



CATADIOPTRIC LENS WITH REFRACTIVE
COMPONENTS MOVABLE FOR FOCUSING

This invention relates to catadioptric lenses, and more particularly relates to catadioptric lenses which are focused by movement of internal refractive components.

Catadioptric lenses are used to provide extremely long focal lengths while requiring only a relatively short physical length of the lens. Primary and secondary reflective surfaces or mirrors within the lens are utilized to increase the length of the optical path through the lens while decreasing the overall length of the lens and thereby provide a very high telephoto ratio. The telephoto ratio is the ratio of the front vertex distance (FVD) of the lens to its equivalent focal length, the front vertex distance being the dimension from the front vertex of the lens to the film plane.

In catadioptric lenses of the type to which this invention pertains, light entering the housing passes to a primary mirror where it is reflected to a secondary mirror on the object side of the primary mirror, and hence to the refractive portion of the optical system. Most, if not all, catadioptric lenses are focused by relative motion of the primary and secondary mirrors. Optically, this is satisfactory. However, if the lens is to have a large relative aperture, large primary mirrors are required. These mirrors are inherently sensitive in positioning. Movement of the primary mirror requires large, and hence more expensive helicoidal focusing mechanisms.

It would be desirable to seal the main mirror system and achieve focusing by moving smaller refractive elements within the

lens. However, this presents a difficult optical problem. Catadioptric systems covering the relatively large angles required for consumer photography, typically four to ten degrees full field angle, necessarily need rear refractive corrective elements to compensate
5 for the inherent field curvature of the main mirror system.

An object of this invention is to provide new and improved catadioptric lenses.

Another object of the invention is to provide a catadioptric lens design wherein refractive groups other than a mirror are
10 moved to accomplish focusing.

A further object of this invention is to provide a new and improved catadioptric lens which may utilize a relatively large primary mirror which is not required to move for focusing to thereby achieve a fast relative aperture and long focal length in a compact
15 lens.

According to the present invention there is provided a catadioptric lens having object and image sides comprising a first component having a first reflective surface with a central aperture therethrough, a second component having a reflective surface disposed
20 on the object side of said first component, said second component arranged to reflect light to refractive lens groups on the image side of said second component, said first and second components being arranged in fixed relationship, a first lens group of positive power disposed to the image side of said second component, and a second
25 refractive lens group of negative power disposed on the image side of said first refractive group, said second refractive group being

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axially movable to focus said lens.

The present invention provides catadioptric lenses where refractive elements internal to the lens are moved axially for focusing, and also provides stability of aberration corrections as these elements are moved.

The invention as hereinafter explained may be embodied in either a Cassegrain or Mangin type catadioptric lens. In either case, the first refractive lens group is a positive group of relatively weak optical power, and the second or moving refractive group is preferably a three component negative group of strong power, the first and last components may be singlets or doublets while the middle component in all examples is a doublet. This method of focusing also permits the design of relatively fast lenses, for example, an aperture of $F/4.5$ for an equivalent focal length (EFL) close to 450mm.

The invention will now be described, by way of example, with reference to the accompanying drawings, in which:-

Figures 1 - 4 are schematic side elevations of lenses embodying the invention.

Throughout the drawings and description, refractory lens elements will be indicated by the letter "L" followed by an Arabic number. Groups of lens elements will be identified by the letter "G" followed by an Arabic numeral. Refractive surfaces of various elements will be identified by the letter "S" followed by an Arabic numeral, and mirror surfaces which have no refractive value are designated "M" followed by an Arabic numeral.

Figure 1 exemplifies the invention embodied in a Cassegrain type catadioptric lens. The lens of Figure 1 comprises a first or primary mirror having a reflective surface M1, and a secondary mirror having a reflective surface M2. As shown, a light ray R striking mirror surface M1 is reflected by mirror surface M1 to surface M2 and then re-reflected to refractive elements comprising a stationary positive group G1 and a movable negative group G2. Group G1 comprises lens elements L1 and L2 in the form

of a cemented positive doublet having surfaces S1, S2 and S3. Group G2 comprises a positive biconvex singlet L3 having surfaces S4 and S5; a doublet comprising a biconcave element L4, and a positive meniscus L5 having surfaces S6-S8; and a doublet comprising a biconcave element L6 and a biconvex element L7 having surfaces S9-S11. Group G2 is followed by two plano elements LS and F. Elements LS and F are not optically required. Element LS is a seal or protective member, and element F represents a filter. The image plane is indicated by the reference FP. A lens according to Figure 1 would further include a double plano sealing element on the object side of mirror M2. Group G2 is movable for focusing.

The lens of Figure 1 is substantially described in Table I where N_d is the index of refraction of each refractive element and V_d is the dispersion of each element as expressed by its Abbe number. Positive radii which are struck on the axis of the lens to the right of the surface, while negative radii are struck on the axis of the lens to the left of the surface. All axial distances between the surfaces are set forth from the object end to the image end. The distance from the axial center of reflective surface M1 to surface M2 is shown as negative.

Figure 2 exemplifies a catadioptric lens of the Mangin Type where both the primary mirror and the secondary mirror are formed on refractive elements.

The lens comprises a first corrector element L1, having surfaces S1 and S2; a second refractive element L2 having a surface S3 and a reflective surface M1 on the image side thereof;

a refractive element L3 having a surface S4 and reflective surface M2 on the object side thereof; a fixed positive group G1 comprising a doublet consisting of a biconvex element L4 and a negative meniscus L5; Group G1 has surfaces S5-S7 as shown. Group G1 is
5 followed by a negative group G2 which comprises a biconvex singlet L6, a doublet consisting of biconcave element L7 and positive meniscus L8 followed by a doublet comprising a biconcave element L9 and a positive meniscus L10, then two plano elements LS and F. The lens elements L6-L10 have surfaces S8-S15, as shown. The group
10 G2 comprising the elements L6-L10 are axially movable to focus the lens. Element L5 is merely a sealing unit and element F is a removable filter. A lens as shown in Figure 2 is substantially described in Table II using the same nomenclature as in Table I.

Figure 3 exemplifies a Mangin type catadioptric lens
15 embodying the invention which utilizes a corrector L1 having aspheric surface S1 and S2. The corrector L1 is positioned behind a double plano sealing element on the object side (not shown). Light entering from the object side through the corrector element L1 is reflected by a primary mirror surface M1 of element L2 to the image
20 side surface of a secondary mirror M2 and hence to a fixed positive group G1. Group G1 comprises a positive doublet which consists of a biconvex element L3 and a negative meniscus L4 having surfaces S4-S6. Group G1 is followed by a movable focusing group G2 which comprises a first doublet consisting of a negative meniscus L5 and
25 a biconvex element L6; a second doublet consisting of a negative meniscus L7 and a positive meniscus L8; and a negative meniscus L9 followed by a double plano sealing element LS.

Surface S1 of element L1 is aspheric and is defined by the following equation:

$$X = \frac{Cy^2}{1+[1-(1+k)c^2y^2]^{\frac{1}{2}}} + Dy^4 + Ey^6 + Fy^8 + Gy^{10}$$

where X is the surface sag at a semi-aperture distance y from the axis of the lens;

C is the curvature of a lens surface at the optical axis equal to the reciprocal of the radius at the optical axis,

K is a constant, and

D, E, F, and G are coefficients

A lens as shown in Figure 3 is substantially described in Table III using the same nomenclature as in Tables I and II.

Figure 4 exemplifies another catadioptric lens embodying the invention which also uses a corrector having an aspheric surface defined by the foregoing equation. This lens is of the Cassegrain type and comprises from the object end a protective element P having plano surfaces a corrector element L1 having surfaces S1 and S2, a primary mirror M1, and a secondary mirror M2. The lens further comprises a stationary positive group G1 comprising a doublet consisting of a positive element L2, and a negative meniscus L3 having surfaces S3-S5. Group G1 is followed by an axial movable negative group G2 which comprises a positive doublet L4, L5; a negative doublet L6, L7, and a biconcave singlet L8. Group G2 is followed by a bi-plano sealing element LS and a removable filter F. Group G2 has surfaces S6-S13.

A lens as shown in Figure 4 is substantially defined in Table IV, using the same nomenclature as used in Tables I-III.

The internal focusing of the refractory elements of groups G1 and G2 will produce some variation in EFL as the lens is focused as shown in the prescription tables. This is due to the movement of negative group G2 to achieve satisfactory performance between a range of magnifications of zero (infinity) to approximately minus one hundred twenty-five thousandths (.125) at about three meters.

The relative optical powers of K_1 and K_2 of groups G1 and G2 respectively should have a relationship of

$$3.5 > |K_2/K_1| > 1.8$$

where the optical power of the groups are expressed as the reciprocal of the EFL of the group in millimeters. This will provide the necessary optical correction, while permitting movement of negative group II for focusing.

In all of the following tables, the lenses are set forth as sealed to an image frame of 24 x 36 mm.

TABLE I

ELEMENT	SURFACE RADIUS (MM)	AXIAL DISTANCE BETWEEN SURFACES (MM)	N_D	V_D
mirror	M1 -235.42		Reflective	
body		-60.83		
mirror	M2 -163.995		Reflective	
body		59.66		
L1	S1 180.151	7.60	1.517	64.2
	S2 -35.596			
L2		2.54	1.648	33.8
	S3 -70.640			
		15.54		
L3	S4 113.479	5.00	1.847	23.8
	S5 -143.114			
		.10		:
	S6 -786.272			
L4		2.43	1.834	37.3
	S7 30.664			
L5		3.87	1.501	58.6
	S8 79.859			
		19.322		
	S9 -33.498			
L6		2.12	1.487	55.4
	S10 199.250			
L7		3.00	1.648	33.8
	S11 -325.400			

Relative Aperture=1/6.0

EFL=437.1mm - 281.6mm

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TABLE II

<u>ELEMENT</u>	<u>SURFACE RADIUS (MM)</u>	<u>AXIAL DISTANCE BETWEEN SURFACES (MM)</u>	<u>N_D</u>	<u>V_D</u>
L1	S1 251.16			
		8.00	1.517	52.2
	S2 708.47	72.00		
L2	S3 -146.41			
		10.13	1.517	64.2
	M1 -248.91		Reflective	
L3		-73.14		
	S4 -119.10			
		-5.07	1.517	52.2
L4	M2 -183.44		Reflective	
		25.07		
	S5 198.63			
L5		7.98	1.517	52.2
	S6 -60.22			
		2.66	1.673	32.2
L6	S7 -166.09			
		33.30		
	S8 95.93			
L7		3.50	1.741	27.8
	S9 -158.82			
		0.72		
L7	S10-1125.26			
		2.20	1.834	37.3

	S11	40.32			
L8			3.50	1.487	70.4
	S12	142.91			
			19.55		
	S13	-44.18			
L9			1.92	1.650	39.9
	S14	39.27			
L10			3.80	1.805	25.5
	S15	-6824.24			

Relative Aperture=1/4.65

EFL=436.6mm - 260.9mm



TABLE III

<u>ELEMENT</u>	<u>SURFACE RADIUS (MM)</u>	<u>AXIAL DISTANCE BETWEEN SURFACES (MM)</u>	<u>N_D</u>	<u>V_D</u>
	S1 856.98			
L1		40.00	1.491	57.1
	S2 -266.81			
		9.10		
	S3 -167.53			
L2		25.62	1.491	57.1
	M1 -242.65		Reflective	
		73.17		
	M2 -152.58		Reflective	
		55.45		
	S4 374.06			
L3		5.60	1.517	64.2
	S5 -40.50			
L4		2.21	1.620	36.3
	S6 -86.61			
		23.16		
	S7 160.91			
L5		2.21	1.776	49.4
	S8 52.65			
L6		5.70	1.740	28.2
	S9 -125.17			
		0.75		
	S10-1399.06			
L7		2.21	1.806	40.7
	S11 33.15			

L8



4.60

1.517

64.2

S12 181.78

13.74

S13 -42.28

L9

2.00

1.766

49.4

S14 -178.63

Aspheric Surface: S1

S1

K 0.010

D 0.5892×10^{-9} E 0.1893×10^{-11} F 0.7951×10^{-15} G 0.1502×10^{-18}

EFL=436.2-263.5mm

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TABLE IV

<u>ELEMENT</u>	<u>SURFACE RADIUS (MM)</u>	<u>AXIAL DISTANCE BETWEEN SURFACES (MM)</u>	<u>N_D</u>	<u>V_D</u>
	S1 ∞			
L1		36.75	1.491	57.2
	S2 -1107.79			
		27.30		
	M1 -217.43		Reflective	
		-64.55		
	M2 -143.54		Reflective	
		53.50		
	S3 634.30			
L2		6.88	1.517	64.2
	S4 -50.64			
L3		2.30	1.673	32.2
	S5 -87.29			
		4.25		
	S6 116.03			
L4		2.20	1.720	50.3
	S7 50.04			
L5		5.17	1.728	26.1
	S8 -204.60			
		0.72		
	S9 -800.99			
L6		2.20	1.834	37.3
	S10 31.89			
L7		3.50	1.517	64.2
	S11 96.80			

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23.08

Ⓕ
S12 -44.48

L8

1.92

1.720 50.3

S13 -286.84

Aspheric Surface S1

K .010

D $-.289 \times 10^{-7}$

E $.365 \times 10^{-12}$

F $-.579 \times 10^{-15}$

G $.913 \times 10^{-19}$

EFL=437.4mm

The relationship of the powers (K_1 and K_2) of groups G1 and G2, respectively is set forth in Table V below:

TABLE V

	Power of Group G1 (K_1)	Power of Group G2 (K_2)	$ K_2/K_1 $
Table I	.00829	-.0163	1.966
Table II	.00406	-.0134	3.300
Table III	.00598	-.0153	2.559
Table IV	.00545	-.0186	3.413

The foregoing technique of focusing catadioptric lens permits the design of fast lens systems for a given EFL, while using relatively large primary mirrors that are inherently sensitive from the standpoint of positioning, and which would otherwise require expensive helicoidal focusing mechanisms if the mirror had to be moved for focusing. With the internal focusing disclosed herein, the overall lens may be sealed at its front and rear ends against moisture and dust.

It may thus be seen that the objects of the invention set forth as well as those made apparent from the foregoing description are efficiently attained. While preferred embodiments of the invention have been set forth for purposes of disclosure, modification to the disclosed embodiments of the invention as well as other embodiments thereof may occur to those skilled in the art. Accordingly, the appended claims are intended to cover all embodiments of the invention and modifications to the disclosed embodiments which do not depart from the spirit and scope of the invention.



Claims

1. A catadioptric lens having object and image sides comprising a first component having a first reflective surface with a central aperture therethrough, a second component having a reflective surface disposed on the object side of said first component, said second component arranged to reflect light to refractive lens groups on the image side of said second component, said first and second components being arranged in fixed relationship, a first lens group of positive power disposed to the image side of said second component, and a second refractive lens group of negative power disposed on the image side of said first refractive group, said second refractive group being axially movable to focus said lens.
2. The lens of claim 1 where the absolute optical power of said second negative refractive group is greater than the power of said first positive refractive group.
3. The lens of claim 2 where the absolute optical power of said second negative refractive group is substantially twice or greater than the optical power of said first refractive group.
4. The lens of claim 1 where the ratio of the absolute optical powers of said first and second refractive groups are

$$3.5 > |K_2/K_1| > 1.8$$

where K_2 is the optical power of the second refractive group and K_1 is the optical power of the first refractive group.



5. A lens according to claim 1 having a corrector with an aspheric surface between the first and second components, the aspheric surface being defined by the equation:-

$$X = \frac{Cy^2}{1 + [1 - (1+k)c^2y^2]^{\frac{1}{2}}} + Dy^4 + Ey^6 + Fy^8 + Gy^{10}$$

where

X is the surface sag at a semi-aperture distance y from the axis of the lens;

C is the curvature of a lens surface at the optical axis equal to the reciprocal of the radius at the optical axis,

K is a constant, and

D, E, F, and G are coefficients.

6. A lens according to claim 1 scaled to an image frame of 24 x 36mm substantially as described below:

ELEMENT	SURFACE RADIUS (MM)	AXIAL DISTANCE BETWEEN SURFACES (MM)	N_D	V_D
mirror	M1 -235.42			Reflective
body		-60.83		
mirror	M2 -163.995			Reflective
body		59.66		
	S1 180.151			
L1		7.60	1.517	64.2
	S2 -35.596			
L2		2.54	1.648	33.8
	S3 -70.640			

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15.54

	S4	113.479			
L3			5.00	1.847	23.8
	S5	-143.114			
			.10		
	S6	-786.272			
L4			2.43	1.834	37.3
	S7	30.664			
L5			3.87	1.501	58.6
	S8	79.859			
			19.322		
	S9	-33.498			
L6			2.12	1.487	55.4
	S10	199.250			
L7			3.00	1.648	33.8
	S11	-325.400			

Relative Aperture=1/6.0

EFL=437.1mm - 281.6mm

where L1-L7 designates lens elements having surfaces S1-S11, N_D is the index of refraction, and V_D is the dispersion of the lens elements as measured by their Abbe Number.

7. A lens according to claim 1 scaled to an image frame of 24 x 36mm substantially as described below:

<u>ELEMENT</u>	<u>SURFACE RADIUS (MM)</u>	<u>AXIAL DISTANCE BETWEEN SURFACES (MM)</u>	<u>N_D</u>	<u>V_D</u>
	S1 251.16			
L1		8.00	1.517	52.2
	S2 708.47			



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(64)

72.00

	S3	-146.41			
L2			10.13	1.517	64.2
	M1	-248.91		Reflective	
			-73.14		
	S4	-119.10			
L3			-5.07	1.517	52.2
	M2	-183.44		Reflective	
			25.07		
	S5	198.63			
L4			7.98	1.517	52.2
	S6	-60.22			
L5			2.66	1.673	32.2
	S7	-166.09			
			33.30		
	S8	95.93			
L6			3.50	1.741	27.8
	S9	-158.82			
			0.72		
	S10	-1125.26			
L7			2.20	1.834	37.3
	S11	40.32			
L8			3.50	1.487	70.4
	S12	142.91			
			19.55		
	S13	-44.18			
L9			1.92	1.650	39.9
	S14	39.27			
L10			3.80	1.805	25.5
	S15	-6824.24			

Relative Aperture=1/4.65



EFL=436.6mm - 260.9mm

where L1-L10 designates lens elements having surfaces S1-S15, N_D is the index of refraction, and V_D is the dispersion of the lens elements as measured by their Abbe Number.

8. A lens according to claim 5 scaled to an image frame of 24 x 36 mm substantially as described below:

<u>ELEMENT</u>	<u>SURFACE RADIUS (MM)</u>	<u>AXIAL DISTANCE BETWEEN SURFACES (MM)</u>	<u>N_D</u>	<u>V_D</u>
	S1 856.98			
L1		40.00	1.491	57.1
	S2 -266.81			
		9.10		
	S3 -167.53			
L2		25.62	1.491	57.1
	M1 -242.65		Reflective	
		73.17		
	M2 -152.58		Reflective	
		55.45		
	S4 374.06			
L3		5.60	1.517	64.2
	S5 -40.50			
L4		2.21	1.620	36.3
	S6 -86.61			
		23.16		
	S7 160.91			
L5		2.21	1.776	49.4



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(66)

S8 52.65

L6 5.70 1.740 28.2

S9 -125.17

0.75

S10-1399.06

L7 2.21 1.806 40.7

S11 33.15

L8 4.60 1.517 64.2

S12 181.78

13.74

S13 -42.28

L9 2.00 1.766 49.4

S14 -178.63

Aspheric Surface: S1

S1

K 0.010

D 0.5892×10^{-9} E 0.1893×10^{-11} F 0.7951×10^{-15} G 0.1502×10^{-18}

EFL=436.2mm-263.5mm

where L1-L9 designates lens elements having surfaces S1-S14, N_D is the index of refraction, V_D is the dispersion of the lens



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9. A lens according to claim 5 scaled to an image frame of 24 x 36mm substantially as described below:

<u>ELEMENT</u>	<u>SURFACE RADIUS (MM)</u>	<u>AXIAL DISTANCE BETWEEN SURFACES (MM)</u>	<u>N_D</u>	<u>V_D</u>
	S1 ∞			
L1		36.75	1.491	57.2
	S2 -1107.79			
		27.30		
	M1 -217.43		Reflective	
		-64.55		
	M2 -143.54		Reflective	
		53.50		
	S3 634.30			
L2		6.88	1.517	64.2
	S4 -50.64			
L3		2.30	1.673	32.2
	S5 -87.29			
		4.25		
	S6 116.03			
L4		2.20	1.720	50.3
	S7 50.04			
L5		5.17	1.728	26.1
	S8 -204.60			
		0.72		
	S9 -800.99			
L6		2.20	1.834	37.3
	S10 31.89			
L7		3.50	1.517	64.2



24

68

S11 96.80

23.08

S12 -44.48

L8

1.92

1.720 50.3

S13 -286.84

Aspheric Surface S1

K .010

D $-.289 \times 10^{-7}$ E $.365 \times 10^{-12}$ F $-.579 \times 10^{-15}$ G $.913 \times 10^{-19}$

EFL=437.4mm

where L1-L8 designates lens elements having surfaces S1-S13, N_D is the index of refraction, V_D is the dispersion of the lens

10. A catadioptric lens constructed, arranged and adapted to operate substantially as hereinbefore described with reference to, and as illustrated in, the accompanying drawings.
