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Shimizu

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[54] **FISHEYE LENS SYSTEMS**

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[51] **Int. Cl.** G02b 9/60
[58] **Field of Search** 350/216, 215, 214, 350/196

[56] **References Cited**

UNITED STATES PATENTS

3,601,473	8/1971	Mandler	350/215
3,497,291	2/1970	Woltche	350/215
3,524,697	8/1970	Isshiki et al	350/196

FOREIGN PATENTS OR APPLICATIONS

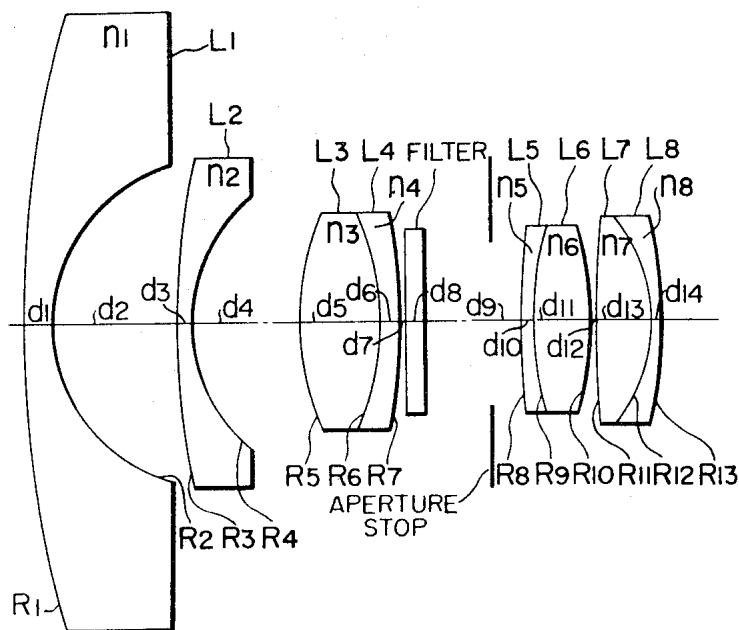|			
1,137,788	12/1968	Great Britain	350/215

Primary Examiner—John K. Corbin
Attorney—Joseph M. Fitzpatrick et al.

[57] **ABSTRACT**

A lens system comprises, in sequence moving from the object side, first and second negative meniscus lenses both convex to the object side, a biconvex lens, a negative meniscus lens cemented to the third lens, and fifth to eighth lenses including one or two negative lenses and cemented together so as to form two lens groups. An aperture stop is interposed between the fourth and fifth lenses. The lenses are arranged to satisfy predetermined conditions, thereby providing a fisheye lens system having a long back-focus two to three times greater than its focal length and yet having a compact construction.
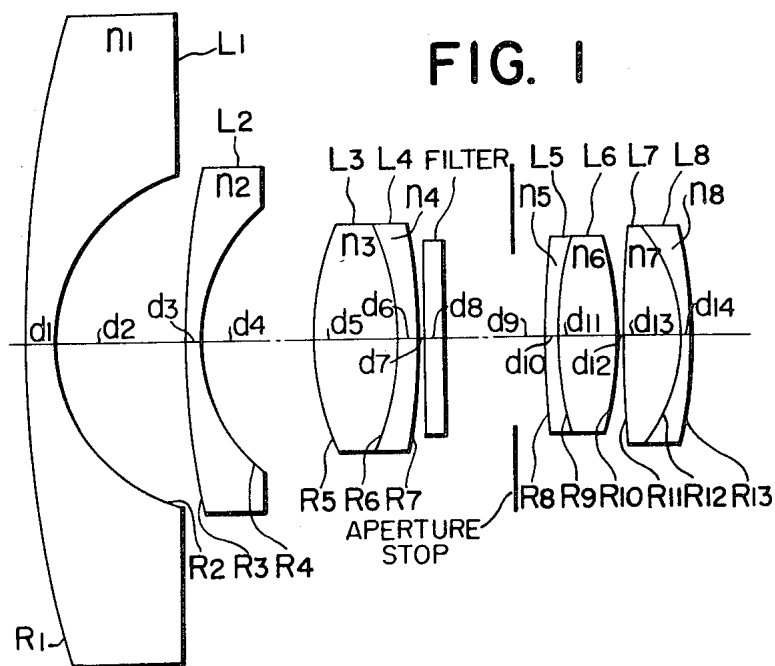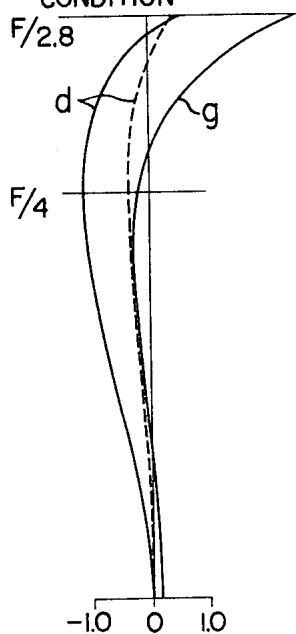
4 Claims, 14 Drawing Figures

FIG. 1

Labels: n1, L1, L2, n2, L3, L4, FILTER, L5, L6, L7, L8, n4, n3, n5, n6, n7, n8

d1, d2, d3, d4, d5, d6, d7, d8, d9, d10, d11, d12, d13, d14

R1, R2 R3 R4, R5 R6 R7, APERTURE STOP, R8 R9 R10 R11 R12 R13

FIG. 2A

SPHERICAL ABERRATION ———
SINE CONDITION - - - - -

F/2.8

d, g

F/4

-1.0 0 1.0

FIG. 2B

ASTIGMATISM SAGITAL ———
MERIDIONAL - - - - -
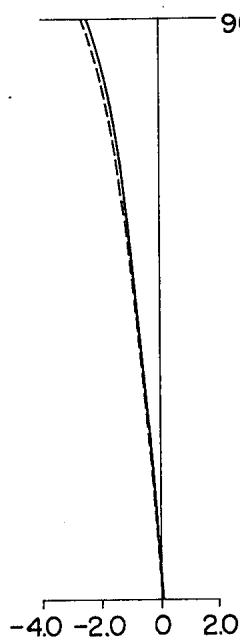
90°

-4.0 -2.0 0 2.0

FIG. 2C

DISTORTION

90°

-100% 0

FIG. 3

FIG. 4A

SPHERICAL
ABERRATION —————
SINE
CONDITION — — — —
F/2.8

d

g

F/4

-1.0   0   1.0

FIG. 4B

SAGITAL —————
ASTIGMATISM
MERIDIONAL — — — —
90°

-2.0   0   2.0

FIG. 4C

DISTORTION

90°

-100% 0

FIG. 5A

SPHERICAL ABERRATION ⎯⎯⎯
SINE CONDITION ⎯ ⎯ ⎯

F/2.8

g

F/4

d

-1.0   0   1.0

FIG. 5B

ASTIGMATISM

SAGITAL ⎯⎯⎯
MERIDIONAL ⎯ ⎯ ⎯

90°

-2.0   0   2.0

FIG. 5C

DISTORTION

90°

-100% 0

FIG. 6A

SPHERICAL ABERRATION ⎯⎯⎯
SINE CONDITION ⎯ ⎯ ⎯

F/2.8

d   g

F/4

-1.0   0   1.0

FIG. 6B

ASTIGMATISM

SAGITAL ⎯⎯⎯
MERIDIONAL ⎯ ⎯ ⎯

80°

-2.0   0   2.0

FIG. 6C

DISTORTION

80°

-100% 0
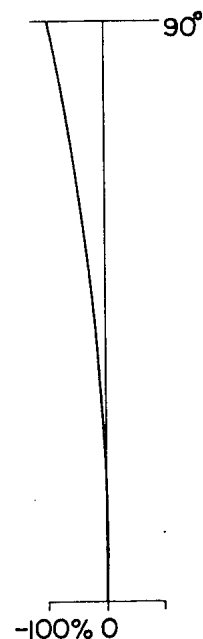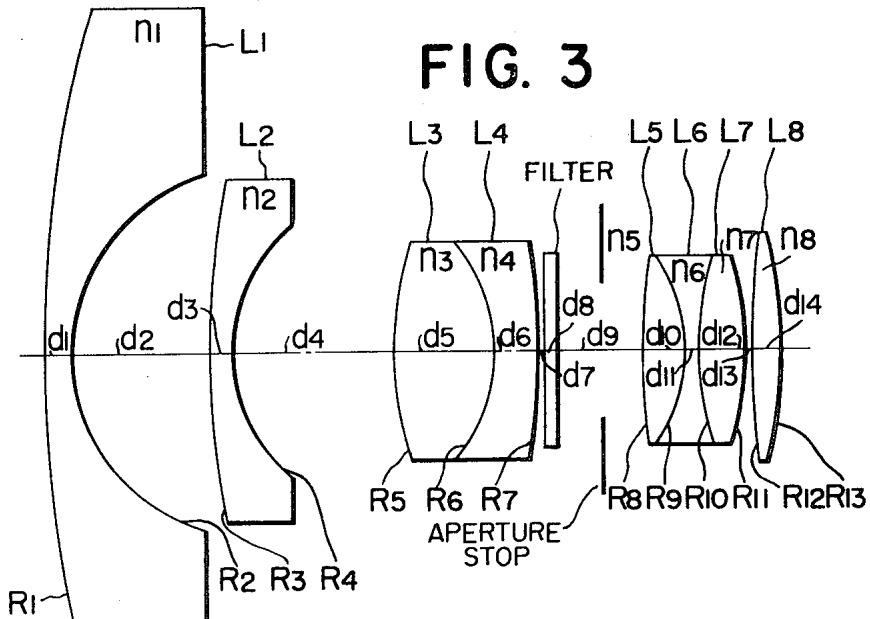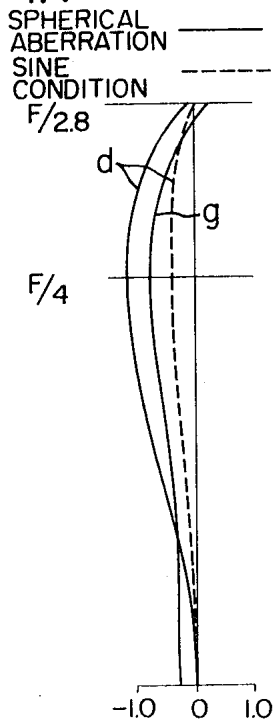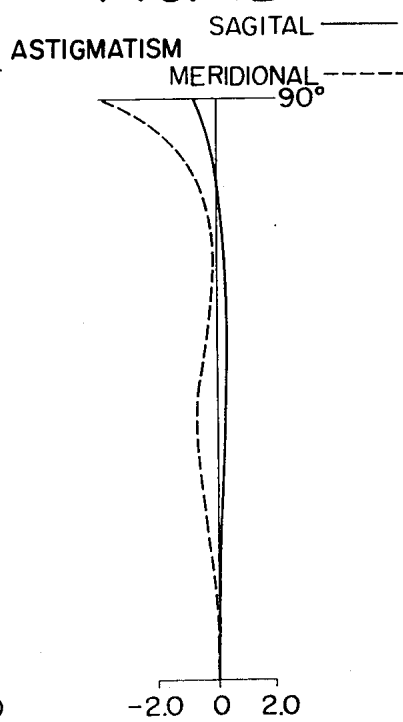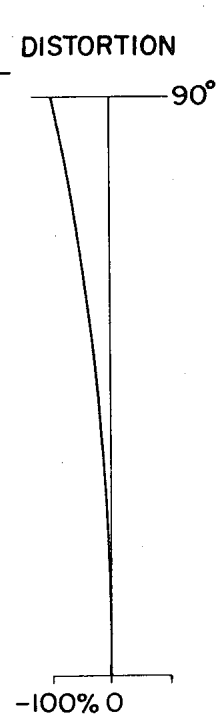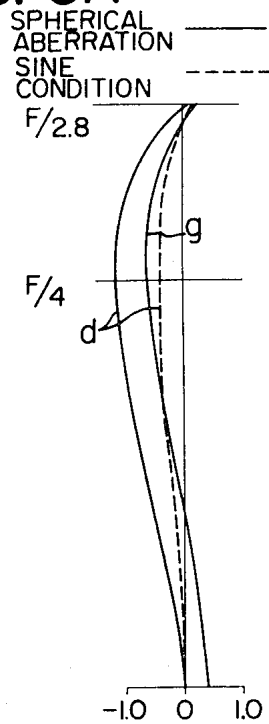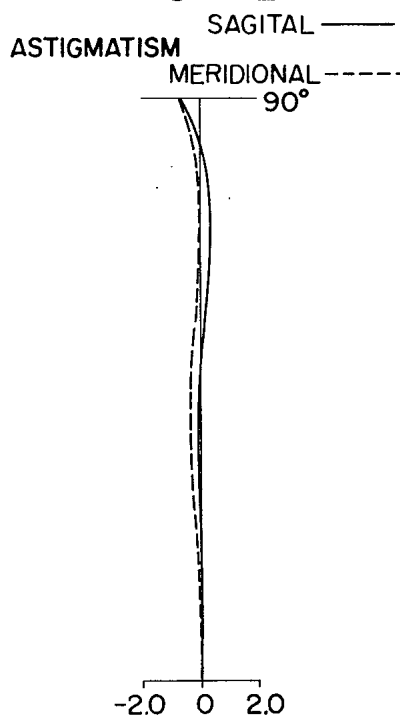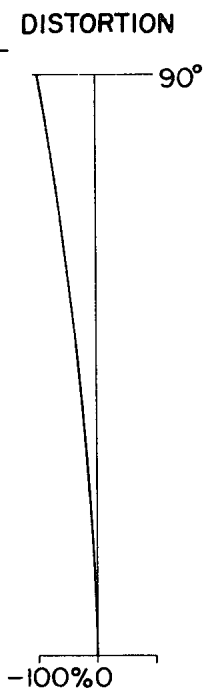
FISHEYE LENS SYSTEMS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to optical systems, and more particularly to a fisheye lens system having a long back-focus.

2. Description of the Prior Art

Conventional fisheye lens systems have been of relatively large dimension in relation to their respective focal lengths, and this has led to certain disadvantages in the practical use of same.

SUMMARY OF THE INVENTION

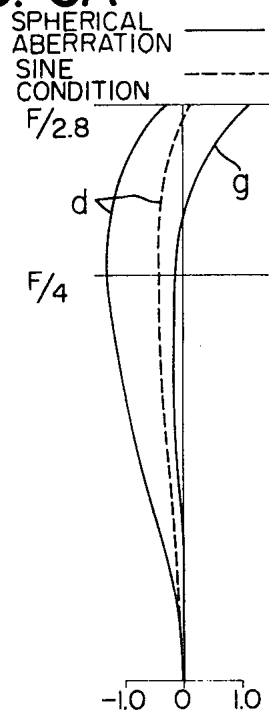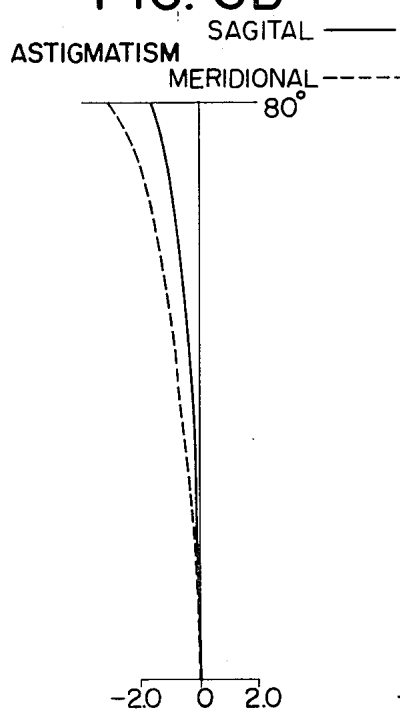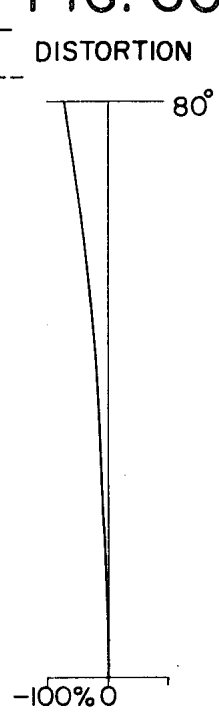The present invention seeks to realize a compact optical system which has an aperture ratio of F/2.8 and also provides a back-focus which is two or more times longer than its focal length.

According to the present invention, there is provided a speed fisheye lens system which comprises, as viewed in the direction running from the object to the image, first and second negative meniscus lenses both convex to the object side of the system, a third lens which is biconvex, a fourth lens which is a negative meniscus lens cemented to the third lens, fifth to eighth lenses including one or two lens groups, and an aperture stop interposed between the fourth and fifth lenses. The lens system is arranged to satisfy certain conditions to be described, and provide a back-focus two to three times longer than its focal length.

There has thus been outlined rather broadly the more important features of the invention in order that the detailed description thereof that follows may be better understood, and in order that the present contribution to the art may be better appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will form the subject of the claims appended hereto. Those skilled in the art will appreciate that the conception upon which this disclosure is based may readily be utilized as a basis for the designing of other structures for carrying out the several purposes of the invention. It is important, therefore, that the claims be regarded as including such equivalent construction as do not depart from the spirit and scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

A specific embodiment of the invention has been chosen for purposes of illustration and description, and is shown in the accompanying drawings, forming a part of the specification, wherein:

FIGS. 1 and 3 are longitudinal sections of Examples I and II of the present invention; and

FIGS. 2(A), 2(B), 2(C), 4(A), 4(B), 4(C), 5(A), 5(B), 5(C), 6(A), 6(B), and 6(C) are graphs of various aberration curves in Examples I, II, III and IV of the present invention, wherein FIGS. 2(A), 4(A), 5(A) and 6(A) show the spherical aberration (d and g indicate curves for the wavelengths of d- and g-lines), FIGS. 2(B), 4(B), 5(B) and 6(B) show the astigmatism and FIGS. 2(C), 4(C), 5(C) and 6(C) show the distortional aberration.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIGS. 1 or 3, as viewed from object to image, a first lens L_1 and a second lens L_2 are meniscus lenses

of negative focal length with their convex surfaces facing toward the object. A third lens L_3 is a biconvex lens, to which is cemented a fourth lens L_4 which is a negative meniscus lens. The fourth lens L_4 is followed by fifth, sixth, seventh and eighth lenses L_5, L_6, L_7 and L_8, respectively, and an aperture stop is interposed between the lenses L_4 and L_5. A filter may further be interposed between the lens L_4 and the aperture stop. One or two of the four lenses L_5 to L_8 are negative lenses, and these last four lenses may be such that each two of them are cemented together to provide two lens groups as shown in FIG. 1, or that three of them are cemented together to divide the four lenses into two groups in the manner shown in FIG. 3.

Let the focal length of the entire lens system be f, the radius of curvature of the ith lens surface be R_i, the inter-vertex distance of the ith lens be d_i, the refractive index and the dispersive power of the jth lens L_j be n_j and ν_j, respectively. According to the invention then, the lens system must satisfy the following relations:

$$3f < R_1 < 7f, \; 3f < R_3 < 7f \tag{1}$$

$$0.5f < R_2 < 2f, \; 0.5f < R_4 < 2f \tag{2}$$

$$R_7 < 0 \tag{3}$$

Also, let the mean value of the refractive indices and the mean value of the dispersive powers of the materials forming the concave lenses among the lenses L_5 to L_8 be n_M and ν_M, respectively, and the mean value of the refractive indices and the mean value of the dispersive powers of the materials forming the convex lenses among the lenses L_5 to L_8 be n_P and ν_P, respectively. Then the following relation must also be satisfied:

$$n_M > n_P$$
$$\nu_M < \nu_P \tag{4}$$

The significances of the foregoing conditions will now be described.

Condition (1) relates to the radii of curvature R_1 and R_3 in the object-facing surfaces of the lenses L_1 and L_2. If the values of R_1 and R_3 are lower than the lower limits of condition (1), the effective apertures of the lenses L_1 and L_2 will be greater. If the radii of curvature R_1 and R_3 exceed the upper limits of condition (1), light rays having wide angles of field will be incident on the object-facing surfaces of the lenses L_1 and L_2 at greater angles of incidence, thus resulting in an insufficient quantity of peripheral light. Thus, condition (1) is directed to reduce the dimensions of the lens system while securing a sufficient quantity of peripheral light.

Condition (2) is concerned with the radii of curvature R_2 and R_4 in the image-facing surfaces of the lenses L_1 and L_2. If the values of R_2 and R_4 are lower than the lower limits of this condition, off-axis rays incident with certain angles of field (i.e., rays incident at certain angles with the optical axis) will suffer from an excessive inner coma which cannot be corrected. Conversely, if the values of R_2 and R_4 exceed the upper limits of condition (2), it will become difficult to attain a long back-focus. Thus, condition (2) is intended to prevent occur-

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rence of any excessive coma while maintaining a long back-focus.

Condition (3) deals with the radius of curvature R_7 in the image-facing surface of the lens L_4 and prescribes a negative value for the radius of curvature R_7. This condition is meant to correct the inner coma which may be produced in the off-axis rays incident on the lens L_4 at the angles of field provided by the image-facing surfaces of the preceding lenses L_1 and L_2. Since the aperture stop is located rearwardly from the lens L_4, such off-axis rays are subjected to greater refractions than the principal rays because of the limitations imposed upon the image-facing surface of the lens L_4 and the said refractions occur in the direction for correcting the inner coma. Thus, condition (3) is useful to correct the coma.

Finally, condition (4) is meant for the correction of astigmatism and this calls for a lower mean refractive index for the positive lenses than for the negative lenses in the lens groups succeeding to the aperture stop. This is effective to render the Petzval sum positive, and useful to correct the deviation of the Petzval sum of the lenses L_1 and L_2 toward the negative. Condition (4) also calls for a greater mean dispersive power for the positive lenses than for the negative lenses in the same lens groups, and this is useful to correct the axial chromatic aberration and the chromatic difference of magnification which results from the lenses L_1 and L_2.

Numerical data for the various examples of the present invention will be shown below. In the tables below, R represents the radius of curvature, vd the inter-vertex distance, n the refractive index, and vd the dispersive power. Although the arrangements of Examples I and II have been shown in FIGS. 1 and 3, those of Examples III and IV are omitted because they are similar to the arrangements of FIGS. 3 and 1, respectively.

Example I

Focal length f=100.0, Angle of field 180°, F/2.8, Back-focus 237.38

R_1=−581.25			
	d_1=17.5	n_1=1.62041	vd=60.3
R_2=+92.375			
	d_2=70.0		
R_3=+546.875			
	d_3=11.25	n_2=1.62041	vd=60.3
R_4=+95.625			
	d_4=60.63		
R_5=+143.75			
	d_5=45.62	n_3=1.57501	vd=41.3
R_6=−133.313			
	d_6=10.0	n_4=1.77279	vd=49.5
R_7=−321.313			
	d_7=3.13		
	d_8=11.25	Filter n=1.51823	Filter
	d_9=54.37		
R_8=+3312.5			
	d_{10}= 6.25	n_5=1.52682	vd=51.1
R_9=+200.0			
	d_{11}=31.56	n_6=1.5200	vd=70.1
R_{10}=−173.75			
	d_{12}=0.625		
R_{11}=+577.688			
	d_{13}=31.25	n_7=1.5200	vd=70.1
R_{12}=−80.625			
	d_{14}=5.63	n_8=1.7552	vd=27.5
R_{13}=−204.319			

The spherical aberration and sine condition in the above Example are shown in FIG. 2 (A), and the astigmatism and distortional aberration are shown in FIGS. 2 (B) and 2 (C), respectively.

Example II

Focal Length f=100.0, Angle of field 180°, F/2.8, Back-focus 246.08

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R_1=+620.463	d_1=15.873	n_1=1.62041	vd=60.3
R_2=+103.244			
	d_2=76.190		
R_3=+438.095			
	d_3=14.603	n_2=1.62041	vd=60.3
R_4=+ 89.206			
	d_4=86.984		
R_5=+200.0			
	d_5=53.333	n_3=1.74950	vd=35.0
R_6=−98.667			
	d_6=24.126	n_4=1.64831	vd=33.8
R_7=−450.793			
	d_7=3.174		
	d_8=11.428	Filter n=1.51823	Filter
	d_9=43.809		
R_8=+1666.667			
	d_{10}=23.492	n_5=1.51835	vd=60.3
R_9=− 79.619			
	d_{11}=5.714	n_6=1.74950	vd=35.0
R_{10}=+151.111			
	d_{12}=26.031	n_7=1.5200	vd=70.1
R_{11}=−156.317			
	d_{13}=0.634		
R_{12}=+506.730			
	d_{14}=17.778	n_8=1.5168	vd=64.2
R_{13}=−218.876			

The spherical aberration and sine condition in the foregoing Example are shown in FIG. 4 (A), and the astigmatism and distortional aberration are shown in FIGS. 4 (B) and 4 (C), respectively.

Example III

Focal length f=100.0, Angle of field 180°, F/2.8, Back-focus 240.33

R_1 =+620.463	d_1 =15.873	n_1 =1.62041	vd =60.3
R_2 =+103.244			
	d_2 =73.015		
R_3 =+400.190			
	d_3 =14.603	n_2 =1.62041	vd =60.3
R_4 =+87.460			
	d_4 =90.158		
R_5 =+189.968			
	d_5 =53.333	n_3 =1.744	vd =44.9
R_6 =−103.244			
	d_6 =23.492	n_4 =1.62041	vd =60.3
R_7 =−480.980			
	d_7 =3.174		
	d_8 =11.428	Filter n=1.51823	Filter
	d_9 =42.539		
R_8 =+1666.667			
	d_{10}=20.952	n_5 =1.51835	vd =60.3
R_9 =−75.936			
	d_{11} =5.714	n_6 =1.74950	vd =35.0
R_{10}=+148.571			
	d_{12}=26.031	n_7 =1.52000	vd =70.1
R_{11}=−156.317			
	d_{13} =0.634		
R_{12}=+506.730			
	d_{14}=17.777	n_8 =1.51680	vd =64.2
R_{13}=−219.993			

The spherical aberration and sine condition in this Example are shown in FIG. 5 (A) and the astigmatism and distortional aberration are shown in FIGS. 5 (B) and 5 (C), respectively.

Example IV

Focal length f=100.0, Angle of field 160°, F/2.8, Back-focus 240.69

R_1 =+548.000	d_1 =16.0	n_1 =1.62041	vd =60.3
R_2 =+92.400			
	d_2 =70.0		
R_3 =+578.000			
	d_3 =11.333	n_2 =1.62041	vd =60.3
R_4 =+93.866			
	d_4 =60.667		
R_5 =+144.000			
	d_5 =49.333	n_3 =1.57501	vd =41.3
R_6 =−133.333			
	d_6 =13.333	n_4 =1.77279	vd =49.5
R_7 =−321.333			
	d_7 =3.333		
	d_8 =12.000	Filter n=1.51823	Filter
	d_9 =51.333		

	$d_{10} = 6.666$	$n_5 = 1.52682$	$\nu d = 51.1$
$R_8 = +3333.333$			
$R_9 = +200.000$	$d_{11} = 33.333$	$n_6 = 1.52000$	$\nu d = 70.1$
$R_{10} = -180.000$			
$R_{11} = +520.000$	$d_{12} = 0.666$		
$R_{12} = -83.333$	$d_{13} = 33.333$	$n_7 = 1.52000$	$\nu d = 70.1$
	$d_{14} = 3.333$	$n_8 = 1.75520$	$\nu d = 27.5$
$R_{13} = -212.057$			

The spherical aberration and sine condition in the above Example are shown in FIG. 6 (A) and the astigmatism and distortional aberration are shown in FIGS. 6 (B) and 6 (C), respectively.

It will thus be appreciated that the present invention can provide a compact, bright fisheye lens system having a long back-focus two to three times the total focal length thereof.

I claim:

1. A fisheye lens system comprising, as viewed in the direction from the object to the image, first and second negative meniscus lenses both convex to the object side, a third lens which is biconvex, a fourth lens which is a negative meniscus lens cemented to the third lens, fifth and sixth lenses and seventh and eighth lenses are cemented together, respectively, an aperture stop interposed between the fourth and fifth lenses, and a filter interposed between the fourth lens and the aperture stop, the lens system satisfying the following conditions:

Focal length $f = 100.0$, Angle of field 180°, F/2.8, Back-focus 237.38

	$d_1 = 17.5$	$n_1 = 1.62041$	$vd = 60.3$
$R_1 = +581.25$			
$R_2 = +92.375$	$d_2 = 70.0$		
$R_3 = +546.875$	$d_3 = 11.25$	$n_2 = 1.62041$	$vd = 60.3$
$R_4 = +95.625$	$d_4 = 60.63$		
$R_5 = +143.75$	$d_5 = 45.62$	$n_3 = 1.57501$	$vd = 41.3$
$R_6 = -133.313$	$d_6 = 10.0$	$n_4 = 1.77279$	$vd = 49.5$
$R_7 = -321.313$	$d_7 = 3.13$		
	$d_8 = 11.25$	Filter $n = 1.51823$	Filter
	$d_9 = 54.37$		
$R_8 = +3312.5$	$d_{10} = 6.25$	$n_5 = 1.52682$	$vd = 51.1$
$R_9 = +200.0$	$d_{11} = 31.56$	$n_6 = 1.5200$	$vd = 70.1$
$R_{10} = -173.75$	$d_{12} = 0.625$		
$R_{11} = +577.688$	$d_{13} = 31.25$	$n_7 = 1.5200$	$vd = 70.1$
$R_{12} = -80.625$	$d_{14} = 5.63$	$n_8 = 1.7552$	$vd = 27.5$
$R_{13} = -204.319$			

where R represents the radius of curvature, d the intervertex distance, n the refractive index, and ν_d the dispersive power.

2. A fisheye lens system comprising, as viewed in the direction from the object to the image, first and second negative meniscus lenses both convex to the object side, a third lens which is biconvex, a fourth lens which is a negative meniscus lens cemented to the third lens, fifth, sixth and seventh lenses are cemented together, an eighth lens which is biconvex, an aperture stop interposed between the fourth and fifth lenses, and a filter interposed between the fourth lens and the aperture stop, the lens system satisfying the following conditions:

Focal length $f = 100.0$, Angle of field 180°, F/2.8, Back-focus 246.08

	$d_1 = 15.873$	$n_1 = 1.62041$	$\nu_d = 60.3$
$R_1 = +620.463$			
$R_2 = +103.244$	$d_2 = 76.190$		
$R_3 = +438.095$	$d_3 = 14.603$	$n_2 = 1.62041$	$\nu_d = 60.3$
$R_4 = +89.206$	$d_4 = 86.984$		
$R_5 = +200.0$	$d_5 = 53.333$	$n_3 = 1.74950$	$\nu_d = 35.0$
$R_6 = -98.667$	$d_6 = 24.126$	$n_4 = 1.64831$	$\nu_d = 33.8$
$R_7 = -450.793$	$d_7 = 3.174$		
	$d_8 = 11.428$	Filter $n = 1.51823$	Filter
	$d_9 = 43.809$		
$R_8 = +1666.667$	$d_{10} = 23.492$	$n_5 = 1.51835$	$\nu_d = 60.3$
$R_9 = -79.619$	$d_{11} = 5.714$	$n_6 = 1.74950$	$\nu_d = 35.0$
$R_{10} = +151.111$	$d_{12} = 26.031$	$n_7 = 1.5200$	$\nu_d = 70.1$
$R_{11} = -156.317$	$d_{13} = 0.634$		
$R_{12} = +506.730$	$d_{14} = 17.778$	$n = 1.5168$	$\nu_d = 64.2$
$R_{13} = -218.876$			

where R represents the radius of curvature, d the intervertex distance, n the refractive index, and ν_d the dispersive power.

3. A fisheye lens system comprising, as viewed in the direction from the object to the image, first and second negative meniscus lenses both convex to the object side, a third lens which is biconvex, a fourth lens which is a negative meniscus lens cemented to the third lens, fifth, sixth and seventh lenses are cemented together, an eighth lens which is biconvex, an aperture stop interposed between the fourth and fifth lenses, and a filter interposed between the fourth lens and the aperture stop, in which the lens system satisfies the following conditions:

Focal length $f = 100.0$, Angle of field 180°, F/2.8, Back-focus 240.33

	$d_1 = 15.873$	$n_1 = 1.62041$	$\nu_d = 60.3$
$R_1 = +620.463$			
$R_2 = +103.244$	$d_2 = 73.015$		
$R_3 = +400.190$	$d_3 = 14.603$	$n_2 = 1.62041$	$\nu_d = 60.3$
$R_4 = +87.460$	$d_4 = 90.158$		
$R_5 = +189.968$	$d_5 = 53.333$	$n_3 = 1.744$	$\nu_d = 44.9$
$R_6 = -103.244$	$d_6 = 23.492$	$n_4 = 1.62041$	$\nu_d = 60.3$
$R_7 = -481.980$	$d_7 = 3.174$		
	$d_8 = 11.428$	Filter $n = 1.51823$	Filter
	$d_9 = 42.539$		
$R_8 = +1666.667$	$d_{10} = 20.952$	$n_5 = 1.51835$	$\nu_d = 60.3$
$R_9 = -75.936$	$d_{11} = 5.714$	$n_6 = 1.74950$	$\nu_d = 35.0$
$R_{10} = +148.571$	$d_{12} = 26.031$	$n_7 = 1.52000$	$\nu_d = 70.1$
$R_{11} = -156.317$	$d_{13} = 0.634$		
$R_{12} = +506.730$	$d_{14} = 17.777$	$n_8 = 1.51680$	$\nu_d = 64.2$
$R_{13} = -219.993$			

where R represents the radius of curvature, d the intervertex distance, n the refractive index, and ν_d the dispersive power.

4. A fisheye lens system comprising, as viewed in the direction from the object to the image, first and second negative meniscus lenses both convex to the object side, a third lens which is biconvex, a fourth lens which is a negative meniscus lens, fifth and sixth lenses and seventh and eighth lenses are cemented together, re-

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spectively, an aperture stop interposed between the fourth and fifth lenses and a filter interposed between the fourth lens and the aperture stop, in which the lens system satisfied the following conditions:

Focal length f — 100.0, Angle of field 160°, $F/2.8$, Back-focus 240.69

$R_1=+548.000$

$R_2=+92.400$

$d_1=16.0$ $n_1=1.62041$ $\nu_d=60.3$

$R_3=+578.000$

$d_2=70.0$

$R_4=+93.866$

$d_3=11.333$ $n_2=1.62041$ $\nu_d=60.3$

$R_5=+144.000$

$d_4=60.667$

$R_6=-133.333$

$d_5=49.333$ $n_3=1.57501$ $\nu_d=41.3$

$R_7=-321.333$

$d_6=13.333$ $n_4=1.77279$ $\nu_d=49.5$

$d_7=3.333$

$d_8=12.000$ Filter $n=1.51823$ Filter

$d_9=51.333$

$R_8=+3333.333$

$d_{10}=6.666$ $n_5=1.52682$ $\nu_d=51.1$

$R_9=+200.000$

$d_{11}=33.333$ $n_6=1.52000$ $\nu_d=70.1$

$R_{10}=-180.000$

$d_{12}=0.666$

$R_{11}=+520.000$

$d_{13}=33.333$ $n_7=1.52000$ $\nu_d=70.1$

$R_{12}=-83.333$

$d_{14}=3.333$ $n_8=1.75520$ $\nu_d=27.5$

$R_{13}=-212.057$

where R represents the radius of curvature, d the inter-vertex distance, n the refractive index, and ν_d the dis-persive power.

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