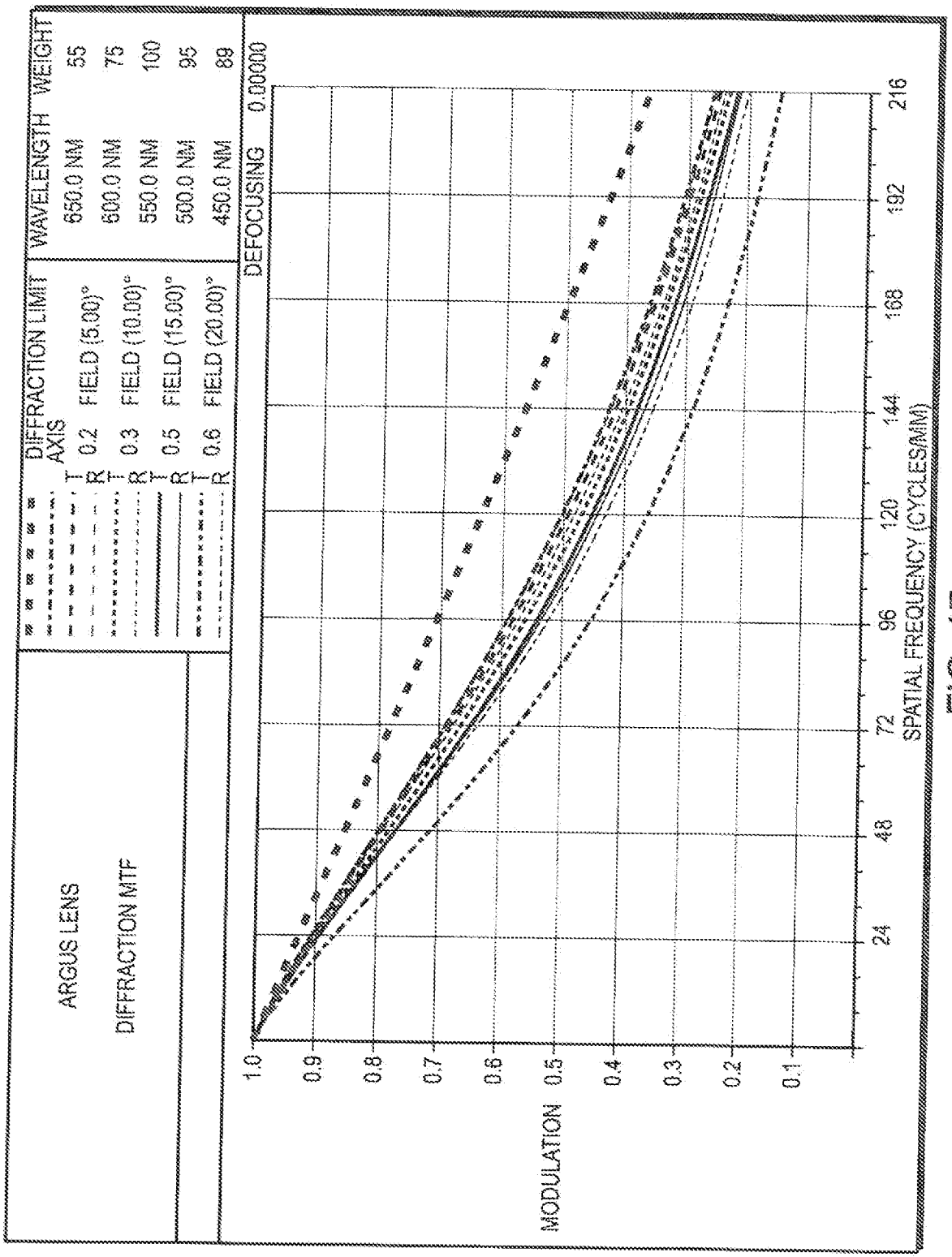

ARGUS LENS
DIFFRACTION MTF
DIFFRACTION LIMIT
AXIS
T 0.2 FIELD (5.00)°
R
T 0.3 FIELD (10.00)°
R
T 0.5 FIELD (15.00)°
R
T 0.6 FIELD (20.00)°
R
WAVELENGTH WEIGHT
650.0 NM 55
600.0 NM 75
550.0 NM 100
500.0 NM 95
450.0 NM 89
DEFOCUSING 0.00000
MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
24 48 72 96 120 144 168 192 216
SPATIAL FREQUENCY (CYCLES/MM)

FIG. 17

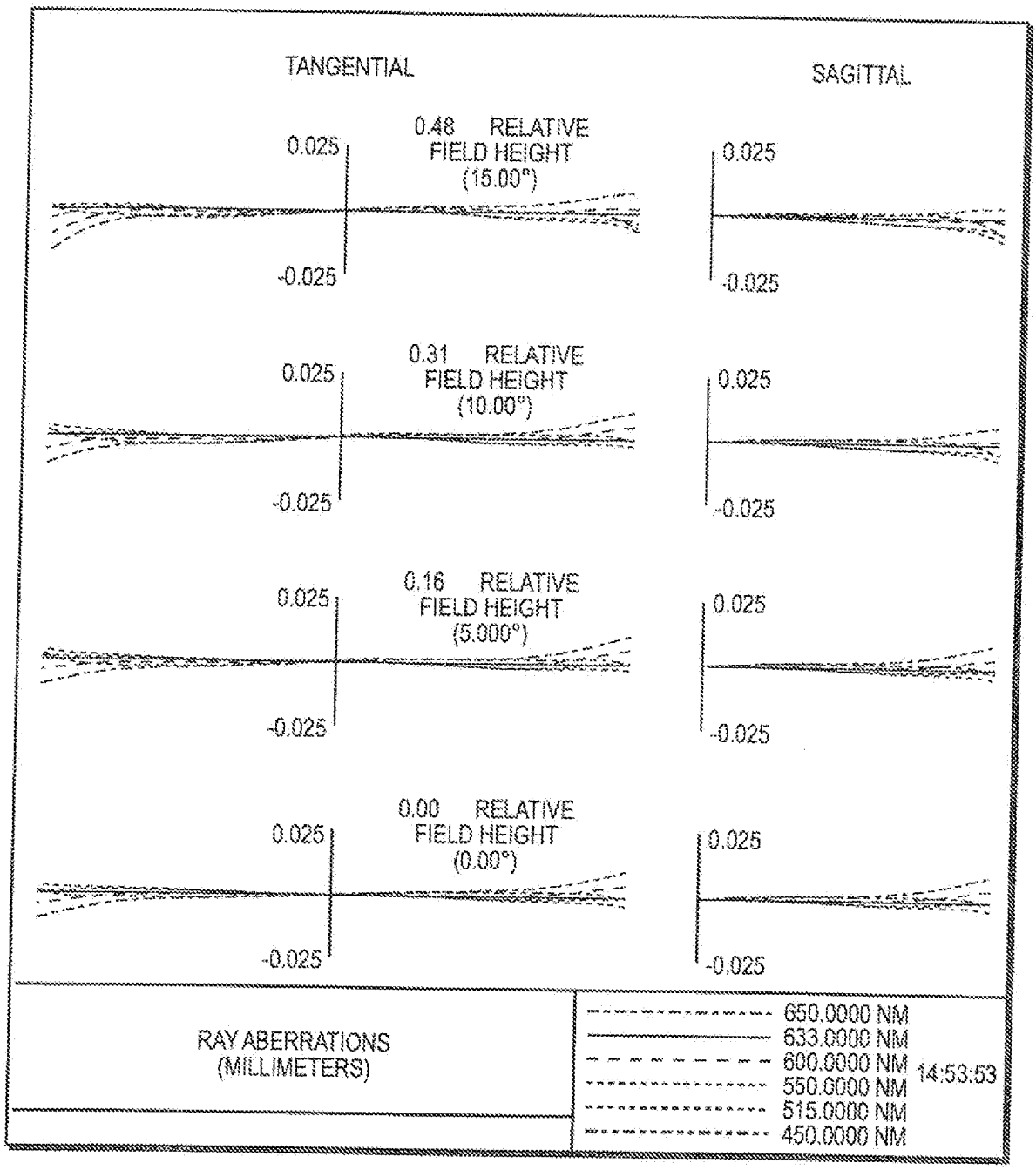

TANGENTIAL
SAGITTAL
0.48 RELATIVE FIELD HEIGHT (15.00°)
0.31 RELATIVE FIELD HEIGHT (10.00°)
0.16 RELATIVE FIELD HEIGHT (5.000°)
0.00 RELATIVE FIELD HEIGHT (0.00°)
0.025
-0.025
RAY ABERRATIONS (MILLIMETERS)
650.0000 NM
633.0000 NM
600.0000 NM
550.0000 NM
515.0000 NM
450.0000 NM
14:53:53

FIG. 18A

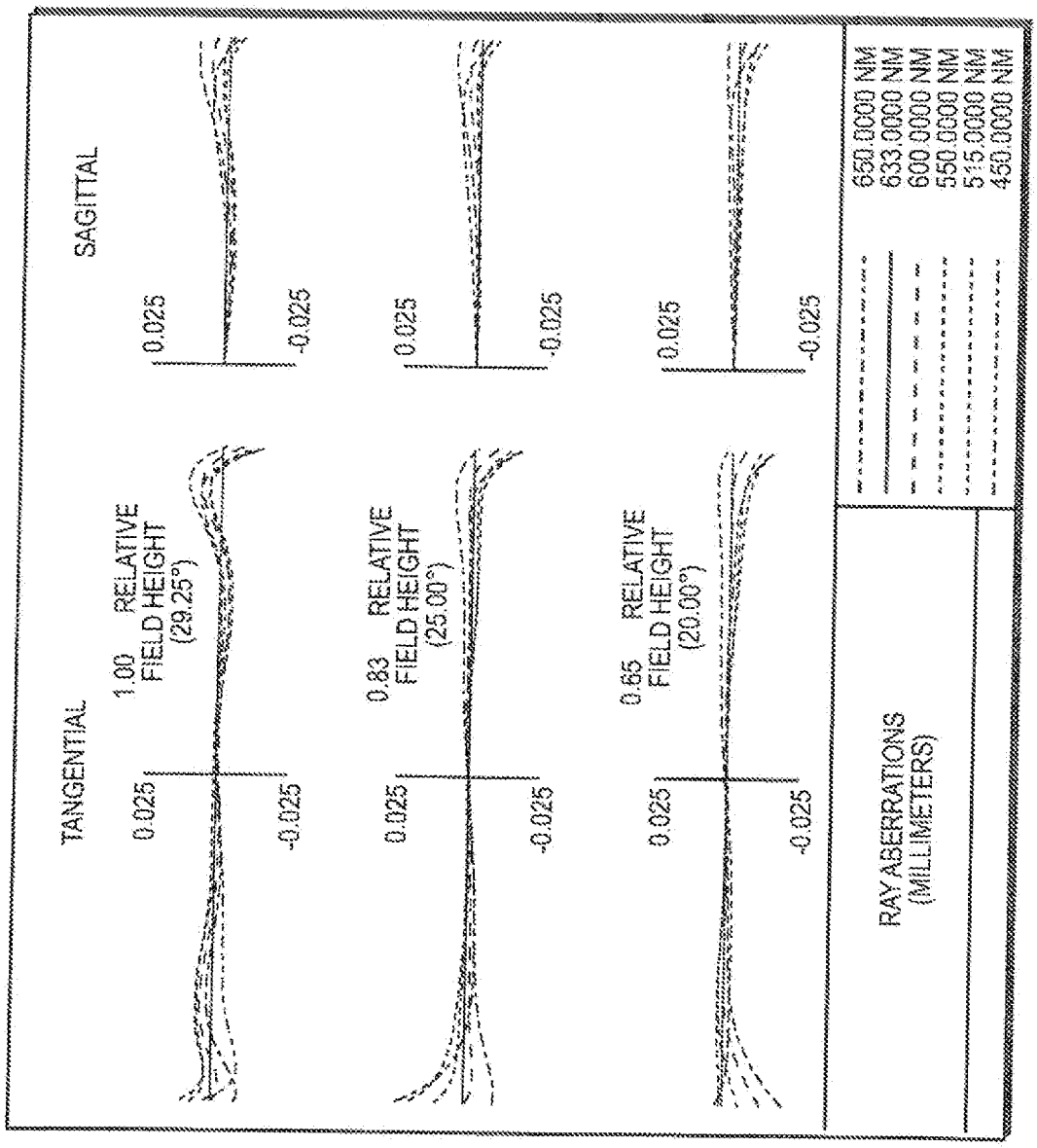

TANGENTIAL
SAGITTAL
1.00 RELATIVE FIELD HEIGHT (29.25°)
0.83 RELATIVE FIELD HEIGHT (25.00°)
0.65 RELATIVE FIELD HEIGHT (20.00°)
0.025
-0.025
RAY ABERRATIONS (MILLIMETERS)
650.0000 NM
633.0000 NM
600.0000 NM
550.0000 NM
515.0000 NM
450.0000 NM

FIG. 18B

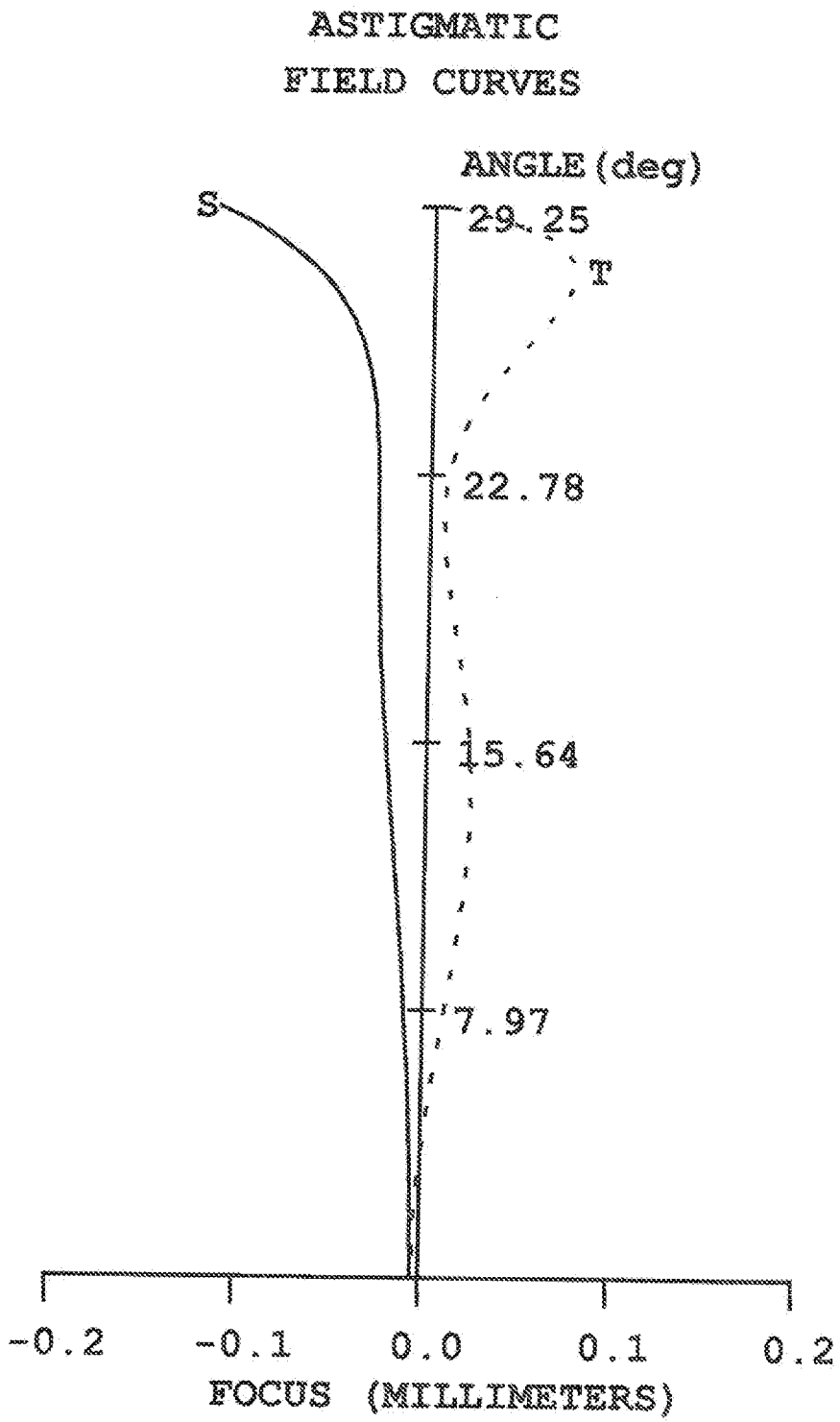

ASTIGMATIC
FIELD CURVES
ANGLE (deg)
S
T
29.25
22.78
15.64
7.97
-0.2
-0.1
0.0
0.1
0.2
FOCUS (MILLIMETERS)

FIG. 19A

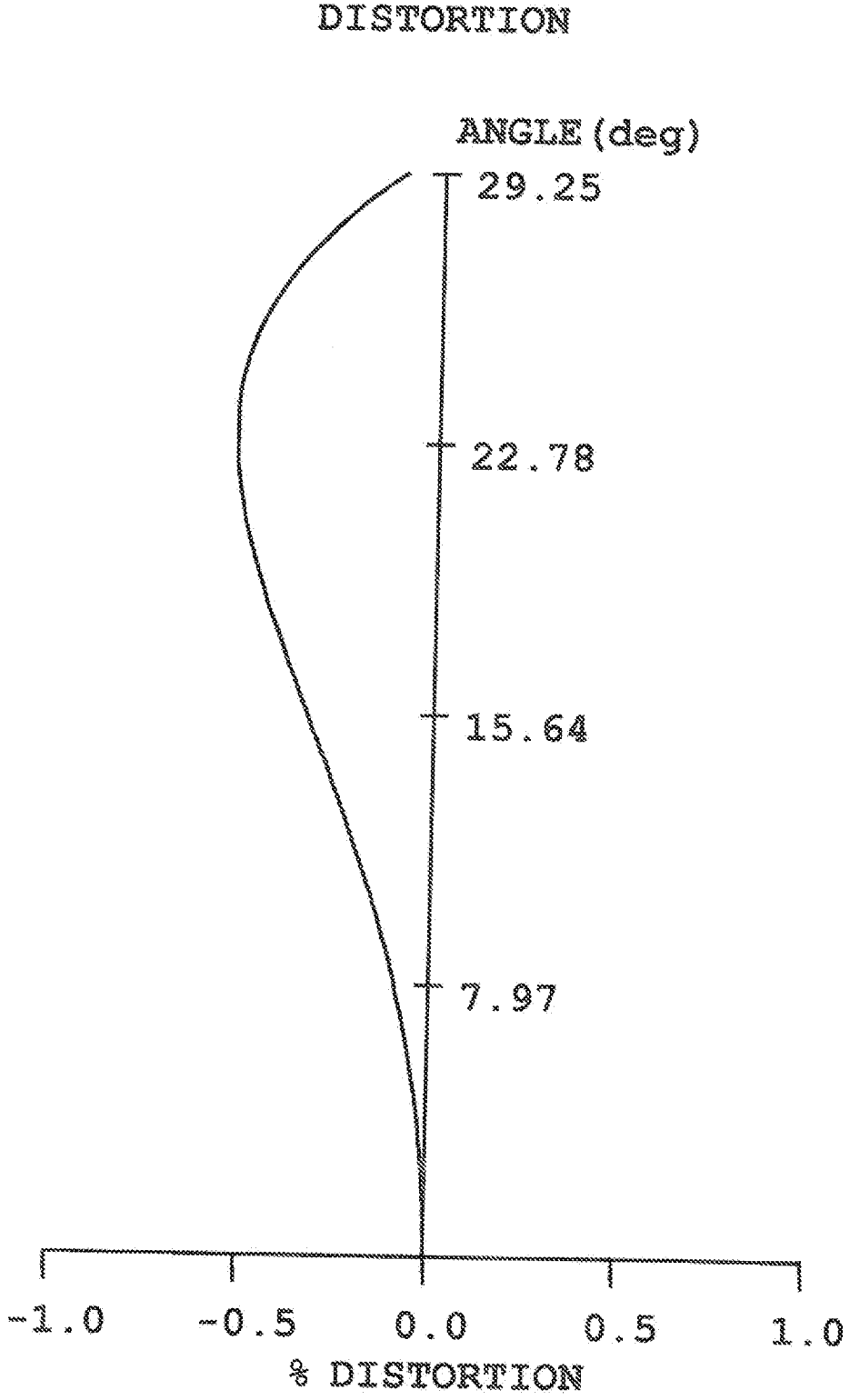

DISTORTION
ANGLE (deg)
29.25
22.78
15.64
7.97
-1.0
-0.5
0.0
0.5
1.0
% DISTORTION

FIG. 19B

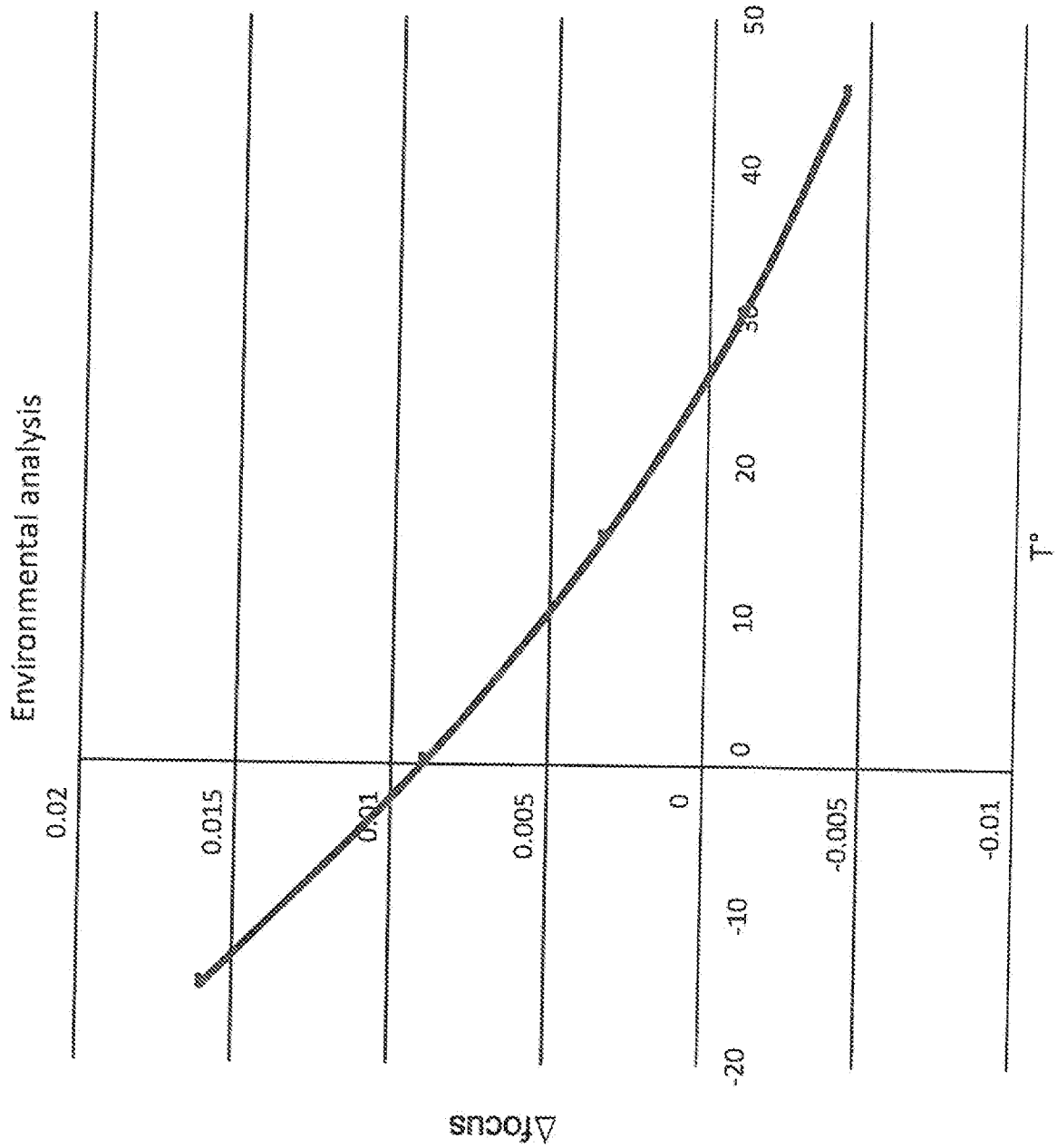

Environmental analysis
0.02
0.015
0.01
0.005
0
-0.005
-0.01
Δfocus
0
10
20
30
40
50
-20
-10
T°

FIG. 20

```
          RDY        THI    RMD     GLA        CCY  THC  GLC
> OBJ:     INFINITY     INFINITY                100  100
  1:    -191.72938     4.450000    SBSL7_OHARA      0  100
  2:     53.34279     15.191850                   0    0
  3:     114.54767     12.321103    SLAH52_OHARA     0    0
  4:    -159.04688     39.818633                   0    0
   ASP:
   K :   0.000000  KC :   100
   CUF:   0.000000  CCF:   100
   A :0.407541E-07  B :-.103013E-09  C :0.239057E-13  D :-.146939E-16
   AC :     0     BC :     0     CC :     0     DC :     0

  5:   -1344.85393     3.000000    KZFSN5_SCHOTT     0  100
  6:     54.76849     2.000000                    0    0
  7:     33.49188     6.565412    SBSL7_OHARA      0    0
  8:    -55.41325     1.000000                    0    0
 STO:     INFINITY     2.888136                    0    0
 10:    -36.12432     1.800000    KZFSN5_SCHOTT     0    0
 11:     23.85626     7.841067    SBAH27_OHARA     0    0
 12:    -62.61419     0.100000                    0    0
 13:     34.67658     7.757688    SBSL7_OHARA      0    0
 14:    -58.88713     1.334412                    0    0
 15:   -102.94094     4.450000    KZFSN5_SCHOTT     0  100
   ASP:
   K :   0.000000  KC :   100
   CUF:   0.000000  CCF:   100
   A :-.841695E-05  B :-.498663E-08  C :0.209013E-11  D :-.457612E-14
   AC :     0     BC :     0     CC :     0     DC :     0

 16:     34.06787     32.253107                   0    0
 17:    -26.28703     5.340000    SBSL7_OHARA      0  100
 18:   -174.79380     2.704923                    0    0
 19:   -131.76874     12.000000    STIH53_OHARA     0  100
   ASP:
   K :   0.000000  KC :   100
   CUF:   0.000000  CCF:   100
   A :0.801597E-06  B :-.463268E-10  C :-.107461E-12  D :0.344151E-16
   AC :     0     BC :     0     CC :     0     DC :     0

 20:    -79.22930     1.000000                    0    0
 21:    202.74308     16.183669    SLAH60_OHARA     0    0
 22:   -157.03730     14.492953                   0    0
IMG:     INFINITY     0.000000                    100  100

SPECIFICATION DATA
 FNO      4.50000
 DIM        MM
 WL       650.00   600.00   550.00   500.00   450.00
 REF         3
 WTW        55      75      100      95      89
 INI        ORA
 XAN      0.00000     0.00000     0.00000     0.00000     0.00000
       0.00000     0.00000
 YAN      0.00000     5.00000     10.00000     15.00000     20.00000
      25.00000     29.25000
 WTF      1.00000     1.00000     1.00000     1.00000     1.00000
       1.00000     1.00000
 VUX      0.00000     -0.00013     -0.00050     -0.00100     -0.00141
      -0.00146     -0.00093
 VLX      0.00000     -0.00013     -0.00050     -0.00100     -0.00141
      -0.00146     -0.00093
 VUY      0.00000     -0.00102     -0.00286     -0.00496     -0.00632
      -0.00542     0.00000
 VLY      0.00000     0.00000     -0.00085     -0.00192     -0.00213
       0.00005     0.00708
 POL         N
```

FIG. 21

APERTURE DATA/EDGE DEFINITIONS

CA APE	
CIR S0	**********
CIR S1	41.747008
CIR S2	36.184688
CIR S3	36.824169
CIR S4	36.641973
CIR S5	16.125087
CIR S6	14.804089
CIR S7	14.064470
CIR S8	13.498355
CIR S9	11.296031
CIR S10	11.526068
CIR S11	13.803559
CIR S12	14.245370
CIR S13	15.632664
CIR S14	15.593224
CIR S15	15.272309
CIR S16	15.391620
CIR S17	22.326183
CIR S18	32.940985
CIR S19	35.409710
CIR S20	38.808977
CIR S21	49.751008
CIR S22	50.036204
CIR S23	50.360377

REFRACTIVE INDICES

GLASS CODE	650.00	600.00	550.00	500.00	450.00
KZFSN5_SCHOTT	1.649587	1.653101	1.657624	1.663660	1.672092
SLAH60_OHARA	1.827894	1.832626	1.838763	1.847011	1.858606
SBAH27_OHARA	1.696897	1.700493	1.705147	1.711390	1.720162
STIH53_OHARA	1.837273	1.844526	1.854151	1.867463	1.886939
SBSL7_OHARA	1.514053	1.515825	1.518051	1.520943	1.524849
SLAH52_OHARA	1.794322	1.798350	1.803543	1.810469	1.820110

No solves defined in system

No pickups defined in system

INFINITE CONJUGATES

EFL	90.0000
BFL	14.4889
FFL	1.3027
FNO	4.5000
IMG DIS	14.4930
OAL	180.0000
PARAXIAL IMAGE	
HT	50.4024
ANG	29.2500
ENTRANCE PUPIL	
DIA	20.0000
THI	55.5505
EXIT PUPIL	
DIA	33.1811
THI	-134.8258

FIG. 21 (continued)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/051795

A. CLASSIFICATION OF SUBJECT MATTER

G02B 13/04(2006.01)i, G02B 13/00(2006.01)i, G02B 9/12(2006.01)i, G02B 11/18(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G02B 13/04; G02B 9/64; G02B 13/22; G02B 15/02; G02B 13/18

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: 'lens', 'low distortion', 'wide angle', and 'telecentric'

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 11-142728 A (NIKON CORP) 28 May 1999 See abstract, claim 1, paragraph [0005] and figure 1.	1-40
A	US 05625495 A (MOSKOVICH; JACOB) 29 April 1997 See abstract, column 3, lines 40-67 and figure 1.	1-40
A	US 05103342 A (KATAOKA; YOSHIKAZU) 07 April 1992 See abstract, column 3, lines 30-44 and figure 1A.	1-40
A	JP 2010-139827 A (TOPCON CORP) 24 June 2010 See abstract, claim 1 and figure 1.	1-40

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 DECEMBER 2012 (24.12.2012)	**26 DECEMBER 2012 (26.12.2012)**

Name and mailing address of the ISA/KR

Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea

Facsimile No. 82-42-472-7140

Authorized officer

KIM, Bo Cheol

Telephone No. 82-42-481-8721

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2012/051795

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 11-142728 A	28.05.1999	None	
US 05625495 A	29.04.1997	EP 0796450 A1	24.09.1997
		EP 0796450 B1	28.05.2003
		JP 11-500834 A	19.01.1999
		KR 10-0387123 B1	10.10.2003
		US RE39424 E1	12.12.2006
		WO 96-18124 A1	13.06.1996
US 05103342 A	07.04.1992	EP 0416651 A2	13.03.1991
		EP 0416651 A3	26.02.1992
		EP 0416651 B1	09.11.1994
		JP 08-023627 B2	06.03.1996
		JP 2105996 C	06.11.1996
		JP 3096912 A	22.04.1991
JP 2010-139827 A	24.06.2010	None	