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(54) **LENS SYSTEM, AND IMAGE PROJECTION APPARATUS AND IMAGING APPARATUS THAT INCLUDE THE SAME**

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G02B 27/09 (2006.01)
G03B 21/14 (2006.01)
G02B 13/16 (2006.01)

(52) **U.S. Cl.**

CPC ***G02B 15/20*** (2013.01); ***G02B 13/16*** (2013.01); ***G03B 21/14*** (2013.01); ***G02B 27/0955*** (2013.01)

(57) **ABSTRACT**

The lens system forms an image conjugately between each of a magnification conjugate point and a reduction conjugate point; and an intermediate image-forming position. The lens system includes a magnification optical system with positive power, the magnification optical system having a plurality of lens elements and positioned closer to the magnification side than the intermediate image-forming position; and a relay optical system with positive power, the relay optical system having a plurality of lens elements and positioned closer to the reduction side than the intermediate image-forming position. The lens system satisfies following conditions (1) and (2).

$$0.08 \leq fp/fr \leq 0.8 \quad (1)$$

$$\{Ymax - ft \cdot \tan(\omega max)\}/\{ft \cdot \tan(\omega max)\} \leq -0.3 \quad (2)$$

where

fr is composite focal length of the relay optical system,

fp is composite focal length of the magnification optical system,

Ymax is a radius of an effective image diameter,

ωmax is a maximum half view angle, and

ft is the focal length of the lens system.

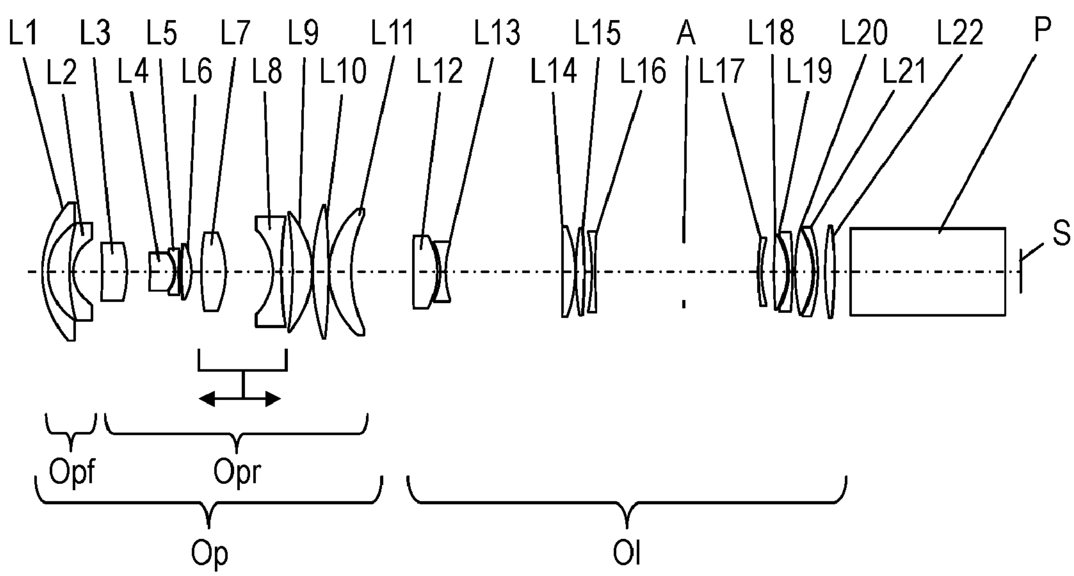

FIG. 1

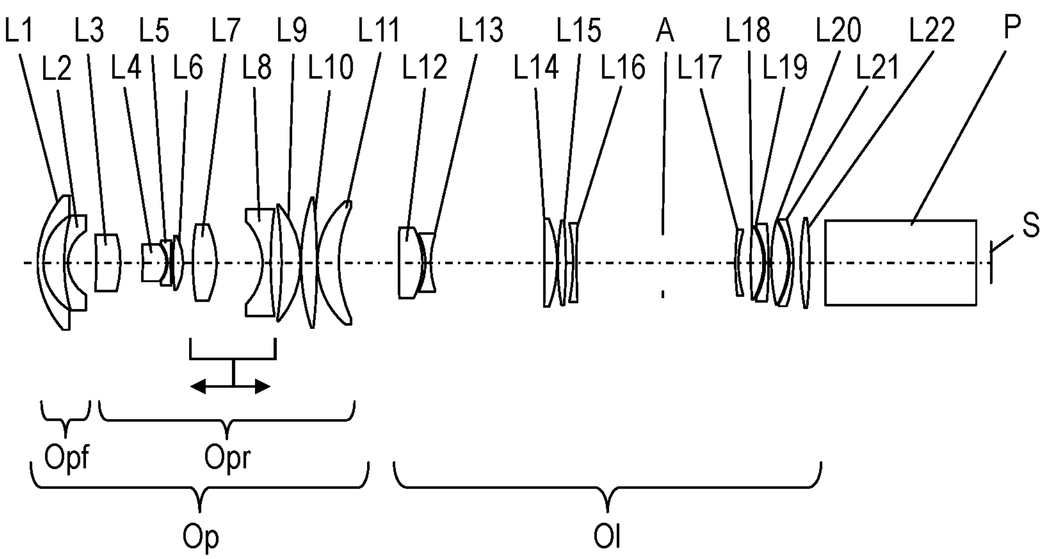
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FIG. 2

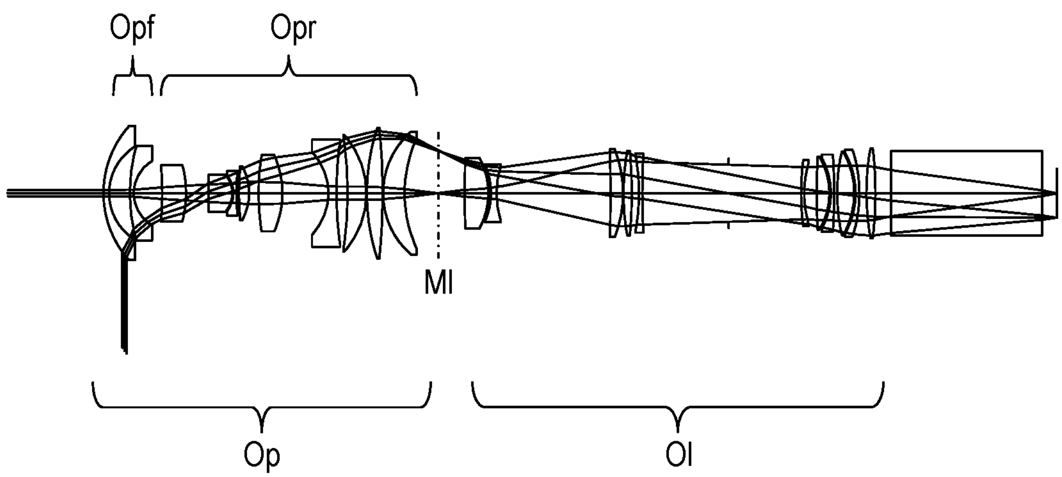
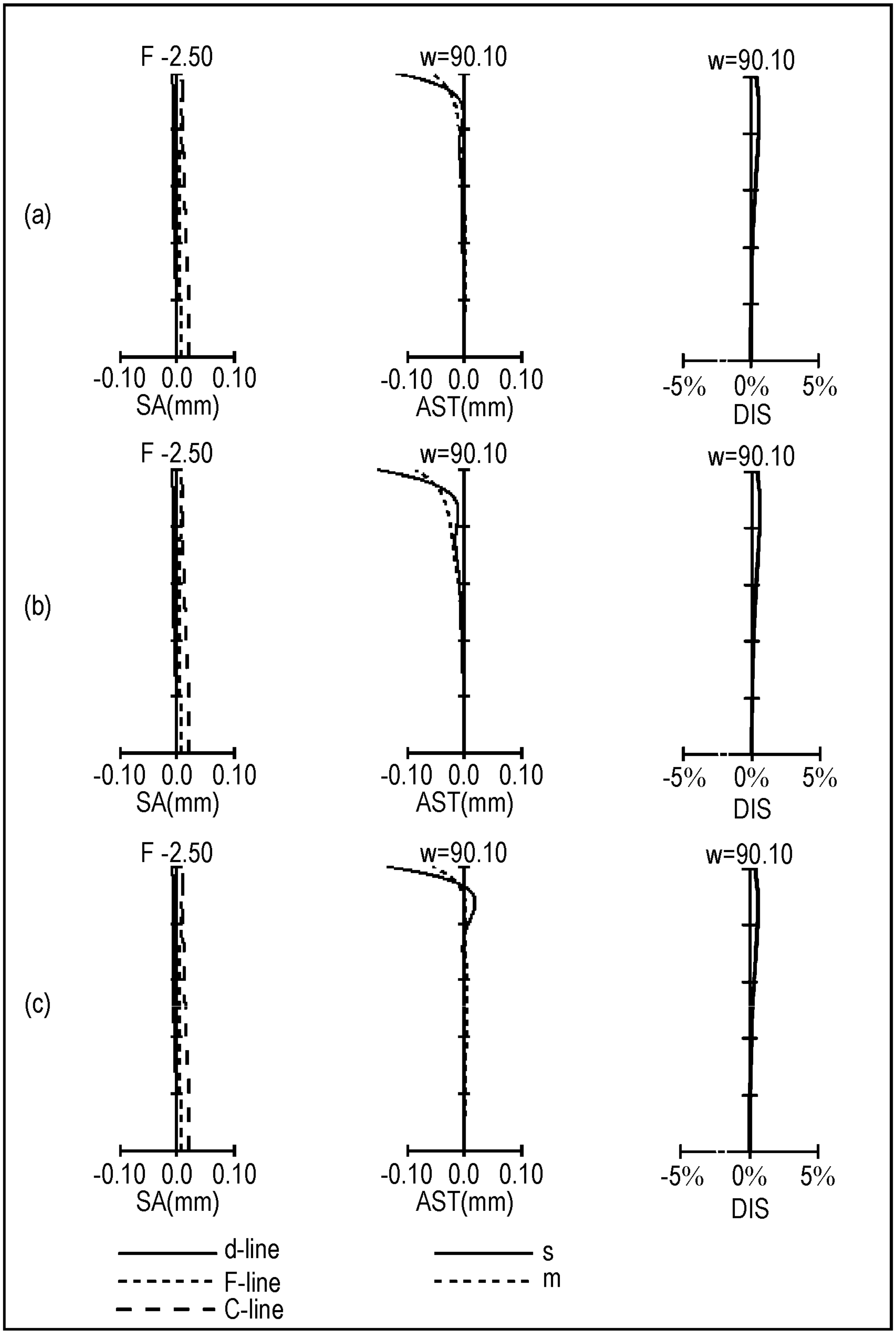


FIG. 3


F -2.50
w=90.10
w=90.10
(a)
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
DIS
F -2.50
w=90.10
w=90.10
(b)
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
DIS
F -2.50
w=90.10
w=90.10
(c)
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
DIS
d-line
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C-line
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FIG. 4

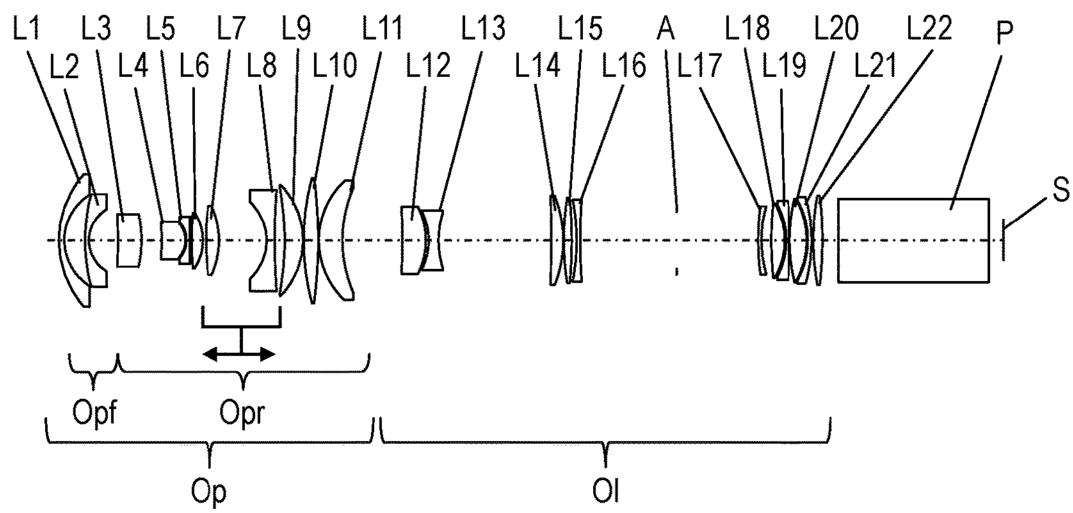
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FIG. 5

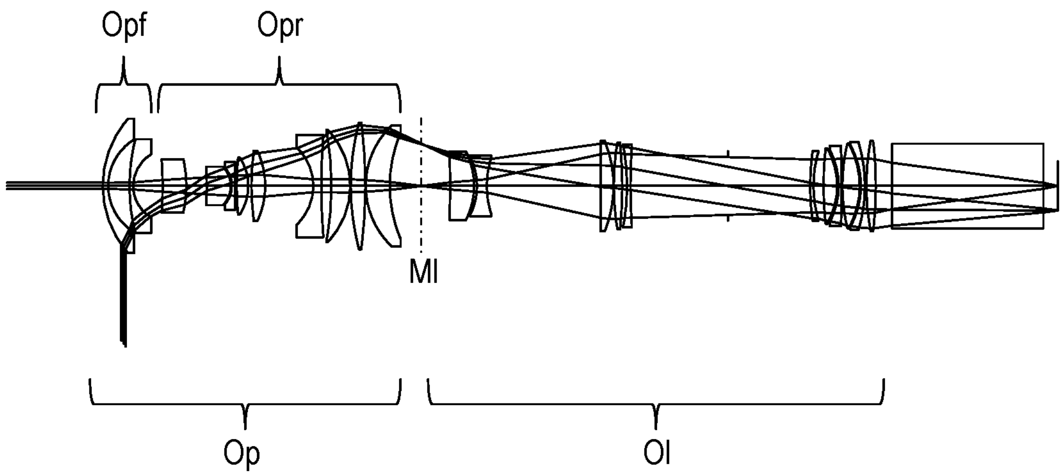

FIG. 6

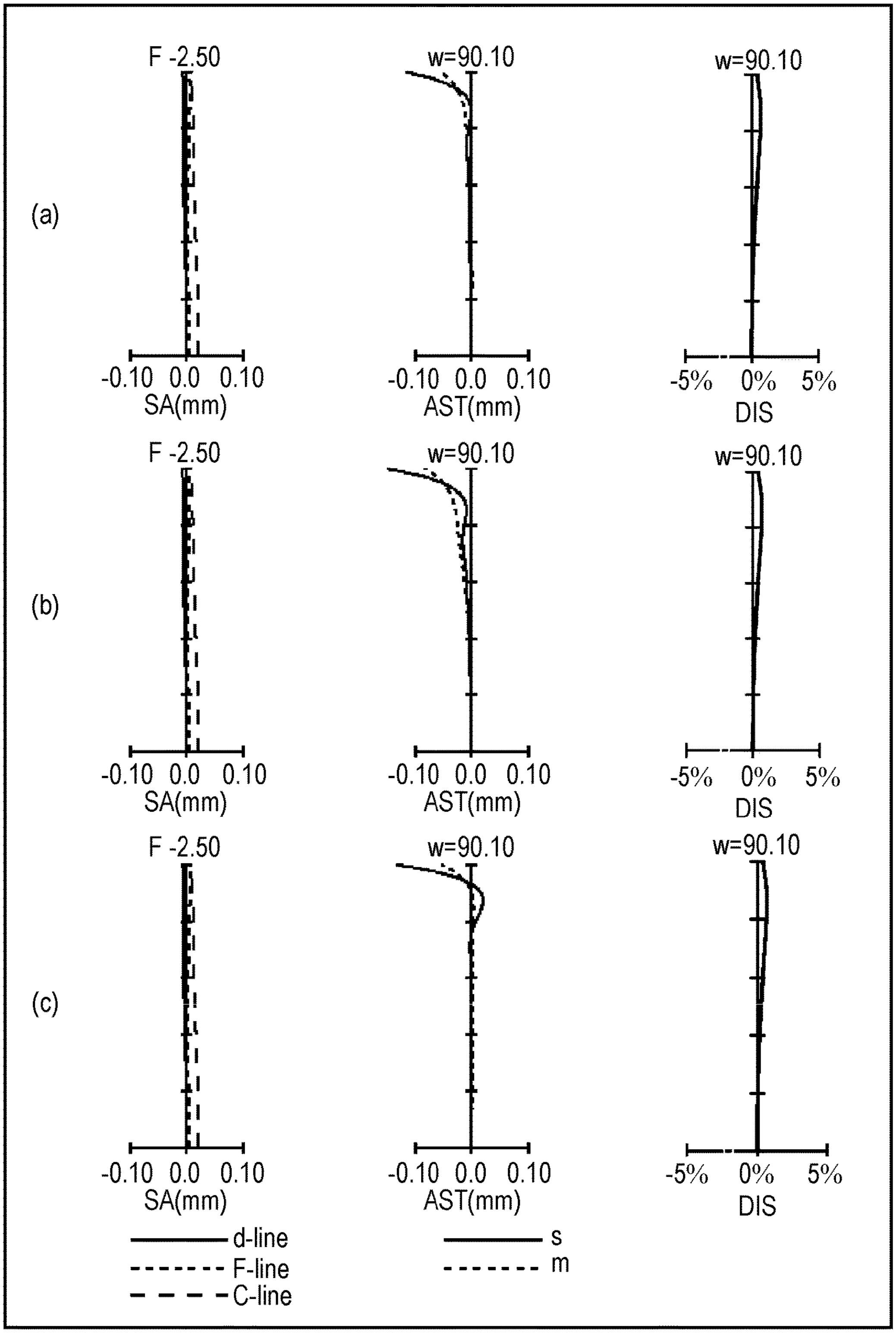
F -2.50
w=90.10
w=90.10
(a)
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
DIS
F -2.50
w=90.10
w=90.10
(b)
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
DIS
F -2.50
w=90.10
w=90.10
(c)
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
DIS
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FIG. 7

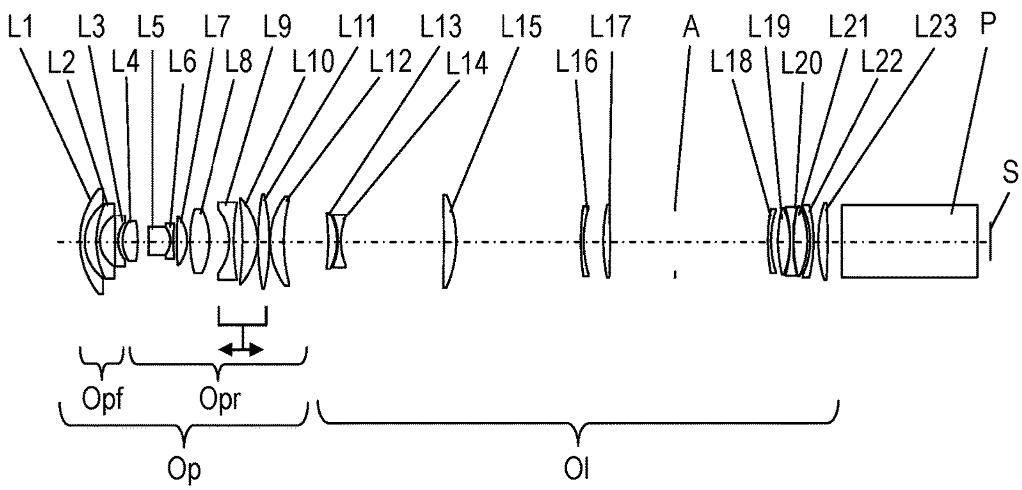
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FIG. 8

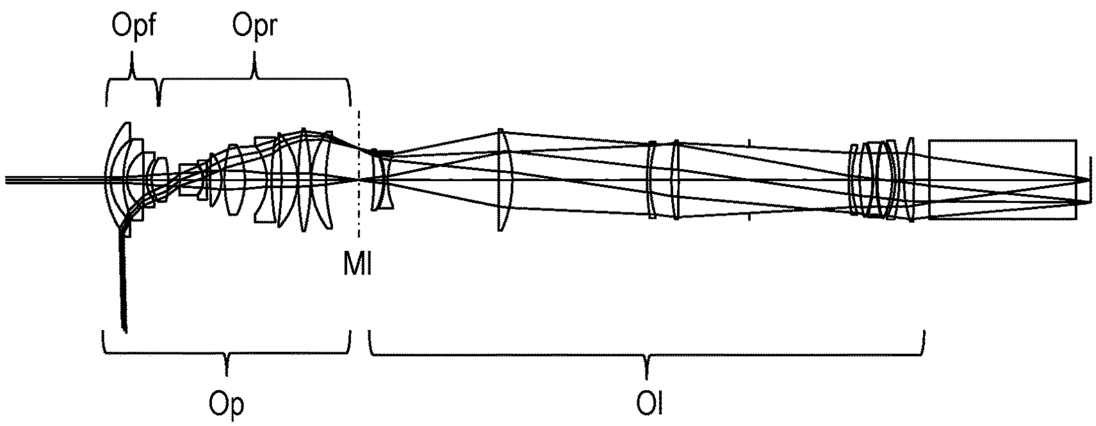

FIG. 9

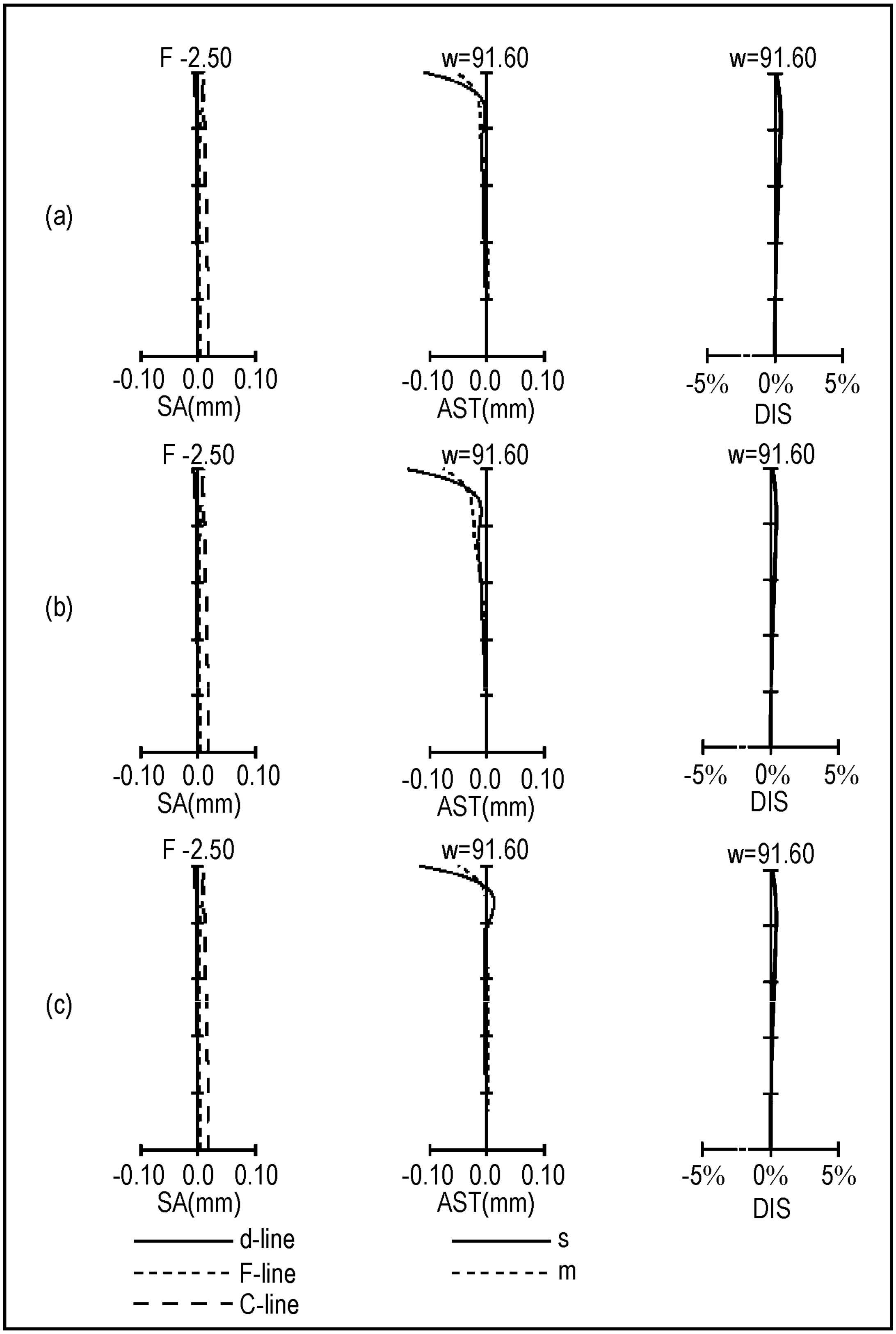
F -2.50
w=91.60
w=91.60
(a)
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
DIS
F -2.50
w=91.60
w=91.60
(b)
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
DIS
F -2.50
w=91.60
w=91.60
(c)
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
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FIG. 10

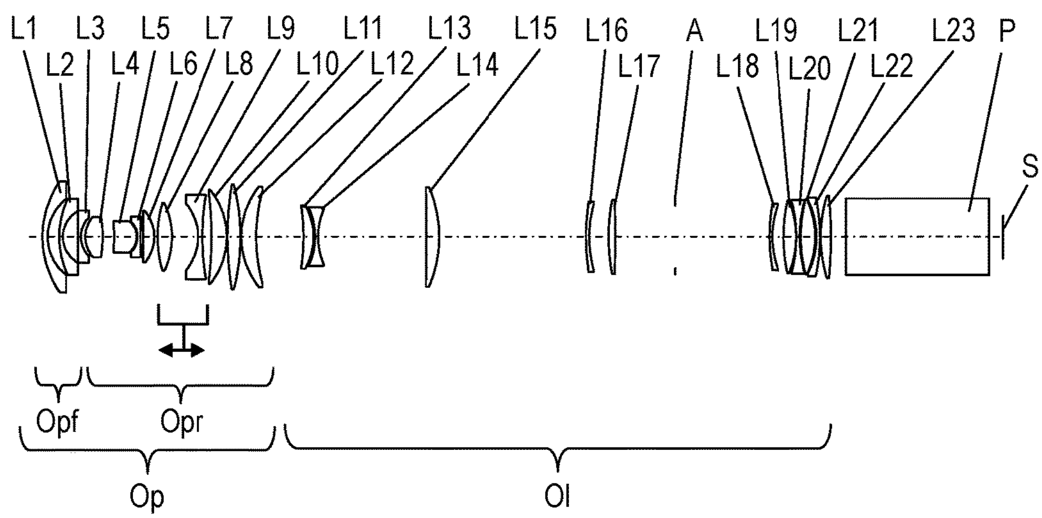
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FIG. 11

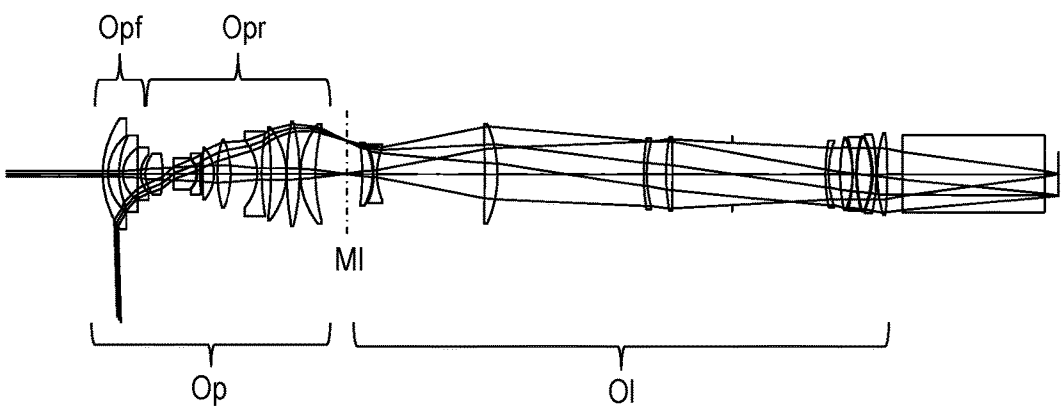
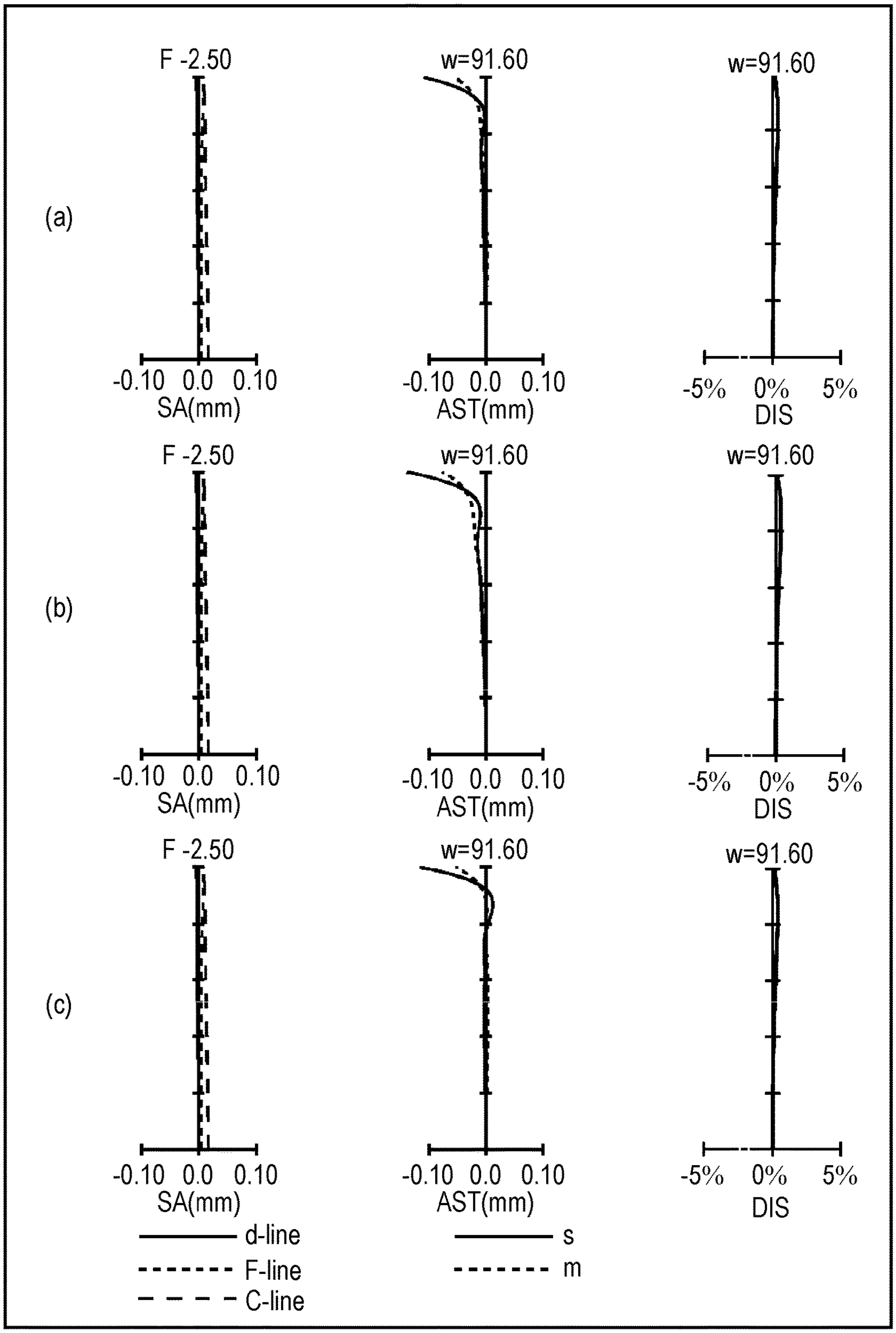


FIG. 12



(a)
(b)
(c)
F -2.50
w=91.60
-0.10 0.0 0.10
SA(mm)
AST(mm)
-5% 0% 5%
DIS
d-line
F-line
C-line
s
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FIG. 13

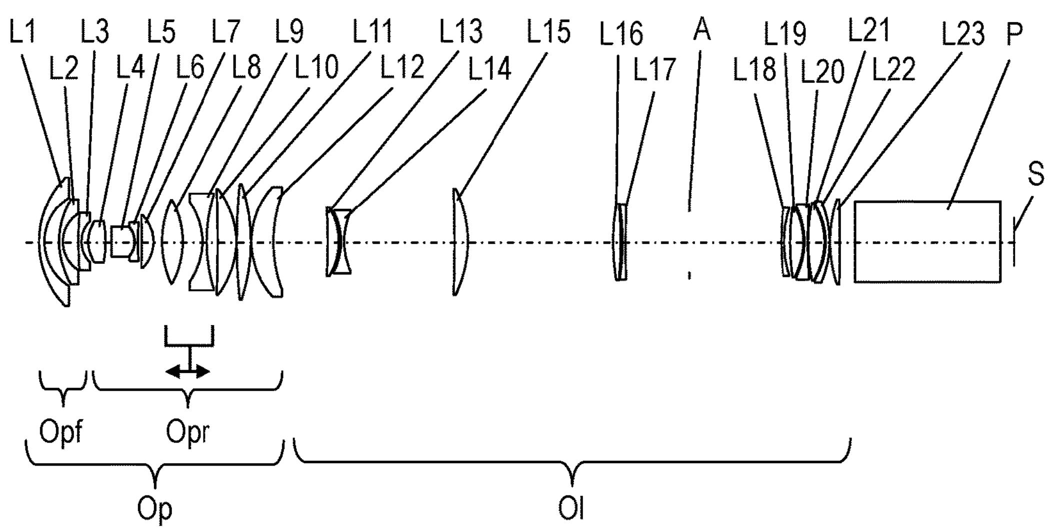

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FIG. 14

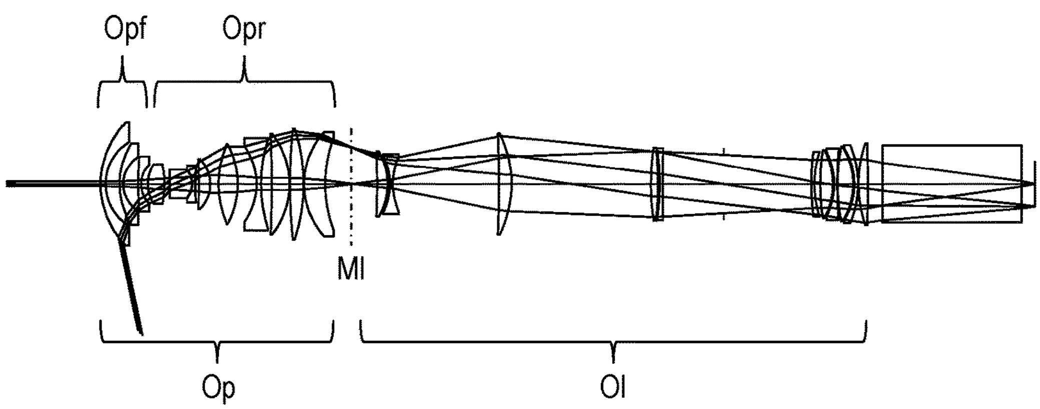
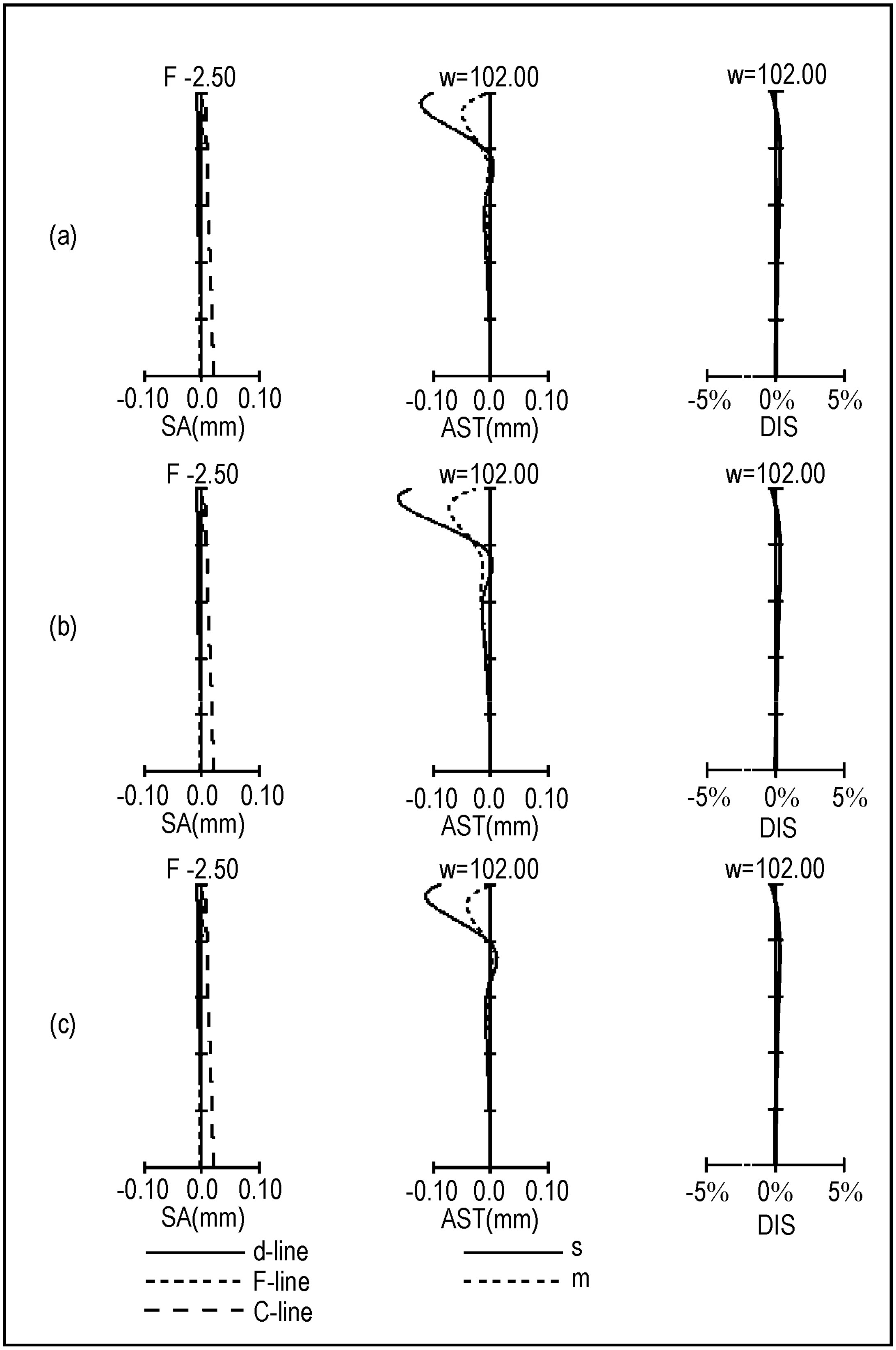


FIG. 15



F -2.50
w=102.00
w=102.00
(a)
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
DIS
F -2.50
w=102.00
w=102.00
(b)
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
DIS
F -2.50
w=102.00
w=102.00
(c)
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
DIS
d-line
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FIG. 16

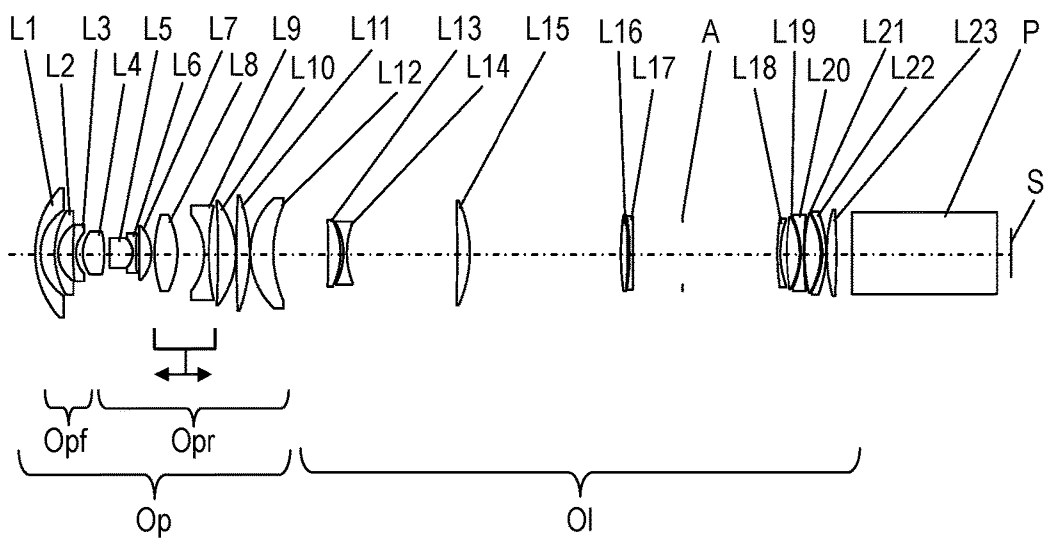
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FIG. 17

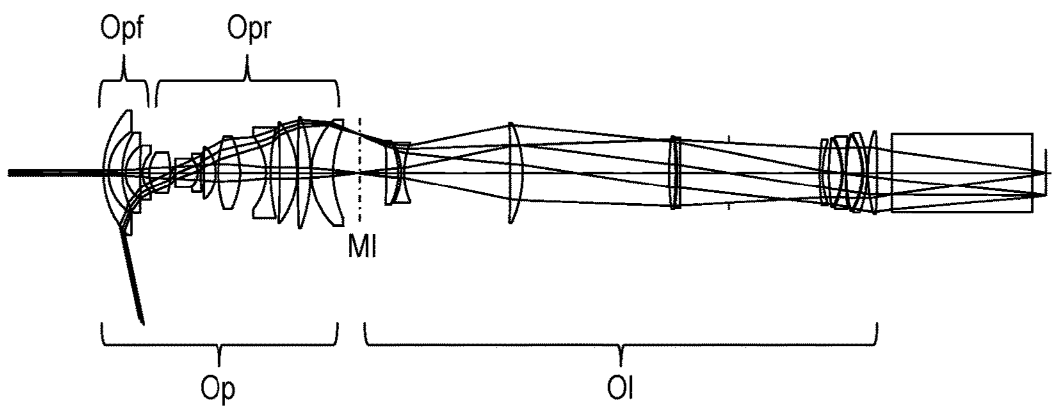
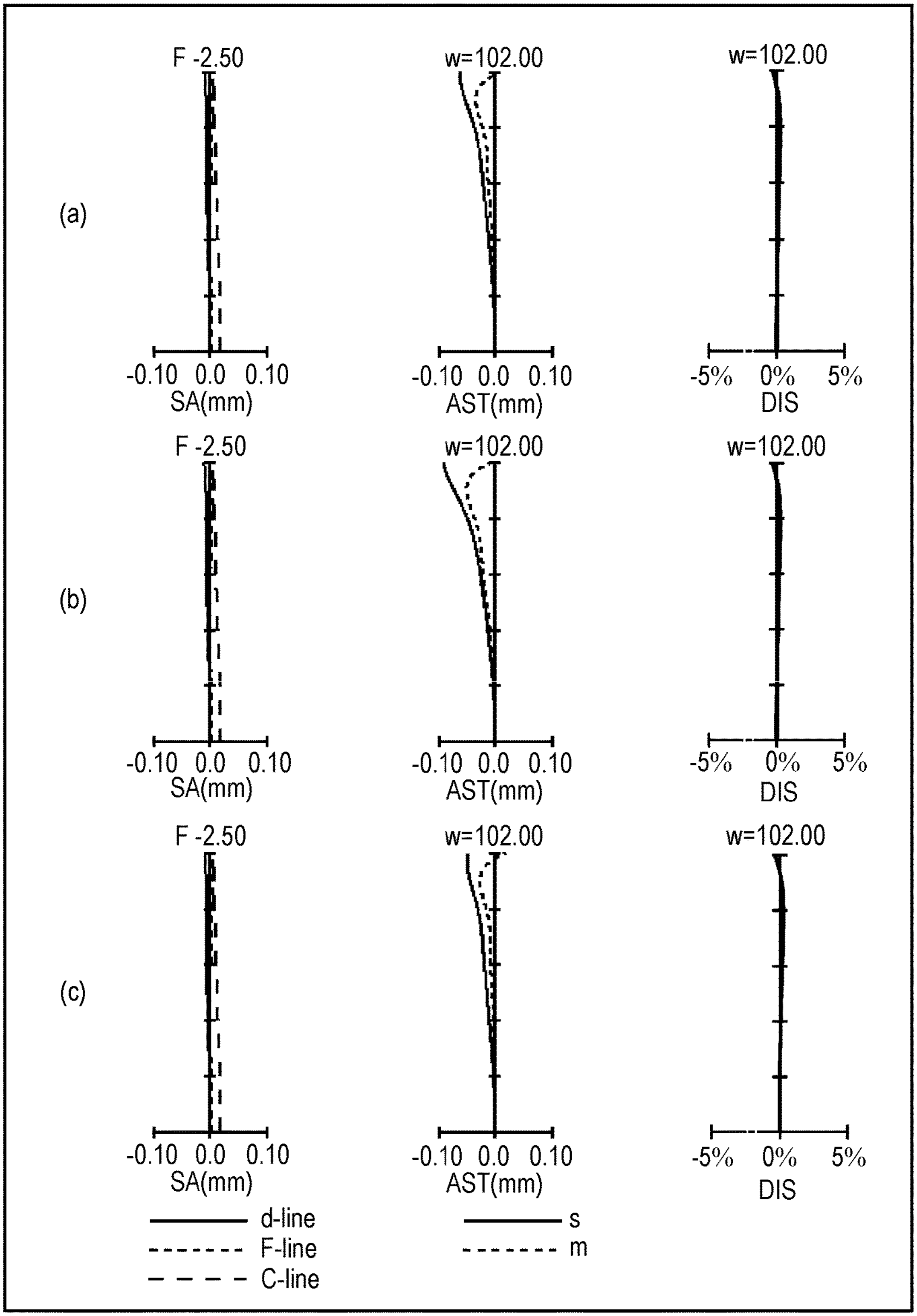


FIG. 18



(a)
F -2.50
-0.10 0.0 0.10
SA(mm)
w=102.00
-0.10 0.0 0.10
AST(mm)
w=102.00
-5% 0% 5%
DIS
(b)
F -2.50
-0.10 0.0 0.10
SA(mm)
w=102.00
-0.10 0.0 0.10
AST(mm)
w=102.00
-5% 0% 5%
DIS
(c)
F -2.50
-0.10 0.0 0.10
SA(mm)
w=102.00
-0.10 0.0 0.10
AST(mm)
w=102.00
-5% 0% 5%
DIS
d-line
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FIG. 19

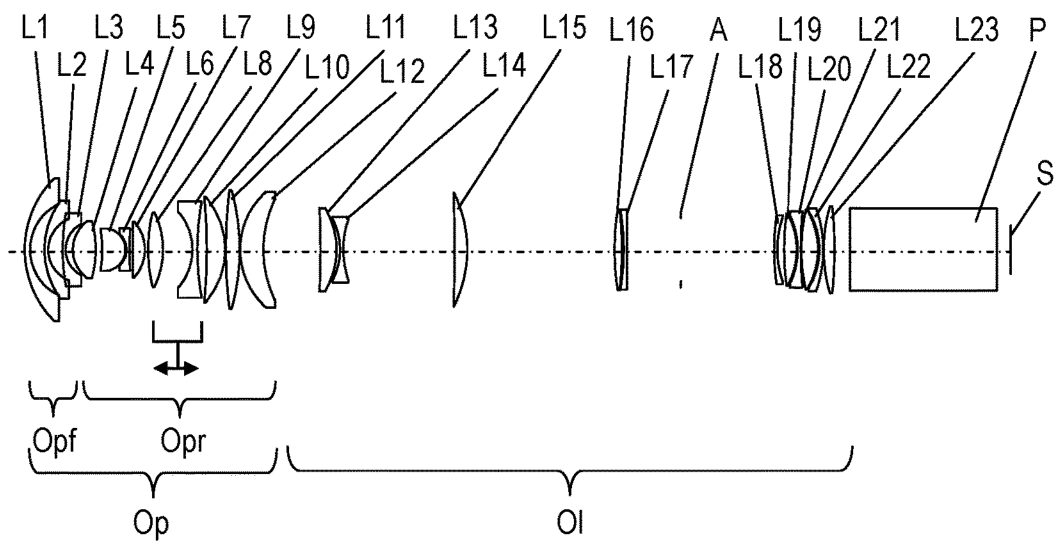
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FIG. 20

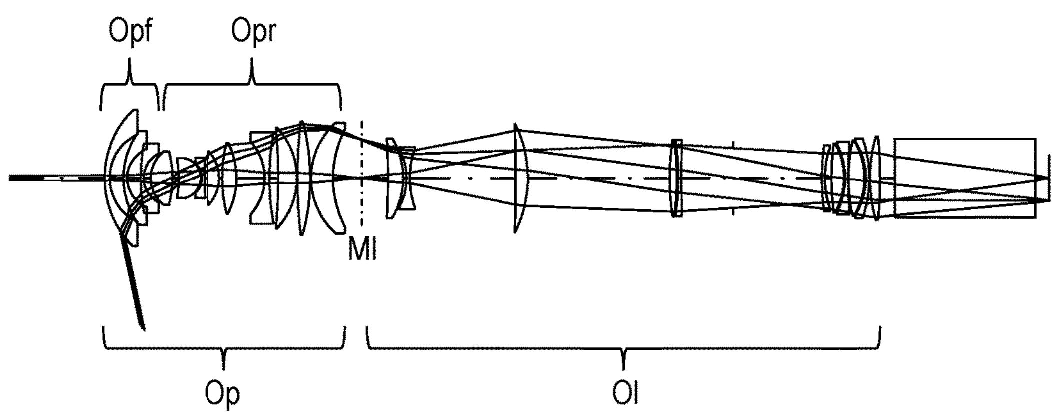
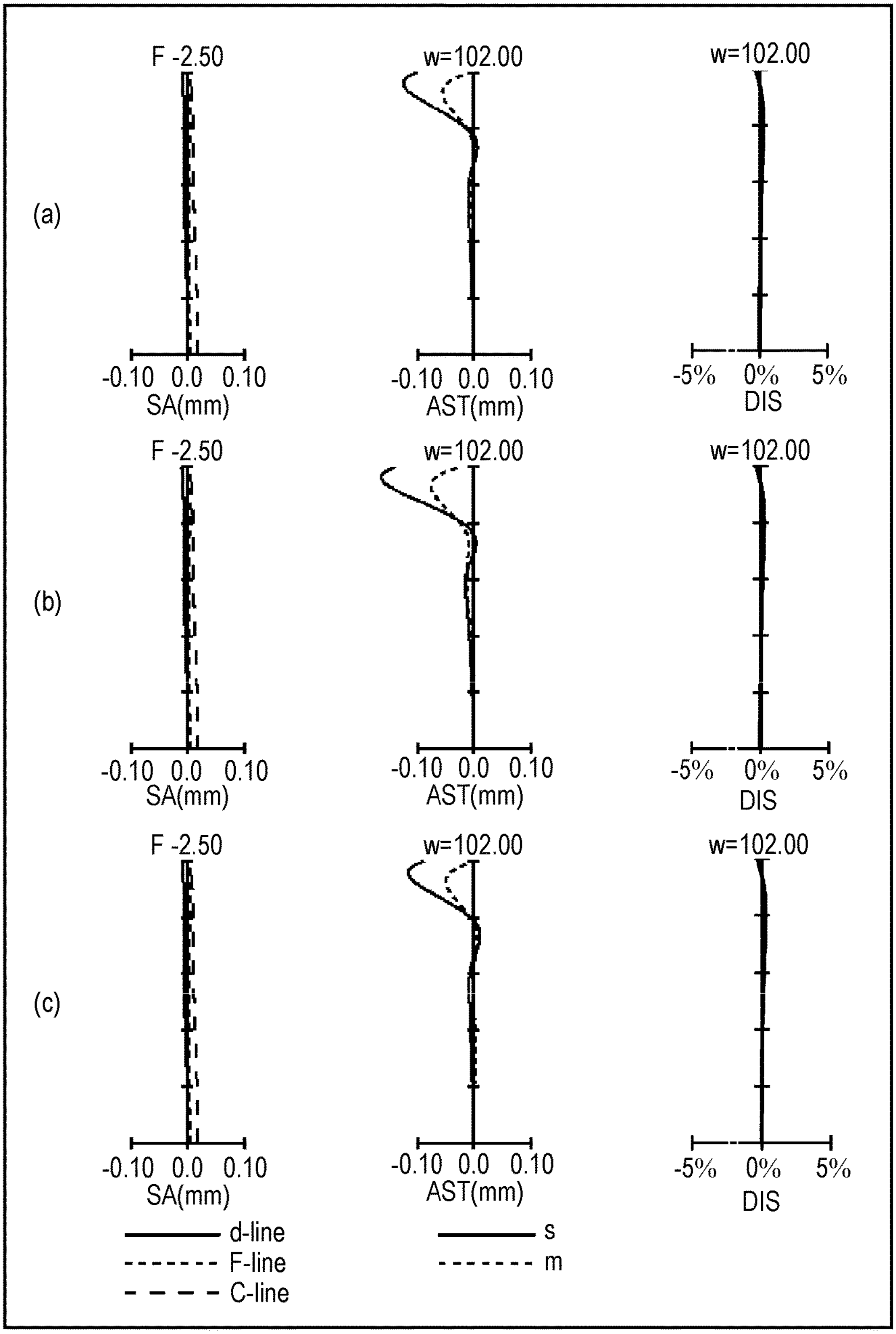


FIG. 21



F -2.50
w=102.00
w=102.00
(a)
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
DIS
F -2.50
w=102.00
w=102.00
(b)
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
DIS
F -2.50
w=102.00
w=102.00
(c)
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
DIS
d-line
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C-line
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FIG. 22

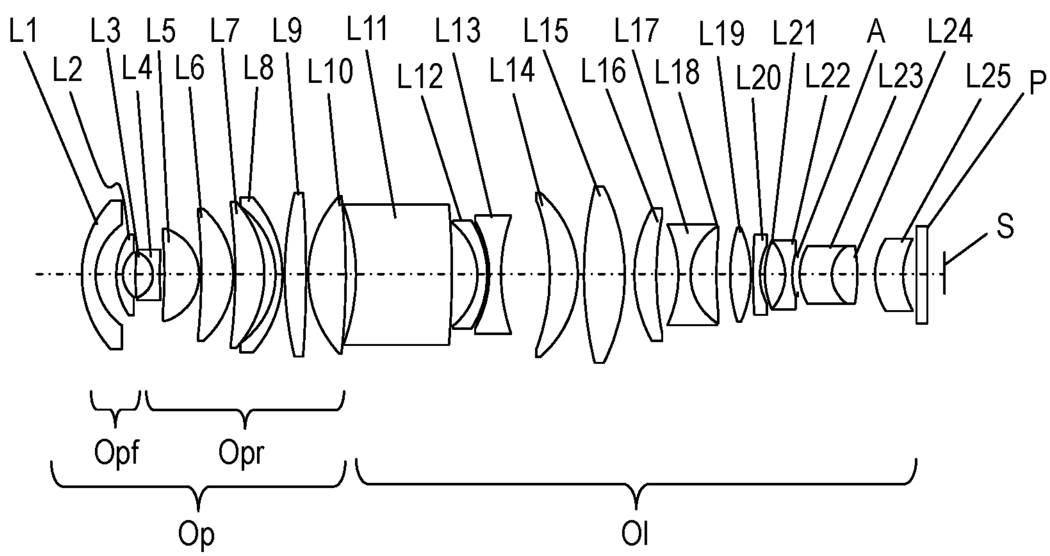
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FIG. 23

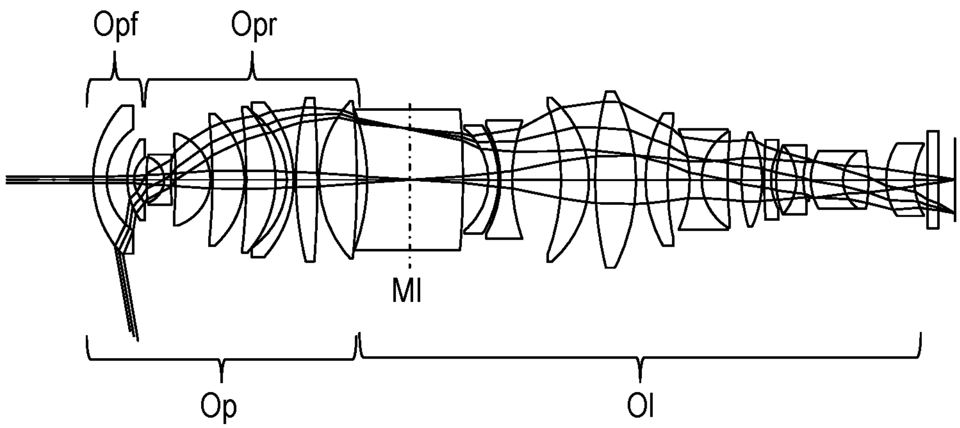
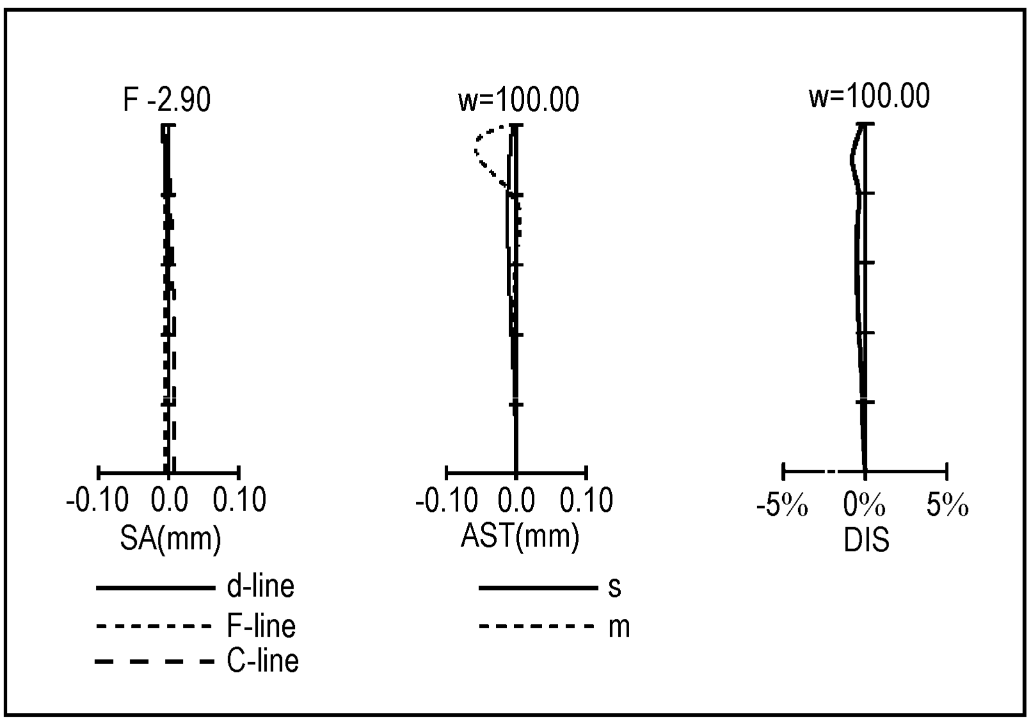


FIG. 24


F -2.90
w=100.00
w=100.00
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
DIS
d-line
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C-line
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FIG. 25

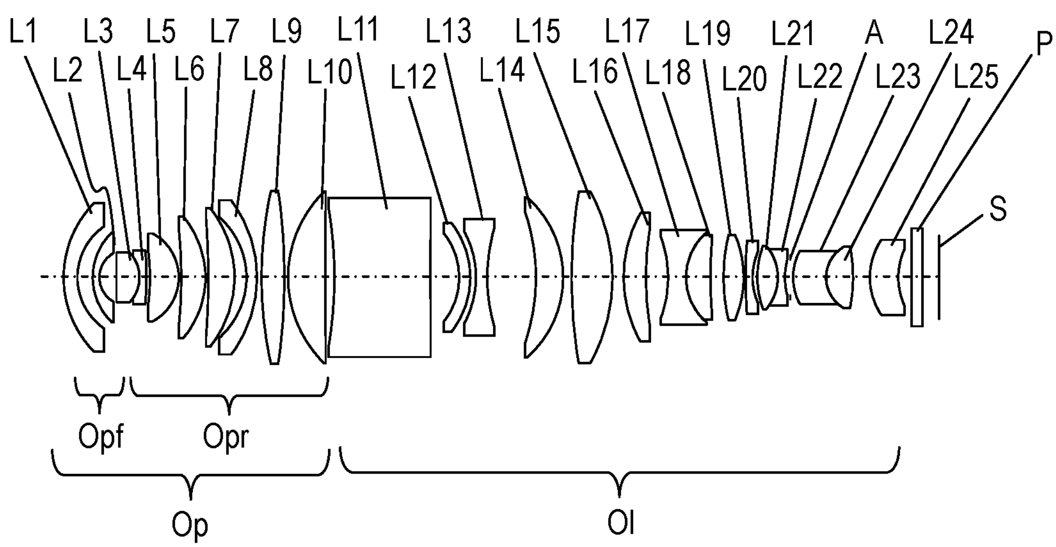
L1
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FIG. 26

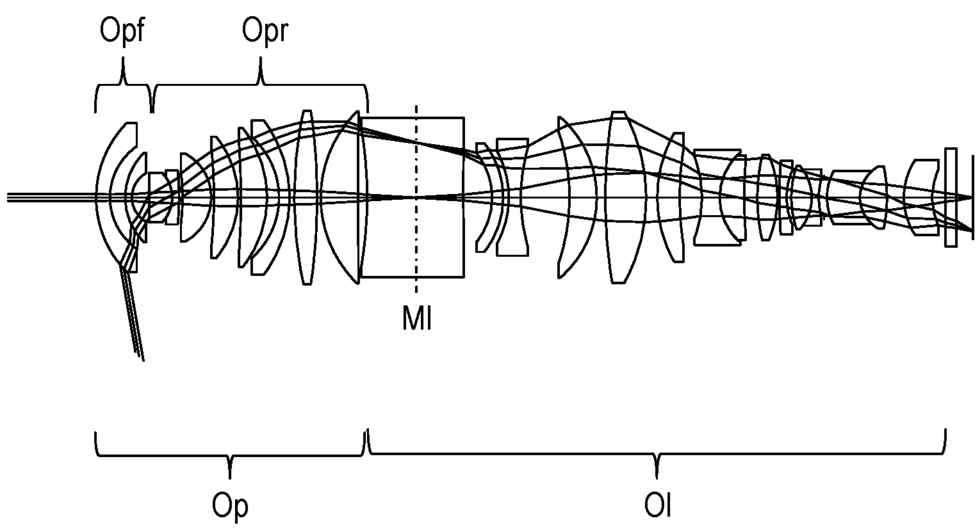

FIG. 27

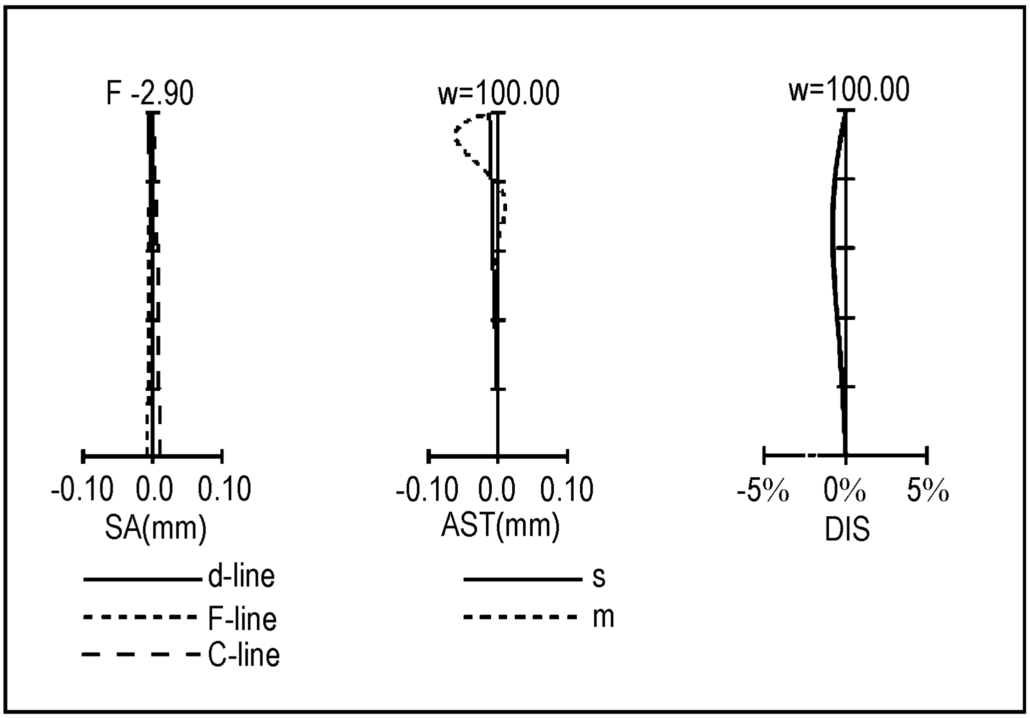
F -2.90
-0.10 0.0 0.10
SA(mm)
d-line
F-line
C-line
w=100.00
-0.10 0.0 0.10
AST(mm)
s
m
w=100.00
-5% 0% 5%
DIS

FIG. 28

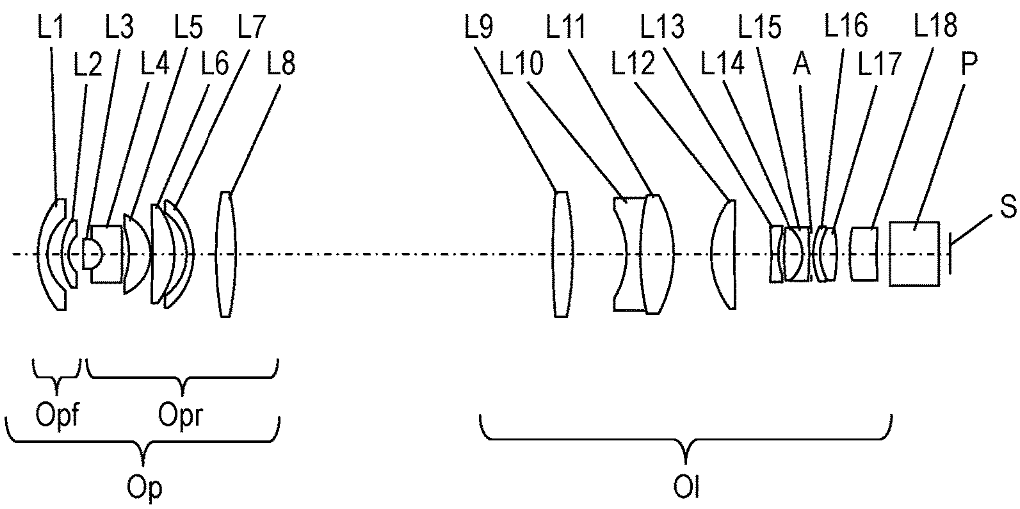
L1
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FIG. 29

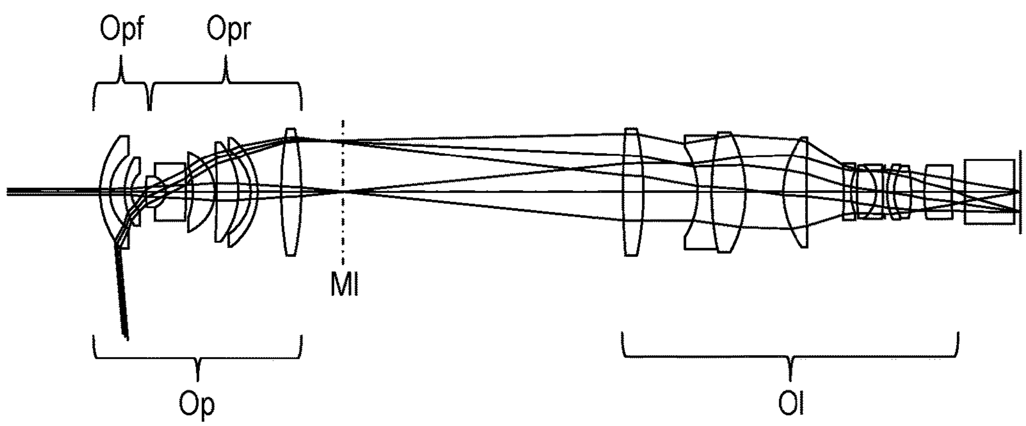

FIG. 30

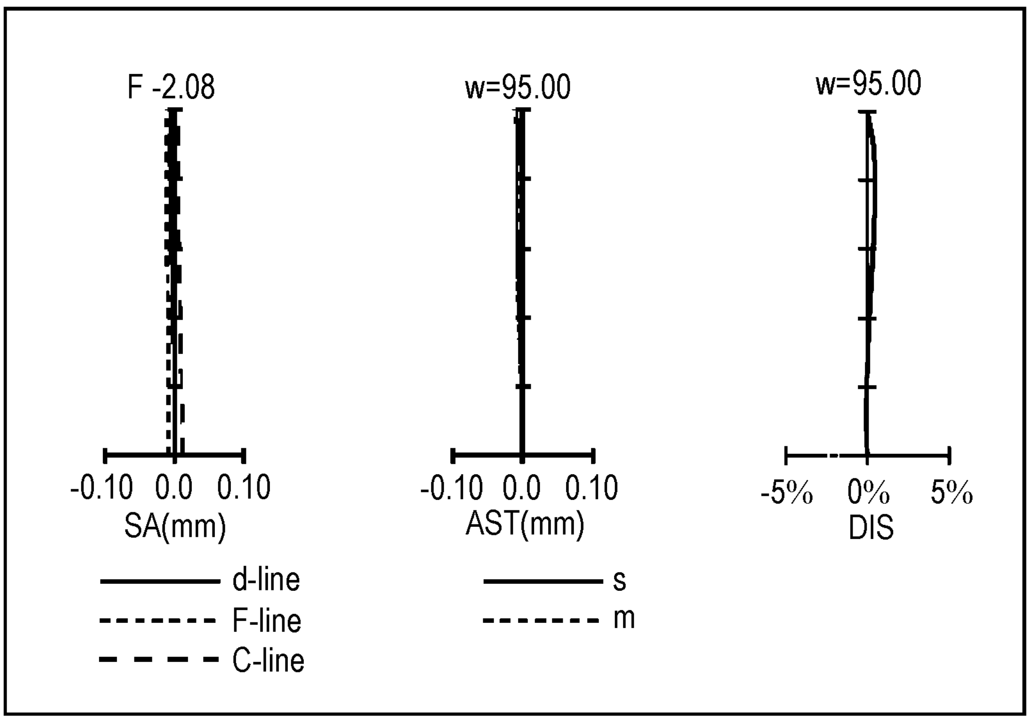
F -2.08
w=95.00
w=95.00
-0.10 0.0 0.10
SA(mm)
-0.10 0.0 0.10
AST(mm)
-5% 0% 5%
DIS
d-line
F-line
C-line
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FIG. 31

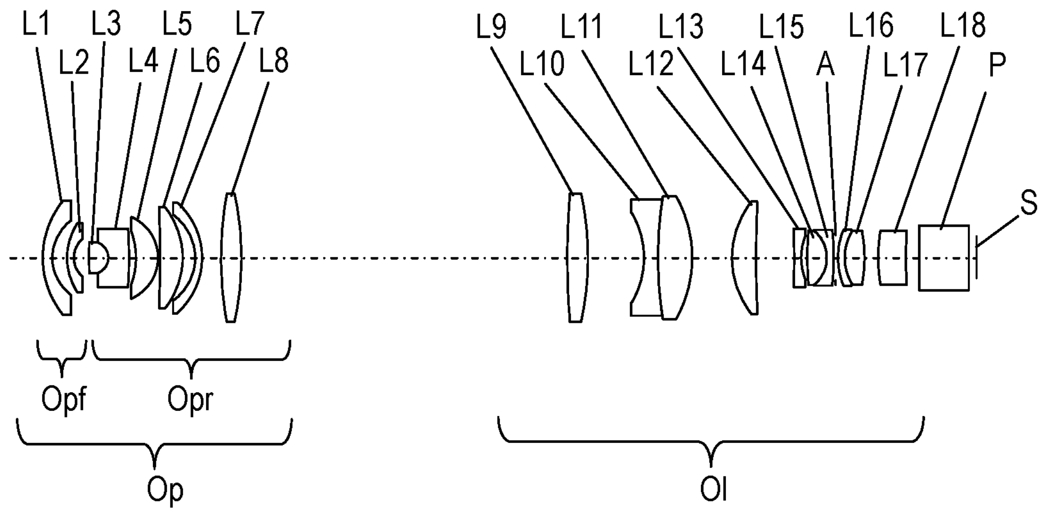
L1
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FIG. 32

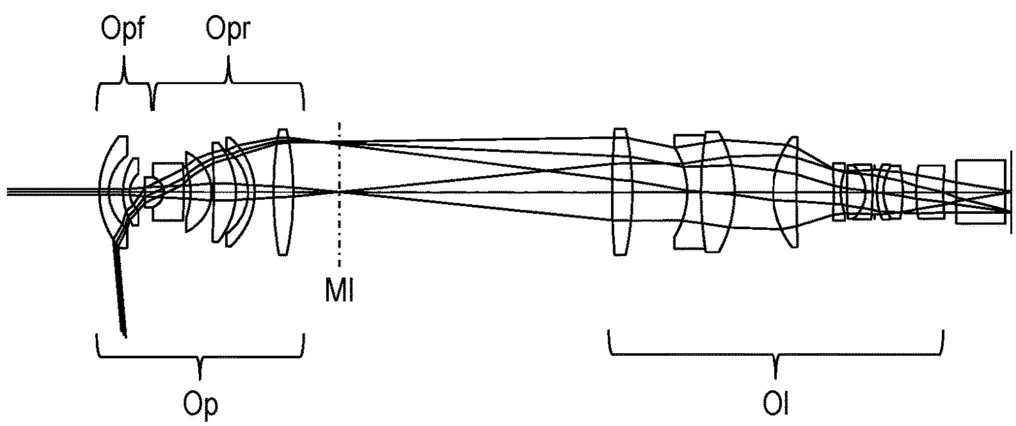
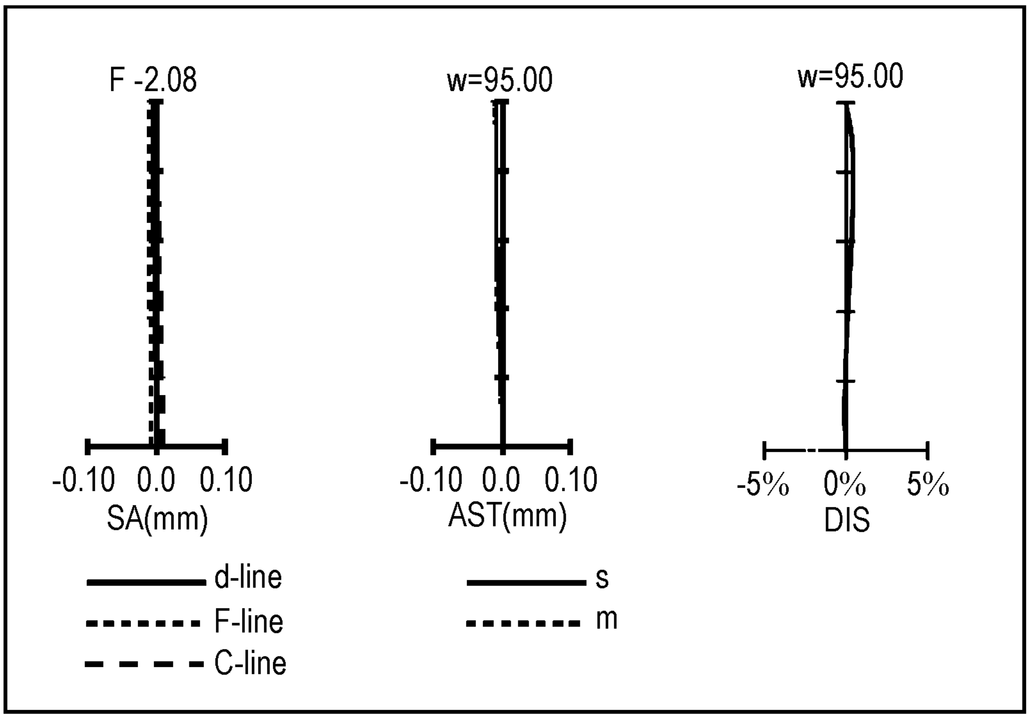


FIG. 33



F -2.08
-0.10 0.0 0.10
SA(mm)
d-line
F-line
C-line
w=95.00
-0.10 0.0 0.10
AST(mm)
s
m
w=95.00
-5% 0% 5%
DIS

LENS SYSTEM, AND IMAGE PROJECTION APPARATUS AND IMAGING APPARATUS THAT INCLUDE THE SAME

BACKGROUND

1. Technical Field

[0001] The present disclosure relates to a lens system that forms an image by means of a series of lenses including multiple lens elements, and to an image projection apparatus and an imaging apparatus that include the lens system.

2. Description and the Related Art

[0002] Patent literature 1 discloses a magnified-projection optical system that includes a projection optical system, a relay optical system, and a display element disposed in order from the screen side along the optical axis. The projection optical system magnify-projects an image primarily formed by the relay optical system onto a screen. The magnified-projection optical system includes a negative group with negative optical power and a positive group with positive optical power that are disposed in order from the screen side. This magnified-projection optical system provides a greatly long back focus despite its short focal length, as well as a small color aberration.

CITATION LIST

Patent Literature

[0003] PTL 1: WO 2009/107553

SUMMARY

[0004] The present disclosure provides a lens system with a small lens diameter while suppressing various aberrations, and an image projection apparatus and an imaging apparatus that include the lens system.

[0005] The lens system that forms an image conjugately between each of a magnification conjugate point at a magnification side and a reduction conjugate point at a reduction side; and an intermediate image-forming position inside the lens system. The lens system includes a magnification optical system with positive power, the magnification optical system having a plurality of lens elements, the magnification optical system positioned closer to the magnification side than the intermediate image-forming position; and a relay optical system with positive power, the relay optical system having a plurality of lens elements, the relay optical system positioned closer to the reduction side than the intermediate image-forming position. The lens system satisfies following conditions (1) and (2).

$$0.08 \leq fp/fr \leq 0.8 \quad (1)$$

$$\{Ymax - ft \cdot \tan(\omega max)\}/\{ft \cdot \tan(\omega max)\} \leq -0.3 \quad (2)$$

[0006] where

[0007] fr is composite focal length of the relay optical system closer to the reduction side than the intermediate image-forming position,

[0008] fp is composite focal length of the magnification optical system closer to the magnification side than the intermediate image-forming position,

[0009] Ymax is a radius of an effective image diameter,

[0010] ωmax is a maximum half view angle, and

[0011] ft is the focal length of the lens system as a whole.

[0012] The image projection apparatus according to the disclosure includes the lens system described above and an image-forming element generating an image to be projected onto a screen.

[0013] The imaging apparatus according to the disclosure includes the lens system described above, and an imaging element photoreceiving an optical image formed by the lens system and converting the optical image to an electrical image signal.

[0014] The disclosure provides a lens system with a small lens diameter while suppressing various aberrations.

BRIEF DESCRIPTION OF DRAWINGS

[0015] FIG. **1** is a lens layout diagram illustrating a lens system according to the first exemplary embodiment, in a focusing state for a projection distance of 4,000 mm.

[0016] FIG. **2** is a lens layout diagram illustrating the optical path of the lens system according to the first exemplary embodiment.

[0017] FIG. **3** is a longitudinal aberration diagram of the lens system according to the first exemplary embodiment.

[0018] FIG. **4** is a lens layout diagram illustrating a lens system according to the second exemplary embodiment, in a focusing state for a projection distance of 4,000 mm.

[0019] FIG. **5** is a lens layout diagram illustrating the optical path of the lens system according to the second exemplary embodiment.

[0020] FIG. **6** is a longitudinal aberration diagram of the lens system according to the second exemplary embodiment.

[0021] FIG. **7** is a lens layout diagram illustrating a lens system according to the third exemplary embodiment, in a focusing state for a projection distance of 4,000 mm.

[0022] FIG. **8** is a lens layout diagram illustrating the optical path of the lens system according to the third exemplary embodiment.

[0023] FIG. **9** is a longitudinal aberration diagram of the lens system according to the third exemplary embodiment.

[0024] FIG. **10** is a lens layout diagram of a lens system according to the fourth exemplary embodiment, in a focusing state for a projection distance of 4,000 mm.

[0025] FIG. **11** is a lens layout diagram illustrating the optical path of the lens system according to the fourth exemplary embodiment.

[0026] FIG. **12** is a longitudinal aberration diagram of the lens system according to the fourth exemplary embodiment.

[0027] FIG. **13** is a lens layout diagram of a lens system according to the fifth exemplary embodiment, in a focusing state for a projection distance of 4,000 mm.

[0028] FIG. **14** is a lens layout diagram illustrating the optical path of the lens system according to the fifth exemplary embodiment.

[0029] FIG. **15** is a longitudinal aberration diagram of the lens system according to the fifth exemplary embodiment.

[0030] FIG. **16** is a lens layout diagram of a lens system according to the sixth exemplary embodiment, in a focusing state for a projection distance of 4,000 mm.

[0031] FIG. **17** is a lens layout diagram illustrating the optical path of the lens system according to the sixth exemplary embodiment.

[0032] FIG. **18** is a longitudinal aberration diagram of the lens system according to the sixth exemplary embodiment.

[0033] FIG. **19** is a lens layout diagram of a lens system according to the seventh exemplary embodiment, in a focusing state for a projection distance of 4,000 mm.

[0034] FIG. **20** is a lens layout diagram illustrating the optical path of the lens system according to the seventh exemplary embodiment.

[0035] FIG. **21** is a longitudinal aberration diagram of the lens system according to the seventh exemplary embodiment.

[0036] FIG. **22** is a lens layout diagram of a lens system according to the eighth exemplary embodiment, in a focusing state for a projection distance of 4,000 mm.

[0037] FIG. **23** is a lens layout diagram illustrating the optical path of the lens system according to the eighth exemplary embodiment.

[0038] FIG. **24** is a longitudinal aberration diagram of the lens system according to the eighth exemplary embodiment.

[0039] FIG. **25** is a lens layout diagram of a lens system according to the ninth exemplary embodiment, in a focusing state for a projection distance of 4,000 mm.

[0040] FIG. **26** is a lens layout diagram illustrating the optical path of the lens system according to the ninth exemplary embodiment.

[0041] FIG. **27** is a longitudinal aberration diagram of the lens system according to the ninth exemplary embodiment.

[0042] FIG. **28** is a lens layout diagram of a lens system according to the tenth exemplary embodiment, in a focusing state for a projection distance of 4,000 mm.

[0043] FIG. **29** is a lens layout diagram illustrating the optical path of the lens system according to the tenth exemplary embodiment.

[0044] FIG. **30** is a longitudinal aberration diagram of the lens system according to the tenth exemplary embodiment.

[0045] FIG. **31** is a lens layout diagram of a lens system according to the eleventh exemplary embodiment, in a focusing state for a projection distance of 4,000 mm.

[0046] FIG. **32** is a lens layout diagram illustrating the optical path of the lens system according to the eleventh exemplary embodiment.

[0047] FIG. **33** is a longitudinal aberration diagram of the lens system according to the eleventh exemplary embodiment.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0048] Hereinafter, a detailed description is made of some embodiments with reference to the related drawings as appropriate. However, a detailed description more than necessary may be omitted, such as a description of a well-known item and a duplicate description for a substantially identical component, to avoid an unnecessarily redundant description and to allow those skilled in the art to easily understand the following description.

[0049] Note that the accompanying drawings and the following description are provided for those skilled in the art to well understand the disclosure and it is not intended that the drawings and the description limit the subjects described in the claims.

[0050] FIGS. **1**, **4**, **7**, **10**, **13**, **16**, **19**, **22**, **25**, **28** and **31** are respectively lens layout diagrams of the lens systems according to the exemplary embodiments first through eleventh. When focusing, the entire lens system moves in the optical axis direction. In FIGS. **1**, **4**, **7**, **10**, **13**, **16**, and **19**, the arrow under the lens groups indicates an image surface curvature correction lens group that moves along the optical axis when adjusting the amount of image surface curvature, where the group moves toward the magnification side or reduction side depending on the object distance and the curvature radius of the screen surface.

[0051] In the respective figures, the image-forming position at the magnification side is on the left; that at the reduction side is on the right. In the respective figures, the rightmost (the reduction side) straight line indicates the position of original image S. On the left (the magnification side) of original image S, optical element P is positioned. Optical element P represents an optical element such as a prism for color separation/synthesis, optical filter, parallel plain-plate glass, crystal low-pass filter, and infrared-cut filter. Here, if a lens element with negative power and that with positive power are joined together, the total power of the cemented lens determines positive or negative power.

[0052] FIGS. **2**, **5**, **8**, **11**, **14**, **17**, **20**, **23**, **26**, **29**, and **32** are respectively optical sectional views of the optical paths of the lens systems according to the exemplary embodiments first through eleventh. The magnification side corresponds to magnification optical system Op and the reduction side corresponds to relay optical system Ol with intermediate image-forming position MI being a boundary. Here, if intermediate image-forming position MI is inside a lens element, the lens is included in relay optical system Ol. A lens system according to the present disclosure conjugates each of the magnification conjugate point (the projected image) at the magnification side and the reduction conjugate point (original image S) at the reduction side; with intermediate image-forming position MI inside the lens system.

[0053] Magnification optical system Op is composed of front group Opf (a magnification optical system) and rear group Opr (a magnification optical system). Front group Opf is a lens group closer to the magnification side than the lens element with positive power closest to the magnification side. Rear group Opr is a lens group, including the lens element with positive power closest to the magnification side, is a lens group closer to the reduction side. Here, if a cemented lens is positioned at the boundary between front group Opf and rear group Opr, the cemented lens belongs to rear group Opr when the total power is positive; the cemented lens belongs to front group Opf when the total power is negative.

[0054] FIGS. **3**, **6**, **9**, **12**, **15**, **18**, and **21** are respectively longitudinal aberration diagrams according to the exemplary embodiments first through seventh. Symbols (a), (b), and (c) in the figures respectively represent longitudinal aberration diagrams for object distances of the lens system according to the disclosure of 4,000 mm, 2,000 mm, and 7,000 mm.

[0055] FIGS. **24**, **27**, **30**, and **33** are respectively longitudinal aberration diagrams of a lens system according to the exemplary embodiments eighth through eleventh, in an infinity focusing state.

[0056] Each longitudinal aberration diagram shows spherical aberration (SA (mm)), astigmatism (AST (mm)), and distortion aberration (DIS), in order from the left. In a spherical aberration diagram, the vertical axis represents an F number (indicated by F in the diagram); the solid line, the characteristics of d-line; the short-broken line, the characteristics of F-line; and the long-broken line, the characteristics of C-line. In an astigmatism diagram, the vertical axis represents an image height (indicated by H in the diagram); the solid line, the characteristics of a sagittal plane (indicated by s in the diagram); and the broken line, the characteristics of a meridional plane (indicated by m in the diagram). In a distortion aberration diagram, the vertical axis represents an image height (indicated by H in the diagram). Distortion aberration is that in equidistant projection.

[0057] A description is made of a case where a lens system according to the following embodiments is used for a projector (an example of an image projection apparatus) that projects image light beams of original image S produced by space-modulating incoming light based on image signals using an image-forming element such as liquid crystal and a digital micro-mirror device (DMD). The lens system of the present disclosure magnify-projects original image S on a liquid crystal display panel for example disposed at the reduction side onto a screen (not shown) disposed on the extended line at the magnification side.

First and Second Exemplary Embodiments

[0058] A description is made of the configuration of a lens system according to the first and second exemplary embodiments using FIGS. **1**, **2**, **4**, and **5**. The lens system includes magnification optical system Op and relay optical system Ol.

[0059] Magnification optical system Op is composed of first lens elements L**1** through 11th lens element L**11**. Magnification optical system Op is composed of front group Opf and rear group Opr. Front group Opf of magnification optical system Op is composed of, in order from the magnification side to the reduction side, first lens element L**1** of a negative meniscus shape with its convex surface facing the magnification side, and second lens element L**2** of a negative meniscus shape with its convex surface facing the magnification side. Rear group Opr of magnification optical system Op is composed of, in order from the magnification side to the reduction side, third lens element L**3** of a positive meniscus shape with its convex surface facing the reduction side, fourth lens element L**4** of a positive meniscus shape with its convex surface facing the object side, fifth lens element L**5** of a biconcave shape, sixth lens element L**6** of a biconvex shape, seventh lens element L**7** of a biconvex shape, eighth lens element L**8** of a biconcave shape, ninth lens element L**9** of a positive meniscus shape with its convex surface facing the reduction side, 10th lens element L**10** of a biconvex shape, and 11th lens element L**11** of a positive meniscus shape with its convex surface facing the magnification side. Seventh lens element L**7** and eighth lens element L**8** compose an image surface curvature correction lens group that moves along the optical axis when adjusting the amount of image surface curvature.

[0060] Relay optical system Ol is composed of, in order from the magnification side to the reduction side, 12th lens element L**12** with positive power, 13th lens element L**13** of a biconcave shape, 14th lens element L**14** of a positive meniscus shape with its convex surface facing the reduction side, 15th lens element L**15** of a biconvex shape, 16th lens element L**16** of a biconcave shape, 17th lens element L**17** of a negative meniscus shape with its convex surface facing magnification side, 18th lens element L**18** of a biconvex shape, 19th lens element L**19** of a negative meniscus shape with its convex surface facing the reduction side, 20th lens element L**20** of a biconvex shape, 21st lens element L**21** of a negative meniscus shape with its convex surface facing the reduction side, and 22nd lens element L**22** of a biconvex shape. There is intermediate image-forming position MI between 11th lens element L**11** and 12th lens element L**12**. There is aperture stop A disposed between 16th lens element L**16** and 17th lens element L**17**.

Third and Fourth Exemplary Embodiments

[0061] A description is made of the configuration of a lens system according to the third and fourth exemplary embodiments using FIGS. **7**, **8**, **10**, and **11**. The lens system includes magnification optical system Op and relay optical system Ol.

[0062] Magnification optical system Op is composed of first lens element L**1** through 12th lens element L**12**. Magnification optical system Op is composed of front group Opf and rear group Opr. Front group Opf of magnification optical system Op is composed of, in order from the magnification side to the reduction side, first lens element L**1** of a negative meniscus shape with its convex surface facing the magnification side, second lens element L**2** of a negative meniscus shape with its convex surface facing the magnification side, and a third lens element of a biconcave shape. Rear group Opr of magnification optical system Op is composed of, in order from the magnification side to the reduction side, fourth lens element L**4** of a biconvex shape, fifth lens element L**5** of a positive meniscus shape with its convex surface facing the reduction side, sixth lens element L**6** of a biconcave shape, seventh lens element L**7** of a biconvex shape, eighth lens element L**8** of a biconvex shape, ninth lens element L**9** of a biconcave shape, 10th lens element L**10** of a positive meniscus shape with its convex surface facing the reduction side, 11th lens element L**11** of a biconvex shape, and 12th lens element L**12** of a positive meniscus shape with its convex surface facing the magnification side. Eighth lens element L**8** and ninth lens element L**9** compose an image surface curvature correction lens group that moves along the optical axis when adjusting the amount of image surface curvature.

[0063] Relay optical system Ol is composed of, in order from the magnification side to the reduction side, 13th lens element L**13** of a positive meniscus shape with its convex surface facing the reduction side, 14th lens element L**14** of a biconcave shape, 15th lens element L**15** of a positive meniscus shape with its convex surface facing the reduction side, 16th lens element L**16** of a negative meniscus shape with its convex surface facing the reduction side, 17th lens element L**17** of a biconvex shape, 18th lens element L**18** of a negative meniscus shape with its convex surface facing the magnification side, 19th lens element L**19** of a biconvex shape, 20th lens element L**20** of a biconcave shape, 21st lens element L**21** of a biconvex shape, 22nd lens element L**22** of a negative meniscus shape with its convex surface facing the reduction side, and 23rd lens element L**23** of a biconvex shape. There is intermediate image-forming position MI between 12th lens element L**12** and 13th lens element L**13**. There is aperture stop A disposed between 17th lens element L**17** and 18th lens element L**18**.

Fifth, Sixth, and Seventh Exemplary Embodiments

[0064] A description is made of the configuration of a lens system according to the fifth, sixth, and seventh exemplary embodiments using FIGS. **13**, **14**, **16**, **17**, **19**, and **20**. The lens system includes magnification optical system Op and relay optical system Ol.

[0065] Magnification optical system Op is composed of first lens element L1 through 12th lens element L12. Magnification optical system Op is composed of front group Opf and rear group Opr. Front group Opf of magnification optical system Op is composed of, in order from the magnification side to the reduction side, first lens element L1 of a negative meniscus shape with its convex surface facing the magnification side, second lens element L2 of a negative meniscus shape with its convex surface facing the magnification side, and third lens element of a negative meniscus shape with its convex surface facing the magnification side. Rear group Opr of magnification optical system Op is composed of, in order from the magnification side to the reduction side, fourth lens element L4 of a biconvex shape, fifth lens element L5 of a positive meniscus shape with its convex surface facing the reduction side, sixth lens element L6 of a biconcave shape, seventh lens element L7 of a biconvex shape, eighth lens element L8 of a biconvex shape, ninth lens element L9 of a biconcave shape, 10th lens element L10 of a positive meniscus shape with its convex surface facing the reduction side, 11th lens element L11 of a biconvex shape, and 12th lens element L12 of a positive meniscus shape with its convex surface facing the magnification side. Eighth lens element L8 and ninth lens element L9 compose an image surface curvature correction lens group that moves along the optical axis when adjusting the amount of image surface curvature.

[0066] Relay optical system Ol is composed of, in order from the magnification side to the reduction side, 13th lens element L13 of a positive meniscus shape with its convex surface facing the reduction side, 14th lens element L14 of a biconcave shape, 15th lens element L15 of a positive meniscus shape with its convex surface facing the reduction side, 16th lens element L16 of a biconvex shape, 17th lens element L17 of a biconcave shape, 18th lens element L18 of a negative meniscus shape with its convex surface facing the magnification side, 19th lens element L19 of a biconvex shape, 20th lens element L20 of a biconcave shape, 21st lens element L21 of a biconvex shape, 22nd lens element L22 of a negative meniscus shape with its convex surface facing the reduction side, and 23rd lens element L23 of a biconvex shape. There is intermediate image-forming position MI between 12th lens element L12 and 13th lens element L13. There is aperture stop A disposed between 17th lens element L17 and 18th lens element L18.

Eighth and Ninth Exemplary Embodiments

[0067] A description is made of the configuration of a lens system according to the eighth and ninth exemplary embodiments using FIGS. 22, 23, 25, and 26. The lens system includes magnification optical system Op and relay optical system Ol.

[0068] Magnification optical system Op is composed of first lens element L1 through 10th lens element L10. Magnification optical system Op is composed of front group Opf and rear group Opr. Front group Opf of magnification optical system Op is composed of, in order from the magnification side to the reduction side, first lens element L1 of a negative meniscus shape with its convex surface facing the magnification side, and second lens element L2 of a negative meniscus shape with its convex surface facing the magnification side. Rear group Opr of magnification optical system Op is composed of, in order from the magnification side to the reduction side, third lens element L3 of a positive meniscus shape with its convex surface facing the reduction side, fourth lens element L4 of a negative meniscus shape with its convex surface facing the reduction side, fifth lens element L5 of a positive meniscus shape with its convex surface facing the reduction side, sixth lens element L6 of a positive meniscus shape with its convex surface facing the reduction side, seventh lens element L7 of a positive meniscus shape with its convex surface facing the reduction side, eighth lens element L8 of a negative meniscus shape with its convex surface facing the reduction side, ninth lens element L9 of a biconvex shape, and 10th lens element L10 of a biconvex shape. Third lens element L3 and fourth lens element L4 are joined together and have positive power in total.

[0069] Relay optical system Ol is composed of, in order from the magnification side to the reduction side, 11th lens element L11 with negative power, 12th lens element L12 of a negative meniscus shape with its convex surface facing the reduction side, 13th lens element L13 of a biconcave shape, 14th lens element L14 of a positive meniscus shape with its convex surface facing the reduction side, 15th lens element L15 of a biconvex shape, 16th lens element L16 of a positive meniscus shape with its convex surface facing the magnification side, 17th lens element L17 of a biconcave shape, 18th lens element L18 of a positive meniscus shape with its convex surface facing the magnification side, 19th lens element L19 of a biconvex shape, 20th lens element L20 of a negative meniscus shape with its convex surface facing the magnification side, 21st lens element L21 of a biconvex shape, 22nd lens element L22 of a biconcave shape, 23rd lens element L23 of a negative meniscus shape with its convex surface facing the magnification side, 24th lens element L24 of a biconvex shape, and 25th lens element L25 of a positive meniscus shape with its convex surface facing the magnification side. Joining is made between 17th lens element L17 and 18th lens element L18, between 21st lens element L21 and 22nd lens element L22, and between 23rd lens element L23 and 24th lens element L24. There is intermediate image-forming position MI inside 11th lens element L11. There is aperture stop A disposed between 22nd lens element L22 and 23rd lens element L23.

Tenth and Eleventh Exemplary Embodiments

[0070] A description is made of the configuration of a lens system according to the tenth and eleventh exemplary embodiments using FIGS. 28, 29, 31, and 32. The lens system includes magnification optical system Op and relay optical system Ol.

[0071] Magnification optical system Op is composed of first lens element L1 through eighth lens element L8. Magnification optical system Op is composed of front group Opf and rear group Opr. Front group Opf of magnification optical system Op is composed of, in order from the magnification side to the reduction side, first lens element L1 of a negative meniscus shape with its convex surface facing the magnification side, and second lens element L2 of a negative meniscus shape with its convex surface facing the magnification side. Rear group Opr of magnification optical system Op is composed of, in order from the magnification side to the reduction side, third lens element L3 of a biconvex shape, fourth lens element L4 of a negative meniscus shape with its convex surface facing the reduction side, fifth lens element L5 of a positive meniscus shape with its convex surface facing the reduction side, sixth lens element L6 of a positive meniscus shape with its convex surface facing the reduction side, seventh lens element L7 of a negative meniscus shape with its convex surface facing the reduction side, and eighth lens element L8 of a biconvex shape. Third lens element L3 and fourth lens element L4 are joined together and has positive power in total.

[0072] Relay optical system Ol is composed of, in order from the magnification side to the reduction side, ninth lens element L9 of a biconvex shape, 10th lens element L10 of a biconcave shape, 11th lens element L11 of a biconvex shape, 12th lens element L12 of a positive meniscus shape with its convex surface facing the magnification side, 13th lens element L13 of a biconcave shape, 14th lens element L14 of a biconvex shape, 15th lens element L15 of a negative meniscus shape with its concave surface facing the reduction side, 16th lens element L16 of a negative meniscus shape with its convex surface facing the magnification side, 17th lens element L17 of a biconvex shape, and 18th lens element L18 of a positive meniscus shape with its convex surface facing the magnification side. Joining is made between 10th lens element L10 and 11th lens element L11, between 14th lens element L14 and 15th lens element L15, and between 16th lens element L16 and 17th lens element L17. There is intermediate image-forming position MI between eighth lens element L8 and ninth lens element L9. There is aperture stop A disposed between 15th lens element L15 and 16th lens element L16.

[0073] A lens system according to the exemplary embodiments first through eleventh forms an image conjugately between each of the magnification conjugate points at the magnification side and at the reduction side; and the intermediate image-forming position inside the lens system. The lens system according to the exemplary embodiments first through eleventh includes a magnification optical system composed of lens elements closer to the magnification side than the intermediate image-forming position; and a relay optical system composed of lens elements closer to the reduction side than the intermediate image-forming position. If the intermediate image-forming position is inside a lens element, the lens group closer to the magnification side than the lens element is a magnification optical system; the lens group closer to the reduction side than the lens element is a relay optical system. Intermediate image forming of an original image by the relay optical system facilitates correcting various aberrations, especially correcting chromatic aberration of magnification for example.

[0074] The lens system according to the exemplary embodiments first through eleventh includes magnification optical system Op composed of front group Opf composed of lens elements closer to the magnification side than the lens element with positive power disposed closest to the magnification side of magnification optical system Op; and rear group Opr composed of lens elements closer to the reduction side than the lens element with positive power disposed closest to the magnification side of magnification optical system Op. This structure prevents light beams entering a lens at the magnification side from an excessive oblique light incidence with respect to the entrance surface and the exit surface, reducing the loss of the light amount due to reflection and aberration of image surface curvature.

[0075] The lens system according to the exemplary embodiments first through eleventh includes front group Opf that has, in order from the magnification side to the reduction side in magnification optical system Op, first lens element L1 of a negative meniscus shape with its convex surface facing the magnification side; and second lens element L2 of a negative meniscus shape with its convex surface facing the magnification side. This structure, which provides a wide view angle like a fish-eye lens, prevents light beams entering a lens at the magnification side from an excessive oblique light incidence with respect to the entrance surface and the exit surface, reducing the loss of the light amount due to reflection and aberration of image surface curvature

[0076] The lens system according to the exemplary embodiments first through eleventh includes a rear group that has an image surface curvature correction lens group that moves in the optical axis direction when adjusting the amount of image surface curvature, in magnification optical system Op. This structure allows determining an optimum amount of image surface curvature according to the object distance and the curvature radius of a screen surface for projection.

[0077] Hereinafter, a description is made of favorable conditions satisfied by a lens system according to the exemplary embodiments first through eleventh. Here, multiple favorable conditions are defined for a lens system according to each embodiment, and the configuration of a lens system is most favorable that satisfies all the conditions. However, satisfying individual conditions provides a lens system that yields the corresponding advantage.

[0078] The lens system according to the exemplary embodiments first through eleventh is a lens system that forms an image conjugately between each of the magnification conjugate points at the magnification side and at the reduction side; and the intermediate image-forming position inside a lens element. The lens system is composed of a magnification optical system with positive power that has multiple lens elements and is positioned closer to the magnification side than the intermediate image-forming position; and a relay optical system with positive power that has multiple lens elements and is positioned closer to the reduction side than the intermediate image-forming position (hereinafter, this lens configuration is referred to as the basic configuration according to an embodiment). The lens system favorably satisfies following conditions (1) and (2).

$$0.08 \leq fp/fr \leq 0.8 \quad (1)$$

$$\{Ymax - ft \cdot \tan(\omega max)\}/\{ft \cdot \tan(\omega max)\} \leq -0.3 \quad (2)$$

[0079] where

[0080] fr is the composite focal length of a relay optical system closer to the reduction side than the intermediate image-forming position,

[0081] fp is the composite focal length of a magnification optical system closer to the magnification side than the intermediate image-forming position,

[0082] Ymax is the radius of an effective image diameter,

[0083] ωmax is the maximum half view angle, and

[0084] ft is the focal length of the lens system as a whole.

[0085] Condition (1) defines a relationship between the composite focal lengths of the magnification optical system and the relay optical system. Satisfying this condition provides a lens system with a small lens diameter despite a wide-angle lens system. Exceeding the upper limit of condition (1) causes too large an effective diameter of the lens element closest to the magnification side. Conversely, falling below the lower limit causes too large an effective diameter of a lens element with positive power closer to the magnification side than the intermediate image-forming position and closest to the intermediate image-forming position. As a result, designing a lens system within the range of condition (1) makes smaller the effective diameter (which tends to be larger for a fish-eye lens) of a lens element in magnification optical system Op.

[0086] Further satisfying at least one of the following conditions (1A) and (1B) enhances the above-described advantage.

$$0.15 \le fp/fr \quad (1A)$$

$$fp/fr \le 0.7 \quad (1B)$$

[0087] Furthermore satisfying at least one of the following conditions (1C) and (1D) enhances the above-described advantage.

$$0.18 \le fp/fr \quad (1C)$$

$$fp/fr \le 0.6 \quad (1D)$$

[0088] Condition (2) expresses distortion aberration with respect to an effective image diameter in a common optical system. Satisfying this condition provides a wide-angle lens system. Exceeding the upper limit of condition (2) makes it difficult to provide a wide-angle lens system.

[0089] A lens system with the basic configuration (e.g., a lens system according to the exemplary embodiments first through eleventh) favorably satisfies following condition (3).

$$0.4 \le fpf/(ft \cdot \omega max - \pi/180) \le 1.8 \quad (3)$$

[0090] where

[0091] fpf is the composite focal length of the front group of a magnification optical system.

[0092] Condition (3) defines a relationship between the composite focal length of a magnification optical system and the ideal image height in equidistant projection. Satisfying this condition suppresses chromatic aberration of magnification. Exceeding the upper limit of condition (3) increases chromatic aberration of magnification; conversely, falling below the lower limit also increases chromatic aberration of magnification.

[0093] Further satisfying at least one of the following conditions (3A) and (3B) enhances the above-described advantage.

$$0.6 \le fpf/(ft \cdot \omega max \cdot \pi/180) \quad (3A)$$

$$fpf/(ft \cdot \omega max \cdot \pi/180) \le 1.6 \quad (3B)$$

[0094] A lens system with the basic configuration (e.g., a lens system according to the exemplary embodiments first through eleventh) favorably satisfies following condition (4).

$$60 < |(Lt \cdot ft \cdot \omega max \cdot \pi/180)/ft^2| < 200 \quad (4)$$

[0095] where

[0096] Lt is the total optical length of a lens system.

[0097] Condition (4) defines a relationship between a value produced by normalizing the total length of a lens system with the focal length; and a value produced by normalizing the ideal image height in equidistant projection with the focal length. Exceeding the upper limit of condition (4) results in too long total length. Conversely, falling below the lower limit increases chromatic aberration of magnification.

[0098] Further satisfying at least one of the following conditions (4A) and (4B) enhances the above-described advantage.

$$70 < |(Lt \cdot ft \cdot \omega max \cdot \pi/180)/ft^2| \quad (4A)$$

$$|(Lt \cdot ft \cdot \omega max \cdot \pi/180)/ft^2| < 160 \quad (4B)$$

[0099] A lens system with the basic configuration (e.g., a lens system according to the exemplary embodiments first through eleventh) favorably satisfies following condition (5).

$$|t/ft| \le 3.0 \quad (5)$$

[0100] where

[0101] t is the distance on the optical axis between a surface of a lens element closest to the reduction side among the at least one lens element in the front group of the magnification optical system; and a surface of a lens element closest to the magnification side among the at least one lens element in the rear group of the magnification optical system.

[0102] Condition (5) defines a relationship between the distance on the optical axis between the lens surface of the front group of the magnification optical system closest to the reduction side and the lens surface of the rear group of the magnification optical system closest to the magnification side; and the focal length of the entire lens system. Satisfying this relationship decreases the effective diameter of the lens element closest to the magnification side. Exceeding the upper limit results in too long an effective diameter of the lens element closest to the magnification side.

[0103] Further satisfying condition (5A) enhances the above-described advantage.

$$|t/ft| \le 2.5 \quad (5A)$$

[0104] A lens system with the basic configuration (e.g., a lens system according to the exemplary embodiments first through eleventh) favorably satisfies following condition (6).

$$36 < |(Lr \cdot ft \cdot \omega max \cdot \pi/180)/ft^2| < 150 \quad (6)$$

[0105] where

[0106] Lr is the distance on the optical axis from the intermediate image-forming position to the image-forming position at the reduction side.

[0107] Condition (6) defines a relationship between a value produced by normalizing the distance on the optical axis from the intermediate image-forming position to the image-forming position at the reduction side with the focal length; and a value produced by normalizing the ideal image height in equidistant projection with the focal length. Satisfying this condition suppresses chromatic aberration of magnification with a small total length. Exceeding the upper limit of condition (6) results in too long total length. Conversely, falling below the lower limit increases chromatic aberration of magnification.

[0108] Further satisfying at least one of the following conditions (6A) and (6B) enhances the above-described advantage.

$$40 < |(Lr \cdot ft \cdot \omega max \cdot \pi/180)/ft^2| \quad (6A)$$

$$|(Lr \cdot ft \cdot \omega max \cdot \pi/180)/ft^2| < 120 \quad (6B)$$

[0109] A lens system with the basic configuration (e.g., a lens system according to the exemplary embodiments first through eleventh) favorably satisfies following condition (7).

$$2.9 < SFL1 < 5.0 \quad (7)$$

[0110] where

[0111] SFL1 is the shape factor of the lens element closest to the magnification side in the lens system.

[0112] Condition (7) defines the shape factor of the lens element closest to the magnification side in the lens system. Exceeding the upper limit of condition (7) results in too large an effective diameter of the lens element closest to the magnification side. Conversely, falling below the lower limit results in a shape of the lens element closest to the magnification side difficult to produce.

[0113] Further satisfying at least one of the following conditions (7A) and (7B) enhances the above-described advantage.

$$3.0 < SFL1 \quad (7A)$$

$$SFL1 < 4.5 \quad (7B)$$

[0114] A lens system with the basic configuration (e.g., a lens system according to the exemplary embodiments first through seventh) that has an image surface curvature correction group that moves along the optical axis when adjusting the amount of image surface curvature, in the rear group of the magnification optical system favorably satisfies following condition (8).

$$10 < |fas/(ft \cdot \omega \cdot \pi/180)| < 1000 \quad (8)$$

[0115] where

[0116] fas is the composite focal length of an image surface curvature correction group.

[0117] Condition (8) defines a relationship between the composite focal length of an image surface curvature correction group and the ideal image height in equidistant projection. Satisfying this condition allows the amount of image surface curvature to be corrected while suppressing changes in back focus despite its small size. Exceeding the upper limit of condition (8) results in too large a moving amount of the image surface curvature correction group for correcting image surface curvature, which extends the total length. Conversely, falling below the lower limit changes back focus due to movement of the image surface curvature correction group, which requires adjusting the back focus, resulting in troublesome correction of image surface curvature.

[0118] Further satisfying at least one of the following conditions (8A) and (8B) enhances the above-described advantage.

$$30 < |fas/(ft \cdot \omega \cdot \pi/180)| \quad (8A)$$

$$|fas/(ft \cdot \omega \cdot \pi/180)| < 700 \quad (8B)$$

[0119] A lens system with the basic configuration (e.g., a lens system according to the exemplary embodiments first through eleventh) favorably satisfies following condition (9).

$$2 < |f1/(f \cdot \omega \cdot \pi/180)| < 10 \quad (9)$$

[0120] where

[0121] f1 is the focal length of the lens element closest to the magnification side in the lens system.

[0122] Condition (9) defines a relationship between the focal length of the lens element closest to the magnification side in the lens system; and the ideal image height in equidistant projection. Satisfying this condition prevents the size of the lens element closest to the magnification side from being larger despite its wide view angle. Exceeding the upper limit of condition (9) results in too large an effective diameter of the lens element closest to the magnification side. Conversely, falling below the lower limit results in too weak power of the lens element closest to the magnification side, causing the lens shape to be difficult to produce.

[0123] Further satisfying at least one of the following conditions (9A) and (9B) enhances the above-described advantage.

$$3 < |f1/(f \cdot \omega \cdot \pi/180)| \quad (9A)$$

$$|f1/(f \cdot \omega \cdot \pi/180)| < 8 \quad (9B)$$

[0124] A lens system with the basic configuration (e.g., a lens system according to the exemplary embodiments first through eleventh) favorably satisfies following condition (10).

$$0.8 < \varphi pf\max/\varphi pr\max < 1.3 \quad (10)$$

[0125] where

[0126] φpfmax is the maximum lens effective diameter of a lens element in the front group of the magnification optical system

[0127] φprmax is the maximum lens effective diameter of a lens element in the rear group of the magnification optical system

[0128] Condition (10) defines the ratio of the maximum lens effective diameter of a lens element in the front group of the magnification optical system; to the maximum lens effective diameter of a lens element in the rear group of the magnification optical system. Exceeding the upper limit results in too large an effective diameter of the lens element closest to the magnification side. Conversely, falling below the lower limit results in too large an effective diameter of a lens element closer to the magnification side than the intermediate image-forming position and close to the intermediate image-forming position.

[0129] Further satisfying at least one of the following conditions (10A) and (10B) enhances the above-described advantage.

$$0.9 < \varphi pf\max/\varphi pr\max \quad (10A)$$

$$\Phi pf\max/\varphi pr\max < 1.2 \quad (10B)$$

[0130] Hereinbefore, the embodiments are described to exemplify the technology disclosed in this application. The technology of the disclosure, however, is not limited to these embodiments, but is applicable to other embodiments appropriately devised through modification, substitution, addition, and omission for example.

[0131] Hereinafter, a description is made of some numerical practical examples of a lens system according to the first through eleventh exemplary embodiments. The practical examples represent each length in tables in the unit of mm; each view angle in the unit of ° (degree). In the practical examples, r is a curvature radius; d, a surface distance; nd, a refractive index for d-line; and vd, an Abbe number for d-line.

Numerical Practical Example 1

[0132] Hereinafter, the lens system of numerical practical example 1 (corresponding to the first exemplary embodiment) is described. Table 1 shows surface data; table 2 shows various types of data; and table 3 shows single lens data.

TABLE 1

Surface No.	r	d	nd	vd	Effective radius
Object surface	variable	variable			
1	62.69070	3.50000	1.90366	31.3	40.002
2	34.32240	13.02190			29.207
3	105.47160	2.50000	1.83481	42.7	27.953
4	23.23070	17.98760			19.626
5	−195.28960	15.00000	1.48749	70.4	16.426
6	−65.95860	14.09830			12.410
7	−136.20600	15.00000	1.72916	54.7	6.552
8	−17.52700	0.58380			10.519
9	−17.38980	2.00000	1.80809	22.8	10.559
10	156.95630	1.50420			12.839
11	157.84770	6.47740	1.59349	67.0	14.654
12	−34.35610	variable			15.598
13	138.60270	15.00000	1.48749	70.4	20.409
14	−57.74380	28.99170			22.365
15	−37.28120	5.00000	1.54072	47.2	25.302
16	222.07570	variable			31.730
17	−221.82780	11.86280	1.80809	22.8	33.625
18	−54.27070	0.20000			34.564
19	129.22220	10.04050	1.80518	25.5	38.830
20	−364.44020	0.20000			38.788
21	50.76810	13.57320	1.80518	25.5	36.546
22	83.01170	37.73970			33.985
23	550.39610	15.00000	1.48749	70.4	20.771
24	−45.21240	1.73260			18.284
25	−39.01460	3.31630	1.83400	37.3	16.822
26	53.30150	71.75870			16.140
27	−1075.96590	7.91760	1.80420	46.5	25.673
28	−74.09750	0.20000			25.979
29	148.27110	5.19390	1.80809	22.8	24.942
30	−279.86580	4.69580			24.626
31	−118.64140	2.00000	1.59349	67.0	23.297
32	375.45370	54.28750			22.672
33 (aperture)	∞	45.61360			17.948
34	161.63410	2.00000	1.80518	25.5	18.931
35	68.06500	7.66990			19.077
36	268.94410	8.15390	1.55032	75.5	20.912
37	−44.80050	0.97200			21.248
38	−44.99690	2.13870	1.80518	25.5	21.222
39	−277.85820	1.63120			22.640
40	109.06800	10.88750	1.55032	75.5	24.413
41	−52.45940	0.81880			24.644
42	−51.07450	2.50000	1.80518	25.5	24.570
43	−85.99100	4.31550			25.459
44	152.01240	5.69150	1.72916	54.7	26.275
45	−243.69600	10.00000			26.217
46	∞	95.00000	1.51680	64.2	24.717
47	∞	BF			16.527
Image surface	∞				

TABLE 2

Object distance	4000.0000	2000.0000	7000.0000
Object curvature radius	4050.0000	2025.0000	7100.0000
Focal length	−9.7000	−9.7001	−9.7000
F number	−2.50010	−2.50015	−2.50007
Half view angle	90.1000	90.1000	90.1000
Effective image radius	−15.3152	−15.3153	−15.3151
Total lens length	600.0334	600.0564	600.0233
BF	9.23349	9.25653	9.22351
d12	5.8933	5.8883	5.8950
d16	7.1305	7.1355	7.1287

TABLE 2-continued

Entrance pupil position	27.2905	27.2910	27.2903
Exit pupil position	−994.6640	−994.6640	−994.6640
Front principal point	17.4967	17.4971	17.4965
Rear principal point	609.7101	609.7101	609.7099

TABLE 3

Lens elements	First surface	Focal length
L1	1	−89.1566
L2	3	−36.1887
L3	5	196.8253
L4	7	26.1912
L5	9	−19.2744
L6	11	48.1449
L7	13	85.7631
L8	15	−58.6398
L9	17	86.1847
L10	19	119.5632
L11	21	136.6668
L12	23	86.4184
L13	25	−26.5757
L14	27	98.6055
L15	29	120.5940
L16	31	−151.6744
L17	34	−147.4318
L18	36	70.4330
L19	38	−66.9573
L20	40	65.9438
L21	42	−161.3723
L22	44	129.1729

Numerical Practical Example 2

[0133] Hereinafter, the lens system of numerical practical example 2 (corresponding to the second exemplary embodiment) is described. Table 4 shows surface data; table 5 shows various types of data; and table 6 shows single lens data.

TABLE 4

Surface No.	r	d	nd	vd	Effective radius
Object surface	variable	variable			
1	63.05300	3.50000	1.84670	23.8	40.004
2	33.98800	13.23470			28.945
3	112.90930	2.50000	1.80420	46.5	27.641
4	22.78180	18.40380			19.229
5	−240.95330	15.00000	1.56865	42.3	15.506
6	−68.72420	12.77320			11.550
7	−109.63800	15.00000	1.71625	55.2	6.979
8	−17.31030	0.64950			11.009
9	−16.98500	2.00000	1.84094	23.9	11.044
10	380.43980	1.22140			13.625
11	208.60810	7.19930	1.59107	61.9	15.407
12	−31.75680	variable			16.412
13	157.68700	8.63680	1.48809	70.3	19.723
14	−51.42000	30.20750			20.428
15	−32.96310	5.00000	1.59774	38.0	23.513
16	356.37720	variable			30.254
17	−185.30010	11.91540	1.84670	23.8	32.321
18	−49.96620	0.20000			33.344
19	150.60280	9.25680	1.84670	23.8	37.667
20	−288.97820	0.20000			37.678
21	51.76330	15.00000	1.84670	23.8	35.930
22	82.29800	38.13980			32.639
23	−336.94820	15.00000	1.62948	59.7	20.792
24	−46.10850	1.74690			19.062

TABLE 4-continued

Surface No.	r	d	nd	vd	Effective radius
25	−40.04800	6.12440	1.79934	40.0	17.692
26	55.01210	71.80140			16.832
27	−1336.58980	7.81710	1.80420	46.5	26.494
28	−74.79370	0.20000			26.763
29	159.00380	5.23580	1.81155	24.7	25.626
30	−275.37430	3.16720			25.307
31	−121.29070	2.00000	1.59229	56.6	24.595
32	334.61080	61.25040			23.805
33(aperture)	∞	51.65310			18.057
34	158.42700	2.00000	1.80033	28.2	20.053
35	69.49600	6.45570			20.155
36	207.48670	8.56850	1.55032	75.5	21.638
37	−47.06510	0.92530			21.960
38	−47.61470	2.00000	1.80376	27.0	21.925
39	−431.07330	0.20000			23.308
40	106.20010	11.09520	1.55032	75.5	24.559
41	−52.54660	0.73100			24.791
42	−51.28940	2.50000	1.80414	27.7	24.723
43	−94.42380	0.79170			25.667
44	139.57700	6.03150	1.73004	54.5	26.330
45	−227.19720	0.30090			26.278
46	∞	10.00000			26.038
47	∞	95.00000	1.51680	64.2	24.720
48	∞	BF			16.504
Image surface	∞				

TABLE 5

Object distance	4000.0000	2000.0000	7000.0000
Object curvature radius	4050.0000	2025.0000	7100.0000
Focal length	−9.7000	−9.7000	−9.7000
F number	−2.50008	−2.50014	−2.50006
Half view angle	90.1000	90.1000	90.1000
Effective image radius	−15.3148	−15.3149	−15.3148
Total lens length	600.0331	600.0561	600.0230
BF	9.03286	9.05591	9.02289
d12	2.0038	2.0000	2.0052
d16	6.3621	6.3659	6.3606
Entrance pupil position	27.2745	27.2750	27.2743
Exit pupil position	−969.1441	−969.1441	−969.1441
Front principal point	17.4783	17.4788	17.4781
Rear principal point	609.7097	609.7097	609.7096

TABLE 6

Lens elements	First surface	Focal length
L1	1	−92.1716
L2	3	−35.9335
L3	5	163.9044
L4	7	26.8768
L5	9	−19.2901
L6	11	47.1542
L7	13	80.5356
L8	15	−50.2360
L9	17	77.6656
L10	19	118.0710
L11	21	134.4837
L12	23	83.2040
L13	25	−28.1874
L14	27	98.2454
L15	29	124.8820
L16	31	−150.0552
L17	34	−156.2543
L18	36	70.5531
L19	38	−66.7513

TABLE 6-continued

Lens elements	First surface	Focal length
L20	40	65.5025
L21	42	−143.3245
L22	44	119.2602

Numerical Practical Example 3

[0134] Hereinafter, the lens system of numerical practical example 3 (corresponding to the third exemplary embodiment) is described. Table 7 shows surface data; table 8 shows various types of data; and table 9 shows single lens data.

TABLE 7

Surface No.	r	d	nd	vd	Effective radius
Object surface	variable	variable			
1	57.48690	3.50000	1.90366	31.3	34.974
2	32.84120	8.24230			26.123
3	60.63820	2.50000	1.83481	42.7	24.572
4	20.51880	10.64190			17.222
5	−361.54150	2.00000	1.51823	59.0	16.468
6	20.23130	3.10960			13.241
7	23.98260	10.83900	1.48749	70.4	12.765
8	−67.26990	7.67080			10.411
9	−64.81820	15.00000	1.72916	54.6	4.358
10	−14.77170	0.20000			8.989
11	−15.23630	2.00000	1.80809	22.8	9.050
12	151.89840	2.31360			11.401
13	305.73490	7.33380	1.59349	67.0	14.375
14	−26.75150	variable			15.494
15	80.10290	13.67660	1.48749	70.4	19.803
16	−50.46080	14.30490			21.042
17	−35.93420	3.00000	1.64769	33.8	21.759
18	152.43020	variable			25.727
19	−195.03790	10.41230	1.80809	22.8	27.602
20	−44.41460	0.20000			28.527
21	182.27070	8.34010	1.80518	25.5	31.284
22	−137.09590	0.20000			31.351
23	51.87420	9.55090	1.80809	22.8	29.613
24	113.67020	31.18070			28.210
25	−150.16630	6.22180	1.48749	70.4	18.154
26	−40.92490	0.72590			17.767
27	−43.41970	2.00000	1.72825	28.3	17.112
28	44.65630	72.07330			16.607
29	−1070.17200	8.80620	1.72916	54.6	30.478
30	−79.87360	87.67920			30.867
31	165.95180	2.00000	1.59349	67.0	23.064
32	80.33410	13.69910			22.685
33	124.92850	4.73250	1.84666	23.8	24.040
34	−704.27020	45.69470			24.006
35(aperture)	∞	5.02880			21.333
36	128.17330	2.00000	1.80610	33.3	21.054
37	63.76750	5.05630			20.962
38	96.26710	8.49050	1.55032	75.5	21.999
39	−64.14960	0.21850			22.143
40	−80.05730	2.00000	1.80518	25.5	22.046
41	90.73560	0.66590			22.666
42	97.75860	9.75670	1.55032	75.5	22.861
43	−55.60920	2.01760			23.146
44	−54.92950	2.50000	1.80518	25.5	23.094
45	−101.92360	2.82240			23.980
46	83.96990	6.83750	1.72916	54.6	25.365
47	−468.91130	10.00000			25.248
48	∞	95.00000	1.51680	64.2	23.842
49	∞	BF			15.638
Image surface	∞				

TABLE 8

Object distance	4000.0000	2000.0000	7000.0000
Object curvature radius	4200.0000	2100.0000	7350.0000
Focal length	−9.0000	−9.0000	−9.0000
F number	−2.50006	−2.50013	−2.50004
Half view angle	91.6000	91.6000	91.6000
Effective image radius	−14.4060	−14.4055	−14.4062
Total lens length	640.0321	640.0521	640.0235
BF	9.35277	9.37268	9.34417
d14	1.9971	2.0000	1.9959
d18	6.4388	6.4360	6.4400
Entrance pupil position	23.2580	23.2578	23.2581
Exit pupil position	−1109.2175	−1109.2175	−1109.2175
Front principal point	14.1856	14.1853	14.1857
Rear principal point	649.0120	649.0121	649.0119

TABLE 9

Lens elements	First surface	Focal length
L1	1	−90.8977
L2	3	−38.2339
L3	5	−36.9044
L4	7	37.7356
L5	9	23.2939
L6	11	−17.0447
L7	13	41.7913
L8	15	65.7636
L9	17	−44.6172
L10	19	69.0365
L11	21	98.3211
L12	23	110.4511
L13	25	113.2859
L14	27	−29.9430
L15	29	117.9349
L16	31	−264.6658
L17	33	125.6519
L18	36	−159.6410
L19	38	71.2922
L20	40	−52.5476
L21	42	65.8976
L22	44	−151.5559
L23	46	98.1817

Numerical Practical Example 4

[0135] Hereinafter, the lens system of numerical practical example 4 (corresponding to the fourth exemplary embodiment) is described. Table 10 shows surface data; table 11 shows various types of data; and table 12 shows single lens data.

TABLE 10

Surface No.	r	d	nd	vd	Effective radius
Object surface	variable	variable			
1	63.65070	3.50000	1.80420	46.5	35.029
2	32.00630	7.65990			25.238
3	58.11770	2.50000	1.80420	46.5	23.933
4	20.04300	9.97980			16.845
5	−16711.84430	2.00000	1.52499	66.7	16.198
6	18.55660	3.00710			12.904
7	21.26180	11.49640	1.49199	69.9	12.470
8	−75.53920	7.56460			9.853
9	−72.56330	15.00000	1.72766	54.7	4.677
10	−14.09960	0.58920			9.524
11	−14.05150	2.00000	1.82460	24.4	9.597
12	283.21550	1.53830			12.430
13	311.87890	7.69690	1.59427	61.8	14.756
14	−26.56900	variable			15.914
15	75.49490	9.71000	1.48700	70.4	20.649
16	−52.28810	17.48840			21.080
17	−34.42240	3.00000	1.66488	31.5	21.907
18	155.62230	variable			26.366
19	−233.64550	10.27600	1.84670	23.8	28.457
20	−48.55530	0.20000			29.445
21	204.32090	8.94120	1.84670	23.8	32.904
22	−129.79800	0.20000			33.031
23	52.80370	10.08930	1.84670	23.8	31.449
24	118.30830	31.43120			30.097
25	−129.17710	6.72370	1.48923	68.9	19.689
26	−43.57940	0.96370			19.213
27	−46.55830	2.00000	1.74151	27.2	18.285
28	46.71980	71.99550			17.680
29	−1609.70270	8.64150	1.72562	54.8	31.275
30	−82.32630	97.95830			31.598
31	159.18330	2.00000	1.59089	42.6	22.224
32	78.55920	12.86530			21.841
33	123.08050	4.53930	1.84670	23.8	23.063
34	−738.23220	39.88540			23.031
35(aperture)	∞	62.54520			20.780
36	113.81370	2.00000	1.80499	32.0	20.668
37	59.82940	7.70280			20.559
38	104.60560	8.59980	1.55032	75.5	22.252
39	−61.85230	0.20000			22.418
40	−84.86380	2.00000	1.80397	28.3	22.296
41	87.69500	0.50270			22.889
42	87.85240	9.86190	1.55032	75.5	23.110
43	−59.67840	0.91180			23.374
44	−55.27030	2.50000	1.80262	28.6	23.361
45	−114.36820	0.20000			24.315
46	88.87840	6.93430	1.73116	54.4	25.393
47	−261.40750	10.00000			25.325
48	∞	95.00000	1.51680	64.2	23.847
49	∞	BF			15.643
Image surface	∞				

TABLE 11

Object distance	4000.0000	2000.0000	7000.0000
Object curvature radius	4200.0000	2100.0000	7350.0000
Focal length	−9.0000	−9.0000	−9.0000
F number	−2.50002	−2.50008	−2.49999
Half view angle	91.6000	91.6000	91.6000
Effective image radius	−14.4061	−14.4057	−14.4063
Total lens length	640.0312	640.0512	640.0225
BF	9.39214	9.41206	9.38354
d0	4000.0000	2000.0000	7000.0000
d14	1.9947	2.0000	1.9927
d18	6.2449	6.2396	6.2468
Entrance pupil position	22.2397	22.2391	22.2399
Exit pupil position	−1075.9930	−1075.9930	−1075.9930
Front principal point	13.1651	13.1644	13.1653
Rear principal point	649.0111	649.0111	649.0110

TABLE 12

Lens elements	First surface	Focal length
L1	1	−84.2043
L2	3	−39.1896
L3	5	−35.3063
L4	7	35.0983
L5	9	21.7042
L6	11	−16.1856
L7	13	41.5513
L8	15	65.0524
L9	17	−42.1296
L10	19	70.5935

TABLE 12-continued

Lens elements	First surface	Focal length
L11	21	94.9099
L12	23	105.2067
L13	25	131.0475
L14	27	−31.1640
L15	29	119.2879
L16	31	−264.9395
L17	33	124.8943
L18	36	−159.3255
L19	38	71.9494
L20	40	−53.3680
L21	42	66.1454
L22	44	−135.8223
L23	46	91.4804

Numerical Practical Example 5

[0136] Hereinafter, the lens system of numerical practical example 5 (corresponding to the fifth exemplary embodiment) is described. Table 13 shows surface data; table 14 shows various types of data; and table 15 shows single lens data.

TABLE 13

Surface No.	r	d	nd	vd	Effective radius
Object surface	variable	variable			
1	59.70620	3.50000	1.90366	31.3	40.016
2	33.73780	9.60340			28.804
3	52.29470	2.50000	1.83481	42.7	26.254
4	21.88760	10.22000			18.475
5	243.49310	2.00000	1.62041	60.3	17.584
6	18.99430	4.47090			13.405
7	24.66120	11.38760	1.48749	70.4	12.456
8	−66.77390	3.86960			9.010
9	−55.20960	15.00000	1.72916	54.6	4.606
10	−14.42010	0.20000			8.916
11	−14.90290	2.00000	1.80809	22.8	8.993
12	164.22930	2.43270			11.605
13	−510.00380	7.87620	1.59349	67.0	14.703
14	−24.31730	variable			16.062
15	65.37140	13.61340	1.48749	70.4	25.486
16	−56.39120	12.87490			25.837
17	−44.66120	3.00000	1.64769	33.8	25.788
18	99.36680	variable			29.911
19	−856.79070	12.17840	1.80809	22.8	31.976
20	−55.46720	0.20000			32.852
21	343.69180	9.39370	1.80518	25.5	35.816
22	−119.89620	0.20000			35.969
23	52.98050	14.48540	1.80809	22.8	33.882
24	87.93510	35.63020			30.716
25	−395.07870	7.20750	1.48749	70.4	20.856
26	−43.93870	1.51360			20.450
27	−42.79770	2.00000	1.72825	28.3	19.047
28	46.85640	72.47530			18.378
29	−771.11340	8.62810	1.72916	54.6	32.639
30	−77.66150	95.57660			32.915
31	161.15510	4.91720	1.84666	23.8	23.545
32	−240.61170	1.26980			23.423
33	−143.95050	2.00000	1.59349	67.0	23.326
34	1171.86340	41.60890			23.098
35(aperture)	∞	60.29990			19.950
36	165.08680	2.00000	1.80610	33.3	20.756
37	66.64960	4.12230			20.785
38	150.84310	8.81970	1.55032	75.5	21.499
39	−47.51940	0.71290			21.771
40	−49.82070	2.00000	1.80518	25.5	21.700
41	239.62850	0.20000			23.105
42	118.64560	10.89680	1.55032	75.5	23.737
43	−47.89690	0.79870			24.088

TABLE 13-continued

Surface No.	r	d	nd	vd	Effective radius
44	−46.01480	2.50000	1.80518	25.5	24.069
45	−68.90210	0.20000			25.167
46	84.33920	6.49800	1.72916	54.6	26.327
47	−1209.19250	10.00000			26.193
48	∞	95.00000	1.51680	64.2	24.830
49	∞	BF			15.500
Image surface	∞				

TABLE 14

Object distance	4000.0000	2000.0000	7000.0000
Object curvature radius	5200.0000	2600.0000	9100.0000
Focal length	−8.6500	−8.6500	−8.6500
F number	−2.50004	−2.50011	−2.50002
Half view angle	102.0000	102.0000	102.0000
Effective image radius	−15.3432	−15.3373	−15.3457
Total lens length	640.0350	640.0534	640.0271
BF	9.23513	9.25350	9.22719
d0	4000.0000	2000.0000	7000.0000
d14	5.5372	5.5531	5.5399
d18	7.3810	7.3651	7.3783
Entrance pupil position	24.2289	24.2277	24.2287
Exit pupil position	−1024.4630	−1024.4630	−1024.4630
Front principal point	15.5065	15.5053	15.5063
Rear principal point	648.6665	648.6664	648.6664

TABLE 15

Lens elements	First surface	Focal length
L1	1	−91.7067
L2	3	−46.8438
L3	5	−33.3197
L4	7	38.5160
L5	9	23.1741
L6	11	−16.8239
L7	13	42.7663
L8	15	64.4661
L9	17	−47.1863
L10	19	72.8960
L11	21	111.4017
L12	23	139.1616
L13	25	100.7334
L14	27	−30.4281
L15	29	117.8181
L16	31	114.6356
L17	33	−215.8909
L18	36	−139.9323
L19	38	66.7157
L20	40	−51.0677
L21	42	63.4778
L22	44	−180.8565
L23	46	108.3543

Numerical Practical Example 6

[0137] Hereinafter, the lens system of numerical practical example 6 (corresponding to the sixth exemplary embodiment) is described. Table 16 shows surface data; table 17 shows various types of data; and table 18 shows single lens data.

TABLE 16

Surface No.	r	d	nd	vd	Effective radius
Object surface	variable	variable			
1	63.28360	3.50000	1.80420	46.5	40.003
2	32.81670	9.18550			27.859
3	51.64690	2.50000	1.80420	46.5	25.592
4	21.43600	9.53340			18.006
5	158.85280	2.00000	1.78637	48.1	17.178
6	19.00120	4.51400			13.418
7	23.46020	14.04160	1.56953	42.2	12.618
8	−66.64780	3.59430			8.539
9	−59.87690	15.00000	1.74062	53.1	4.688
10	−12.78600	0.20000			8.925
11	−12.83280	2.00000	1.81546	24.6	8.954
12	174.37310	2.14230			11.847
13	2743.26670	8.03570	1.60555	61.1	14.859
14	−24.92340	variable			16.153
15	79.62910	15.00000	1.48834	70.3	21.802
16	−54.40420	17.51190			23.174
17	−39.81360	3.00000	1.65446	32.3	24.299
18	127.55140	variable			29.147
19	−592.74720	11.82680	1.84670	23.8	31.386
20	−54.32270	0.20000			32.317
21	774.34520	8.89330	1.84670	23.8	35.411
22	−107.48050	0.20000			35.647
23	49.08360	15.00000	1.84670	23.8	34.085
24	74.45360	36.06340			30.629
25	−470.22450	8.13880	1.60373	61.2	21.229
26	−47.78860	1.89350			20.661
27	−41.80810	2.00000	1.76178	26.4	19.162
28	50.59970	72.37790			18.510
29	−1002.23960	8.46000	1.72883	54.7	31.927
30	−79.65580	98.93920			32.201
31	164.85470	4.71110	1.84218	24.9	23.003
32	−230.01800	1.21420			22.685
33	−140.06960	2.00000	1.59196	60.8	22.599
34	2040.72340	32.78750			22.421
35(aperture)	∞	61.88290			20.397
36	156.14880	2.00000	1.80550	29.4	20.884
37	64.08780	4.25350			20.885
38	146.26200	8.84000	1.55032	75.5	21.609
39	−48.32820	0.62760			21.878
40	−51.45690	2.00000	1.80458	27.5	21.810
41	220.04910	0.20000			23.166
42	105.36540	10.92740	1.55032	75.5	23.896
43	−50.52690	0.90500			24.220
44	−47.73520	2.50000	1.80519	28.9	24.198
45	−76.05490	0.20000			25.293
46	94.94220	6.68120	1.72968	54.6	26.412
47	−371.30530	10.00000			26.320
48	∞	95.00000	1.51680	64.2	24.866
49	∞	BF			15.500
Image surface	∞				

TABLE 17

Object distance	4000.0000	2000.0000	7000.0000
Object curvature radius	5200.0000	2600.0000	9100.0000
Focal length	−8.6500	−8.6499	−8.6500
F number	−2.50006	−2.50013	−2.50003
Half view angle	102.0000	102.0000	102.0000
Effective image radius	−15.3432	−15.3372	−15.3457
Total lens length	640.0345	640.0529	640.0265
BF	9.23470	9.25308	9.22675
d0	4000.0000	2000.0000	7000.0000
d14	1.9847	2.0000	1.9817
d18	6.3331	6.3178	6.3360
Entrance pupil position	23.5648	23.5632	23.5651
Exit pupil position	−1037.1156	−1037.1156	−1037.1156
Front principal point	14.8433	14.8418	14.8435
Rear principal point	648.6659	648.6658	648.6658

TABLE 18

Lens elements	First surface	Focal length
L1	1	−89.3350
L2	3	−47.3132
L3	5	−27.6200
L4	7	32.2939
L5	9	19.3314
L6	11	−14.5881
L7	13	40.8322
L8	15	68.7089
L9	17	−46.0362
L10	19	69.9269
L11	21	111.9863
L12	23	133.8437
L13	25	87.4760
L14	27	−29.7733
L15	29	118.2723
L16	31	114.6509
L17	33	−221.3479
L18	36	−136.2704
L19	38	67.0894
L20	40	−51.6645
L21	42	63.6387
L22	44	−165.7400
L23	46	104.2494

Numerical Practical Example 7

[0138] Hereinafter, the lens system of numerical practical example 7 (corresponding to the seventh exemplary embodiment) is described. Table 19 shows surface data; table 20 shows various types of data; and table 21 shows single lens data.

TABLE 19

Surface No.	r	d	nd	vd	Effective radius
Object surface	variable	variable			
1	64.29010	3.50000	1.80420	46.5	40.000
2	32.48960	9.31610			27.633
3	52.89940	2.50000	1.80420	46.5	25.561
4	21.33780	9.27870			17.956
5	126.87940	2.00000	1.77252	49.4	17.203
6	18.55970	4.61010			13.427
7	22.88660	15.00000	1.54903	46.3	12.650
8	−64.84610	4.15950			8.246
9	−66.36510	15.00000	1.72920	54.7	4.633
10	−13.69560	0.61610			9.475
11	−13.60410	2.00000	1.83688	24.0	9.557
12	284.15600	1.82320			12.619
13	984.51480	8.14890	1.62200	60.2	15.478
14	−26.41060	variable			16.738
15	93.53510	9.73600	1.50466	68.5	22.098
16	−53.10820	19.14100			22.533
17	−36.28870	3.00000	1.66034	31.8	23.850
18	161.00310	variable			29.252
19	−329.56540	12.52760	1.84670	23.8	31.455
20	−49.81420	0.20000			32.465
21	298.52510	8.98000	1.84670	23.8	36.160
22	−140.27760	0.20000			36.314
23	49.60470	15.00000	1.84670	23.8	34.686
24	71.48560	37.13650			31.098
25	−554.12230	10.48350	1.68855	40.6	21.671
26	−51.06390	2.19460			20.797
27	−42.22300	2.00000	1.81709	24.6	19.201
28	57.80090	72.17000			18.687
29	−1426.62310	8.18820	1.72592	54.8	31.871
30	−82.05000	95.88350			32.110
31	165.90130	4.72860	1.84346	24.2	22.919
32	−226.14270	1.22100			22.821

TABLE 19-continued

Surface No.	r	d	nd	vd	Effective radius
33	−138.29940	2.00000	1.59048	49.4	22.731
34	2751.39050	34.91980			22.540
35(aperture)	∞	60.52210			20.248
36	165.52210	2.00000	1.80380	31.4	20.683
37	65.24950	4.33660			20.704
38	165.65600	8.73170	1.55032	75.5	21.425
39	−46.79220	0.63580			21.709
40	−49.66690	2.00000	1.80382	27.9	21.644
41	280.49290	0.20000			23.038
42	111.58540	10.87720	1.55032	75.5	23.792
43	−49.24810	0.96520			24.120
44	−46.23250	2.50000	1.80573	28.3	24.097
45	−77.15290	0.20000			25.284
46	99.33380	6.97460	1.72987	54.6	26.501
47	−254.94490	10.00000			26.436
48	∞	95.00000	1.51680	64.2	24.915
49	∞	BF			15.500
Image surface	∞				

TABLE 20

Object distance	4000.0000	2000.0000	7000.0000
Object curvature radius	5200.0000	2600.0000	9100.0000
Focal length	−8.6500	−8.6499	−8.6500
F number	−2.50006	−2.50013	−2.50003
Half view angle	102.0000	102.0000	102.0000
Effective image radius	−15.3432	−15.3372	−15.3457
Focal length	−8.6497	−8.6497	−8.6497
F number	−2.50004	−2.50010	−2.50001
Half view angle	102.0000	102.0000	102.0000
Effective image radius	−15.3436	−15.3379	−15.3460
Total lens length	640.0344	640.0528	640.0265
BF	9.23441	9.25279	9.22647
d0	4000.0000	2000.0000	7000.0000
d14	1.9902	2.0000	1.9859
d18	6.2037	6.1939	6.2080
Entrance pupil position	23.3342	23.3331	23.3346
Exit pupil position	−1024.3080	−1024.3080	−1024.3080
Front principal point	14.6121	14.6110	14.6126
Rear principal point	648.6655	648.6655	648.6655

TABLE 21

Lens elements	First surface	Focal length
L1	1	−85.8888
L2	3	−46.0986
L3	5	−28.3695
L4	7	32.7984
L5	9	21.1280
L6	11	−15.4657
L7	13	41.4799
L8	15	68.6526
L9	17	−44.5767
L10	19	67.9152
L11	21	113.7796
L12	23	145.6292
L13	25	81.0014
L14	27	−29.5953
L15	29	119.6191
L16	31	114.0867
L17	33	−222.9485
L18	36	−135.2019
L19	38	67.2810
L20	40	−52.3523
L21	42	63.6145
L22	44	−148.5326
L23	46	98.7592

Numerical Practical Example 8

[0139] Hereinafter, the lens system of numerical practical example 8 (corresponding to the eighth exemplary embodiment) is described. Table 22 shows surface data; table 23 shows various types of data; and table 24 shows single lens data.

TABLE 22

Surface No.	r	d	nd	vd	Effective radius
Object surface	∞				
1	7.93240	1.00000	2.05090	26.9	5.449
2	4.45760	1.50350			3.660
3	5.05190	0.50000	2.05090	26.9	2.404
4	2.09070	0.93030			1.606
5	37.69890	1.26120	1.77040	48.3	1.343
6	−1.74860	0.50000	1.75900	29.4	1.156
7	35.35180	0.34100			1.706
8	−30.09070	2.54720	1.49700	81.6	2.206
9	−3.49500	0.15000			2.998
10	−40.42400	2.32370	1.49700	81.6	3.970
11	−6.35630	0.15000			4.307
12	−39.25360	2.13030	1.67393	57.2	4.601
13	−7.81470	0.82060			4.730
14	−6.05640	0.50000	1.83620	26.9	4.674
15	−8.38510	0.14990			5.057
16	24.19860	1.57820	1.71554	55.1	5.317
17	−77.98920	0.14980			5.291
18	8.35920	2.74840	1.84637	23.8	5.075
19	−51.72980	0.74580			4.763
20	−14.34690	7.00000	1.83654	24.0	4.467
21	−58.69460	1.86730			3.315
22	−4.71340	0.71670	1.51986	67.0	3.122
23	−7.17560	0.15000			3.290
24	−7.83070	0.84260	1.59253	61.8	3.284
25	12.37460	3.58760			3.598
26	−15.11890	2.03240	1.81727	28.8	4.728
27	−7.81480	0.44410			5.102
28	25.94870	3.00000	1.80384	36.4	5.423
29	−13.90070	0.67630			5.376
30	9.50560	1.59890	1.78487	48.2	4.058
31	20.19110	1.63620			3.570
32	−8.46590	0.87270	1.80875	29.6	2.925
33	4.11600	1.89360	1.49685	64.5	2.594
34	28.28470	1.00050			2.581
35	11.25950	1.52620	1.83469	24.1	2.613
36	−8.29880	0.15170			2.537
37	40.92670	0.50170	1.60869	36.7	2.210
38	4.54690	0.35460			1.921
39	6.34570	1.49210	1.72250	54.9	1.867
40	−3.65670	0.50020	1.73175	27.7	1.638
41	4.81530	0.39890			1.344
42(aperture)	∞	0.15070			1.289
43	4.05190	2.35840	1.84113	23.9	1.472
44	2.55100	1.86970	1.49700	81.6	1.519
45	−11.58400	1.27610			1.781
46	4.76050	2.05810	1.72932	54.5	2.261
47	5.10650	1.00000			2.072
48	∞	0.80000	1.51680	64.2	2.161
49	∞	BF			2.244
Image surface	∞				

TABLE 23

Focal length	−1.3989
F number	−2.90140
Half view angle	100.0000
Effective image radius	−2.4385
Total lens length	62.9694
BF	0.00613
Entrance pupil position	3.2173
Exit pupil position	−7.0745

TABLE 23-continued

Front principal point	1.5420
Rear principal point	64.3683

TABLE 24

Lens elements	First surface	Focal length
L1	1	−11.3580
L2	3	−3.7155
L3	5	2.1997
L4	6	−2.1826
L5	8	7.7112
L6	10	14.8396
L7	12	14.0936
L8	14	−28.9059
L9	16	25.9777
L10	18	8.6847
L11	20	−24.4569
L12	22	−29.3445
L13	24	−7.9702
L14	26	17.5914
L15	28	11.6515
L16	30	21.4721
L17	32	−3.3214
L18	33	9.4493
L19	35	5.9344
L20	37	−8.4477
L21	39	3.4252
L22	40	−2.7712
L23	43	−29.0202
L24	44	4.3997
L25	46	27.4566

Numerical Practical Example 9

[0140] Hereinafter, the lens system of numerical practical example 9 (corresponding to the ninth exemplary embodiment) is described. Table 25 shows surface data; table 26 shows various types of data; and table 27 shows single lens data.

TABLE 25

Surface No.	r	d	nd	vd	Effective radius
Object surface	∞				
1	7.61010	1.00000	2.00100	29.1	5.455
2	4.45910	1.10470			3.691
3	4.44760	0.50020	2.00100	29.1	2.739
4	2.01120	1.24310			1.755
5	−182.15840	1.67880	1.76458	50.3	1.424
6	−2.56500	0.50800	1.82600	25.3	1.149
7	−19.21760	0.25510			1.568
8	−14.08940	2.09080	1.49700	81.6	1.869
9	−3.61530	0.19040			2.678
10	−34.82460	1.75800	1.49700	81.6	3.466
11	−6.76600	0.20530			3.801
12	−57.50340	1.90120	1.71401	55.3	4.207
13	−7.94150	0.87430			4.371
14	−5.78970	0.76980	1.82830	29.9	4.354
15	−9.15280	0.32570			4.907
16	28.69500	1.68360	1.80420	46.5	5.502
17	−42.30770	0.25150			5.541
18	8.59570	2.71770	1.84670	23.8	5.497
19	431.81660	0.65300			5.221
20	−30.07740	6.99470	1.77093	31.8	5.071
21	342.86640	2.09890			3.439
22	−5.07130	0.81070	1.68341	56.7	3.196
23	−6.26680	0.40990			3.374

TABLE 25-continued

Surface No.	r	d	nd	vd	Effective radius
24	−6.79400	0.86100	1.63030	59.7	3.313
25	12.52510	3.55410			3.638
26	−14.36660	1.98270	1.80621	29.4	4.753
27	−7.65130	0.59260			5.114
28	35.42240	3.00000	1.80044	46.8	5.480
29	−12.64390	0.80130			5.477
30	9.39700	1.61920	1.78465	48.2	4.037
31	20.73920	1.64070			3.548
32	−7.96460	1.27270	1.80858	34.3	2.912
33	4.22410	1.79770	1.49697	69.3	2.566
34	36.02480	0.93990			2.564
35	12.74670	1.47220	1.83456	24.6	2.600
36	−7.83480	0.15000			2.539
37	37.10390	0.50120	1.60758	36.7	2.205
38	4.59710	0.34140			1.923
39	6.47230	1.50810	1.72319	54.9	1.873
40	−3.48000	0.50000	1.73123	28.3	1.650
41	4.78450	0.38870			1.352
42(aperture)	∞	0.21190			1.302
43	4.00370	2.39900	1.84670	23.8	1.525
44	2.53690	1.97170	1.49700	81.6	1.544
45	−11.03860	1.21300			1.816
46	4.79570	2.07570	1.73293	54.1	2.260
47	4.86090	1.00000			2.060
48	∞	0.80000	1.51680	64.2	2.153
49	∞	BF			2.243
Image surface	∞				

TABLE 26

Focal length	−1.3990
F number	−2.90155
Half view angle	100.0000
Effective image radius	−2.4436
Total lens length	63.7980
BF	0.00442
Entrance pupil position	3.0098
Exit pupil position	−7.0169
Front principal point	1.3320
Rear principal point	65.1970

TABLE 27

Lens elements	First surface	Focal length
L1	1	−12.7889
L2	3	−4.0875
L3	5	3.3890
L4	6	−3.6338
L5	8	9.1769
L6	10	16.5522
L7	12	12.7016
L8	14	−21.2241
L9	16	21.4883
L10	18	10.3278
L11	20	−35.5773
L12	22	−53.6750
L13	24	−6.8699
L14	26	17.9396
L15	28	11.9733
L16	30	20.6049
L17	32	−3.2614
L18	33	9.4514
L19	35	6.0098
L20	37	−8.6869
L21	39	3.3419

TABLE 27-continued

Lens elements	First surface	Focal length
L22	40	−2.6865
L23	43	−32.6978
L24	44	4.3608
L25	46	33.7246

Numerical Practical Example 10

[0141] Hereinafter, the lens system of numerical practical example 10 (corresponding to the tenth exemplary embodiment) is described. Table 28 shows surface data; table 29 shows various types of data; and table 30 shows single lens data.

TABLE 28

Surface No.	r	d	nd	vd	Effective radius
Object surface	∞				
1	6.42470	0.70000	2.00100	29.1	4.001
2	3.33470	1.07320			2.689
3	4.51070	0.50000	2.00100	29.1	2.042
4	1.78460	1.09690			1.348
5	30.10470	1.40000	1.80420	46.5	0.821
6	−1.15540	1.50000	1.74077	27.8	0.819
7	−35.29750	0.50970			1.689
8	−5.29520	1.59500	1.80420	46.5	1.894
9	−3.17420	0.15000			2.442
10	−54.42590	1.63070	1.80420	46.5	2.902
11	−5.68200	0.89790			3.082
12	−3.72210	0.50000	1.64769	33.8	3.063
13	−5.05350	1.70010			3.403
14	25.93710	1.50000	1.84666	23.8	3.984
15	−21.06840	23.52770			4.001
16	53.36830	1.50000	1.83481	42.7	4.001
17	−22.45170	3.96820			3.973
18	−6.25070	1.00000	1.72916	54.7	3.264
19	19.24970	2.50000	1.71736	29.5	3.586
20	−9.08540	2.75300			3.781
21	6.43160	1.73300	1.80420	46.5	3.439
22	80.75310	2.74940			3.191
23	−23.20460	0.50000	1.76182	26.6	1.675
24	3.93720	0.44940			1.541
25	19.07260	1.40040	1.72916	54.7	1.553
26	−2.50840	0.50000	1.80518	25.5	1.554
27	−26.19940	0.15000			1.593
28(aperture)	∞	0.15000			1.597
29	4.79790	0.50000	1.91082	35.2	1.609
30	3.62840	1.26020	1.48749	70.4	1.528
31	−9.08010	0.93920			1.491
32	9.81180	2.00000	1.72916	54.7	1.555
33	17.66240	1.00000			1.484
34	∞	3.60000	1.51680	64.2	1.482
35	∞	BF			1.478
Image surface	∞				

Focal length	−0.8914
F number	−2.08038
Half view angle	95.0000
Effective image radius	−1.4794
Total lens length	67.3900
BF	0.45603
Entrance pupil position	2.4843
Exit pupil position	−6.7255
Front principal point	1.4822
Rear principal point	68.2814

TABLE 30

Lens elements	First surface	Focal length
L1	1	−7.8118
L2	3	−3.2479
L3	5	1.4118
L4	6	−1.6432
L5	8	7.3802
L6	10	7.7731
L7	12	−25.5901
L8	14	13.9346
L9	16	19.1024
L10	18	−6.3659
L11	19	8.9333
L12	21	8.6002
L13	23	−4.3835
L14	25	3.1258
L15	26	−3.4779
L16	29	−20.5260
L17	30	5.4966
L18	32	27.3374

Numerical Practical Example 11

[0142] Hereinafter, the lens system of numerical practical example 11 (corresponding to the eleventh exemplary embodiment) is described. Table 31 shows surface data; table 32 shows various types of data; and table 33 shows single lens data.

TABLE 31

Surface No.	r	d	nd	vd	Effective radius
Object surface	∞				
1	6.42800	0.70000	2.00100	29.1	4.001
2	3.33640	1.06390			2.690
3	4.44320	0.50000	2.00100	29.1	2.043
4	1.79130	1.10160			1.352
5	32.22280	1.40000	1.80420	46.5	0.810
6	−1.16780	1.50000	1.74446	27.1	0.826
7	−31.39330	0.50850			1.702
8	−5.32800	1.60360	1.80420	46.5	1.909
9	−3.19420	0.15000			2.459
10	−59.49740	1.63820	1.80420	46.5	2.927
11	−5.76310	0.90300			3.107
12	−3.76490	0.50000	1.62004	35.4	3.088
13	−5.26140	1.36580			3.436
14	24.59900	1.50000	1.84670	23.8	3.982
15	−21.00820	23.64910			3.999
16	57.64090	1.50000	1.81170	39.5	4.004
17	−21.73130	4.07190			3.981
18	−6.17250	1.00000	1.72915	54.7	3.279
19	26.48060	2.50000	1.71826	29.0	3.613
20	−8.89840	2.87560			3.827
21	6.45990	1.75690	1.80391	46.5	3.484
22	86.94070	2.76600			3.236
23	−20.99570	0.50000	1.76551	26.3	1.697
24	4.02680	0.45690			1.563
25	21.73540	1.40710	1.72914	54.7	1.575
26	−2.53210	0.50000	1.80927	24.8	1.579
27	−21.03420	0.15000			1.623
28(aperture)	∞	0.15000			1.626
29	4.96320	0.50000	1.81082	40.2	1.637
30	3.67160	1.45060	1.48700	70.4	1.557
31	−9.42020	0.97430			1.507
32	9.86120	2.00000	1.68517	56.6	1.564
33	17.31120	1.00000			1.492
34	∞	3.60000	1.51680	64.2	1.488
35	∞	BF			1.479
Image surface	∞				

TABLE 32

Focal length	−0.8914
F number	−2.08109
Half view angle	95.0000
Effective image radius	−1.4791
Total lens length	67.6925
BF	0.44950
Entrance pupil position	2.4780
Exit pupil position	−6.9533
Front principal point	1.4793
Rear principal point	68.5839

TABLE 33

Lens elements	First surface	Focal length
L1	1	−7.8152
L2	3	−3.3105
L3	5	1.4280
L4	6	−1.6645
L5	8	7.4290
L6	10	7.8285
L7	12	−24.4780
L8	14	13.5876
L9	16	19.6085
L10	18	−6.7776
L11	19	9.5550
L12	21	8.5969
L13	23	−4.3759
L14	25	3.1883
L15	26	−3.6006
L16	29	−21.0492
L17	30	5.6291
L18	32	30.1516

[0143] Table 34 below shows corresponding values of each condition in the lens systems of the numerical practical examples.

TABLE 34

	Numerical practical examples										
Conditions	1	2	3	4	5	6	7	8	9	10	11
(1)	0.38	0.36	0.29	0.34	0.29	0.30	0.29	0.56	0.59	0.19	0.19
(2)	−1.00	−1.00	−1.04	−1.04	−1.38	−1.38	−1.38	−1.31	−1.31	−1.15	−1.15
(3)	1.54	1.54	0.86	0.84	0.83	0.75	0.75	1.06	1.21	1.41	1.43
(4)	97.3	97.3	113.7	113.7	131.7	131.7	131.7	78.6	79.6	125.3	125.9
(5)	1.85	1.90	0.35	0.33	0.52	0.52	0.53	0.67	0.89	1.23	1.24
(6)	63.1	64.8	84.5	84.8	96.1	96.2	96.3	49.6	50.8	92.1	92.8
(7)	3.42	3.34	3.67	3.02	3.60	3.15	3.04	3.57	3.83	3.16	3.16
(8)	61.4	163.9	72.4	80.4	356.1	422.9	90.0				
(9)	5.84	6.04	6.32	5.85	5.96	5.80	5.58	4.65	5.24	5.29	5.29
(10)	1.03	1.06	1.12	1.06	1.11	1.12	1.10	1.02	0.99	1.00	1.00

Other Exemplary Embodiments

[0144] In the exemplary embodiments first through eleventh described above, the description is made of the case where the lens system of the present disclosure is used for a projector. Besides, the lens system of the present disclosure, by being combined with an imaging element that photoreceives an optical image formed by the lens system and converts the image to an electrical image signal, can be used for an imaging apparatus.

INDUSTRIAL APPLICABILITY

[0145] The present disclosure can be applied to image projection apparatuses such as projectors and head up displays, and imaging apparatuses such as digital still cameras, digital video cameras, surveillance cameras in surveillance systems, web cameras, in-vehicle cameras, and the like. In particular, the present disclosure can be applied to a photographic optical system that requires high image quality such as a projector, a digital still camera system, and a digital video camera system.

What is claimed is:

1. A lens system that forms an image conjugately between each of a magnification conjugate point at a magnification side and a reduction conjugate point at a reduction side; and an intermediate image-forming position inside the lens system, comprising:

a magnification optical system with positive power, the magnification optical system having a plurality of lens elements, the magnification optical system positioned closer to the magnification side than the intermediate image-forming position; and

a relay optical system with positive power, the relay optical system having a plurality of lens elements, the relay optical system positioned closer to the reduction side than the intermediate image-forming position,

wherein the lens system satisfies following conditions (1) and (2)

$$0.08 \le fp/fr \le 0.8 \quad (1)$$

$$\{Ymax - ft \cdot \tan(\omega max)\}/\{ft \cdot \tan(\omega max)\} \le -0.3 \quad (2)$$

where

fr is composite focal length of the relay optical system closer to the reduction side than the intermediate image-forming position,

fp is composite focal length of the magnification optical system closer to the magnification side than the intermediate image-forming position,

Ymax is a radius of an effective image diameter,

ωmax is a maximum half view angle, and

ft is focal length of the lens system as a whole.

2. The lens system of claim **1**,

wherein the magnification optical system includes at least one lens element with positive power and is composed of a rear group and a front group,

the rear group composed of at least one lens element closer to the reduction side than a lens element with positive power disposed closest to the magnification side of the magnification optical system, the at least one lens element including the lens element with positive power disposed closest to the magnification side,

the front group composed of at least one lens element closer to the magnification side than the lens element with positive power disposed closest to the magnification side of the magnification optical system, and

wherein the lens system satisfies following condition (3)

$$0.4 \leq fpf/(ft \cdot \omega max \cdot \pi/180) \leq 1.8 \quad (3)$$

where

fpf is composite focal length of the front group of the magnification optical system.

3. The lens system of claim **1**, satisfying following condition (4)

$$60 < |(Lt \cdot ft \cdot \omega max \cdot \pi/180)/ft^2| < 200 \quad (4)$$

where

Lt is total optical length of the lens system.

4. The lens system of claim **1**,

wherein the magnification optical system includes at least one lens element with positive power and is composed of a rear group and a front group,

the rear group composed of at least one lens element closer to the reduction side than a lens element with positive power disposed closest to the magnification side of the magnification optical system, the at least one lens element including the lens element with positive power disposed closest to the magnification side,

the front group composed of at least one lens element closer to the magnification side than the lens element with positive power disposed closest to the magnification side of the magnification optical system, and

wherein the lens system satisfies following condition (5)

$$|t/ft| \leq 3.0 \quad (5)$$

where

t is distance on an optical axis between a surface of a lens element closest to the reduction side among the at least one lens element in the front group of the magnification optical system; and a surface of a lens element closest to the magnification side among the at least one lens element in the rear group of the magnification optical system.

5. The lens system of claim **1**, wherein the lens system satisfies following condition (6)

$$36 < |(Lr \cdot ft \cdot \omega max \cdot \pi/180)/ft^2| < 150 \quad (6)$$

where

Lr is distance on an optical axis from the intermediate image-forming position to an image-forming position at the reduction side.

6. The lens system of claim **1**, wherein the front group of the magnification optical system includes a first lens element and a second lens element in order from the magnification side to the reduction side,

the first lens element having a negative meniscus shape with a convex surface facing the magnification side,

the second lens element having a negative meniscus shape with a convex surface facing the magnification side.

7. The lens system of claim **1**, wherein the lens system satisfies following condition (7)

$$2.9 < SFL1 < 5.0 \quad (7)$$

where

SFL**1** is a shape factor of a lens element closest to the magnification side in the lens system.

8. The lens system of claim **1**,

wherein the magnification optical system includes at least one lens element with positive power and is composed of a rear group and a front group,

the rear group composed of at least one lens element closer to the reduction side than a lens element with positive power disposed closest to the magnification side of the magnification optical system, the at least one lens element including the lens element with positive power disposed closest to the magnification side,

the front group composed of at least one lens element closer to the magnification side than the lens element with positive power disposed closest to the magnification side of the magnification optical system,

wherein the rear group has an image surface curvature correction lens group that moves in an optical axis direction when an amount of image surface curvature is adjusted, and

wherein the lens system satisfies following condition (8)

$$10 < |fas/(ft \cdot \omega \cdot \pi/180)| < 1000 \quad (8)$$

where

fas is composite focal length of the image surface curvature correction lens group.

9. The lens system of claim **1**, wherein the lens system satisfies following condition (9)

$$2 < |f1/(f \cdot \omega \cdot \pi/180)| < 10 \quad (9)$$

where

f1 is focal length of a lens element closest to the magnification side in the lens system.

10. The lens system of claim **1**,

wherein the magnification optical system includes at least one lens element with positive power and is composed of a rear group and a front group,

the rear group composed of at least one lens element closer to the reduction side than a lens element with positive power disposed closest to the magnification side of the magnification optical system, the at least one lens element including the lens element with positive power disposed closest to the magnification side,

the front group composed of at least one lens element closer to the magnification side than the lens element with positive power disposed closest to the magnification side of the magnification optical system, and

wherein the lens system satisfies following condition (10)

$$0.8 < \varphi pfmax/\varphi prmax < 1.3 \quad (10)$$

where

φpfmax is a maximum lens effective diameter of a lens element in the front group of the magnification optical system, and

φprmax is a maximum lens effective diameter of a lens element in the rear group of the magnification optical system.

11. An image projection apparatus comprising:

the lens system of claim **1**; and

an image-forming element generating an image to be projected onto a screen.

12. An imaging apparatus comprising:

the lens system of claim **1**; and

an imaging element photoreceiving an optical image formed by the lens system and converting the optical image to an electrical image signal.

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