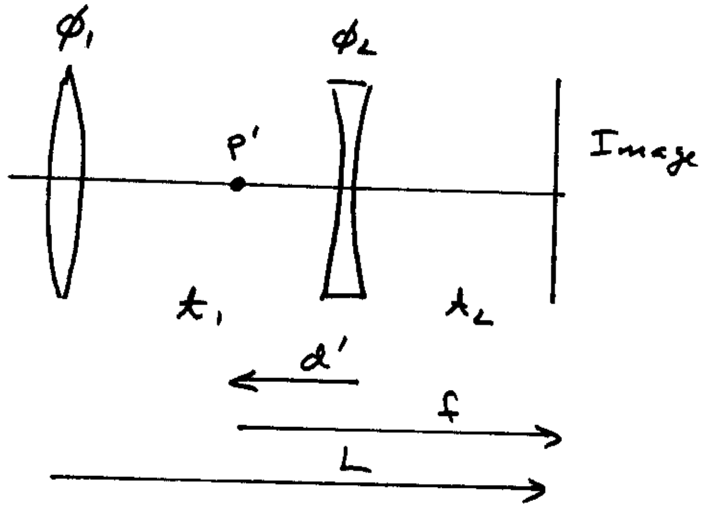
APS Zoom Lens

Two-element telephoto; object at infinity



$$\phi = \phi_1 + \phi_2 - \phi_1 \phi_2 t_1$$

$$d' = -\frac{\phi_1}{\phi} t_1$$

$$t_2 = WD = f + d'$$

$$L = t_1 + t_2$$

If $\phi_1 = -\phi_2$ as specified:

$$\phi = \phi_1^2 t_1 \qquad t_1 = \phi / \phi_1^2$$

$$d' = -1/\phi_1$$

$$t_2 = 1/\phi - 1/\phi_1 = \frac{\phi_1 - \phi}{\phi \phi_1}$$

Define:

$\phi_T \Rightarrow$ Long f limit (tele)

$\phi_W \Rightarrow$ Short f limit (wide)

For a telephoto zoom:

- t_1 is smallest for long f (ϕ_T)
- L is longest for long f (ϕ_T)
- t_2 is smallest for short f (ϕ_W)

These mechanical constraints can be seen in the plot in the class notes or can be derived from the system equations.

At ϕ_T (long f limit):

$$L = 60\ mm = t_1 + t_2$$
$$t_1 = 5\ mm$$
} As specified

$$t_2 = 55\ mm$$

$$t_2 = \frac{\phi_1 - \phi_T}{\phi_1 \phi_T} = 55 \qquad 55\,\phi_1 \phi_T = \phi_1 - \phi_T$$

$$t_1 = \phi_T/\phi_1^2 = 5 \qquad \phi_T = 5\phi_1^2$$

$$55(5\phi_1^2)\phi_1 = \phi_1 - 5\phi_1^2$$

$$275\,\phi_1^2 + 5\phi_1 - 1 = 0$$

$$\phi_1 = \underline{.05189} \quad \text{or} \quad -.0701$$

Choose positive for telephoto.

$$\phi_1 = .05189\ /mm \qquad \phi_2 = -.05189\ /mm$$

$$\underline{f_1 = 19.27\ mm} \qquad \underline{f_2 = -19.27\ mm}$$

$t_1 = \phi/\phi_1^2 = f_1^2/f$

$t_2 = 1/\phi - 1/\phi_1 = f - f_1$

$t_1 = 371.3\ mm^2/f$
$t_2 = f - 19.27\ mm$

Zoom Range:

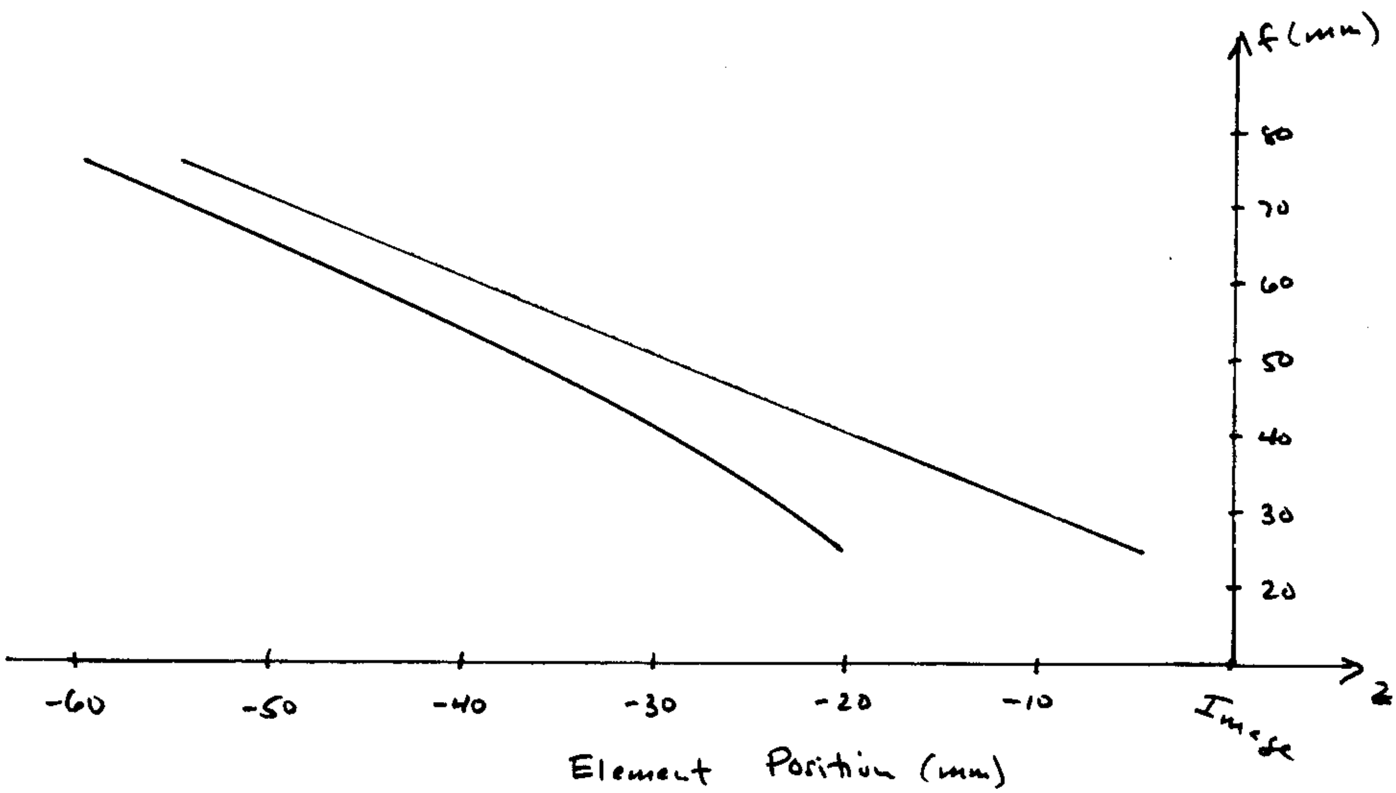
Tele $\rightarrow$ $t_1 = 5\ mm$

$f_T = 74.27\ mm$ $\qquad \phi_T = .0135/mm$

Wide $\rightarrow$ $t_2 = 5\ mm$

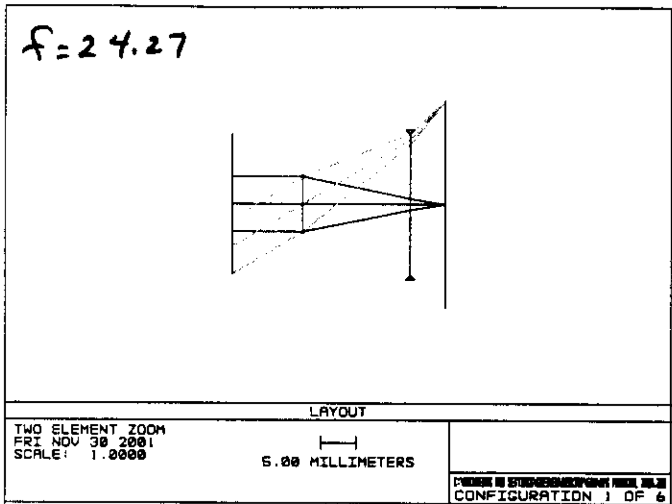
$f_W = 24.27\ mm$ $\qquad \phi_W = .0412/mm$

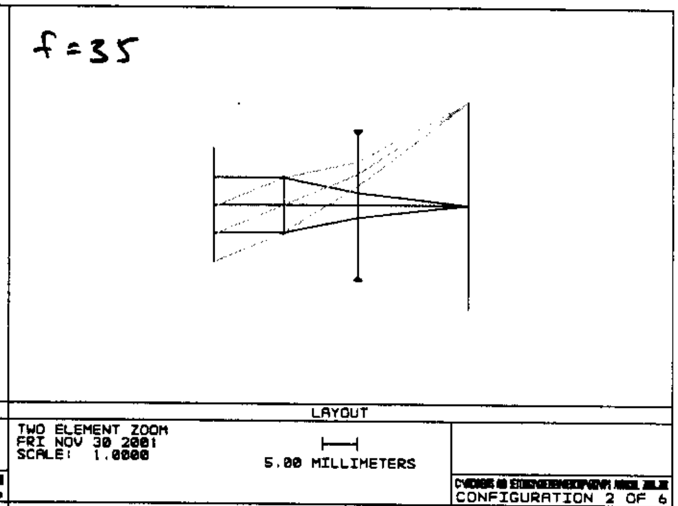
Zoom: 24.27 – 74.27 mm 3.1 X

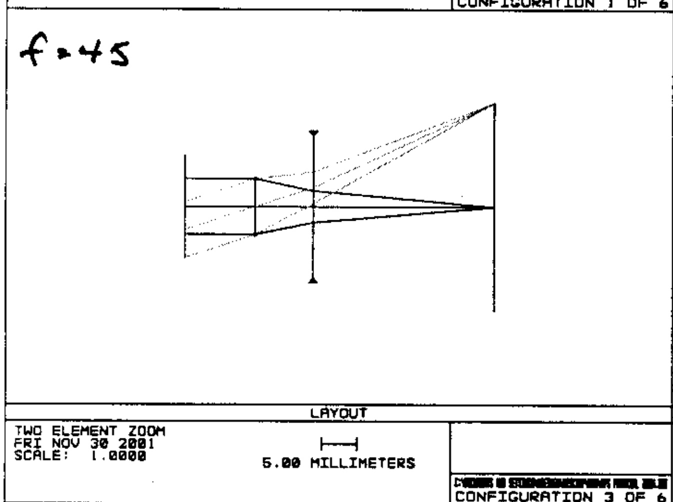


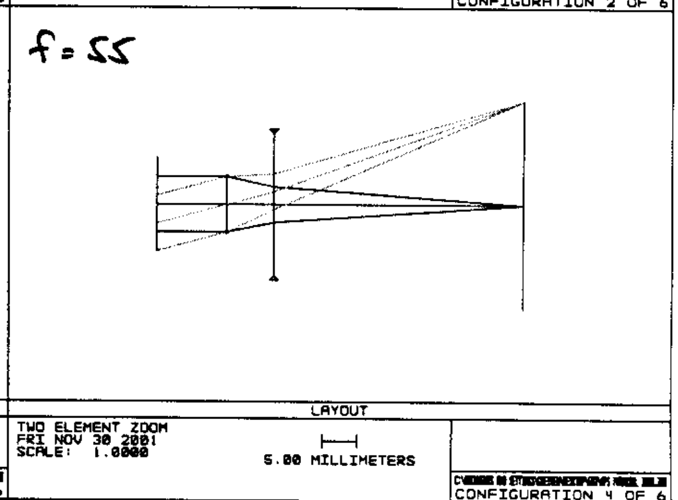
f	t_1	t_2	L
24.27 mm	15.30 mm	5.0 mm	20.30 mm
25	14.85	5.73	20.58
30	12.38	10.73	23.11
35	10.61	15.73	26.34
40	9.28	20.73	30.01
45	8.25	25.73	33.98
50	7.43	30.73	38.16
55	6.75	35.73	42.48
60	6.19	40.73	46.92
65	5.71	45.73	51.44
70	5.30	50.73	56.03
74.27	5.00	55.00	60.00

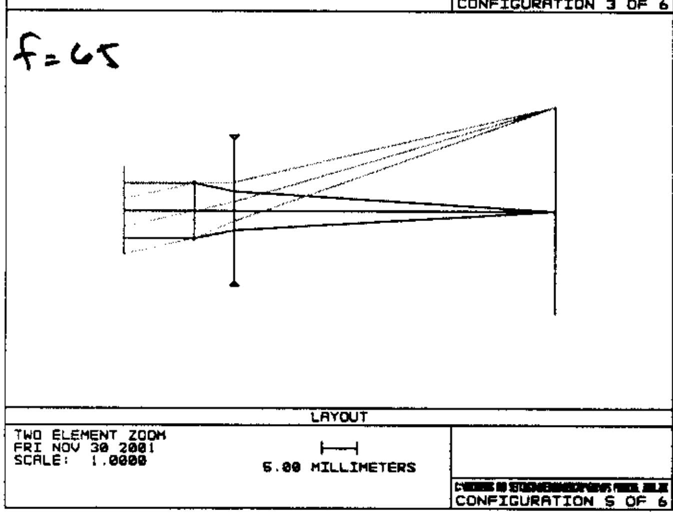
For demonstration, this system was entered into optical design software. The system layout at several zoom positions is shown on the next page.

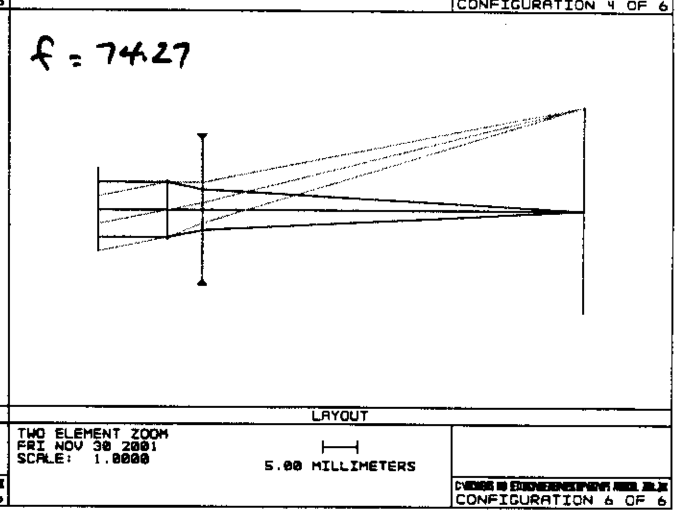

f=24.27
LAYOUT
TWO ELEMENT ZOOM
FRI NOV 30 2001
SCALE: 1.0000
5.00 MILLIMETERS
CONFIGURATION 1 OF 6


f=35
LAYOUT
TWO ELEMENT ZOOM
FRI NOV 30 2001
SCALE: 1.0000
5.00 MILLIMETERS
CONFIGURATION 2 OF 6


f=45
LAYOUT
TWO ELEMENT ZOOM
FRI NOV 30 2001
SCALE: 1.0000
5.00 MILLIMETERS
CONFIGURATION 3 OF 6


f=55
LAYOUT
TWO ELEMENT ZOOM
FRI NOV 30 2001
SCALE: 1.0000
5.00 MILLIMETERS
CONFIGURATION 4 OF 6


f=65
LAYOUT
TWO ELEMENT ZOOM
FRI NOV 30 2001
SCALE: 1.0000
5.00 MILLIMETERS
CONFIGURATION 5 OF 6


f = 74.27
LAYOUT
TWO ELEMENT ZOOM
FRI NOV 30 2001
SCALE: 1.0000
5.00 MILLIMETERS
CONFIGURATION 6 OF 6

Vignetting

Maximum image height $\bar{h}$ (based upon the semi-diagonal of the used area of the APS negative):

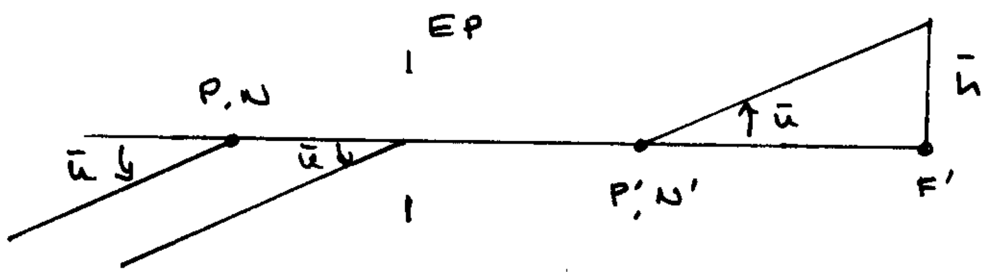
$$\bar{h} = 15.0 \text{ mm}$$

Stop at L1 EP Dia = 8 mm

Marginal Ray:

$$y_1 = 4$$
$$u_1 = -4\phi_1$$
$$y_2 = 4 - 4\phi_1 t_1$$

Chief Ray: Since the object is at infinity, the chief ray (through the center of the EP) is parallel to the ray through P (or N).



$$\bar{u} = \bar{h}/f = \bar{h}\phi$$

$\bar{y}_1 = 0$ $\quad$ $\bar{y}_2 = \bar{u} t_1 = \bar{h}\phi t_1$

Alternate Method: trace an arbitrary chief ray through the stop and scale it to the image height.

Required Element Diameters – Unvignetted:

$$a_1 \geq |y_1| + |\bar{y}_1| = 4$$

$$D1 \geq 8 \text{ mm}$$

$$a_2 \geq |y_2| + |\bar{y}_2|$$

$$a_2 \geq 4 - 4\phi_1 t_1 + \bar{h}\phi t_1$$

$$t_1 = \phi/\phi_1^2$$

$$a_2 \geq 4 - 4\phi/\phi_1 + \bar{h}\phi^2/\phi_1^2$$

$$\phi_1 = .05189/\text{mm}$$

$$a_2 \geq 4 - 77.08\phi + 5570\phi^2$$

- find the max over the zoom range. By inspection (or trial and error) the largest required a_2 occurs at ϕ_w or $f = 24.27$ mm

$$a_2 \geq 10.28 \text{ mm} \qquad D2 \geq 20.56 \text{ mm}$$

Summary:

$f_1 = 19.27$ mm $\quad D1 = 8.0$ mm

$f_2 = -19.27$ mm $\quad D2 = 20.56$ mm

$$t_1 = 371.3 \text{ mm}^2/f$$

$$t_2 = f - 19.27 \text{ mm}$$

Zoom Range: 24.27 – 74.27 mm $\qquad$ 3.1X

Zoom Viewfinder

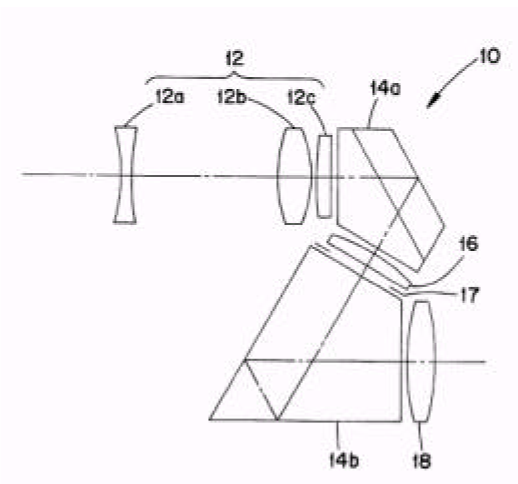
Galilean Design: To vary the MP of this telescope viewfinder, either the objective lens or the eye lens (or both) must be converted into a zoom lens. To do that, split the lens into two elements with varying spacing. To maintain the system as afocal, the spacing between the objective group and the eye group must also be varied. This zoom viewfinder will require a minimum of three elements. There is no internal image plane to place a framing mask, so vignetting is used to define the field of view.

One interesting feature of this system is that it must zoom through a MP of unity.

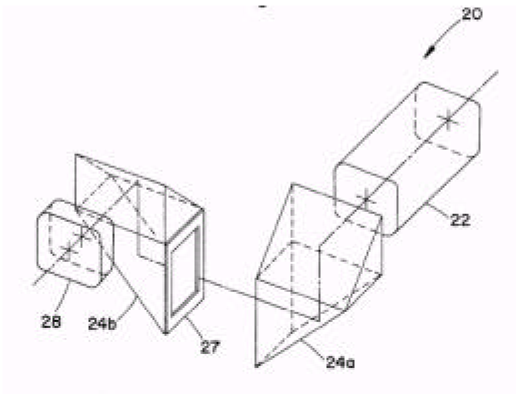
Real-Image Viewfinder: This viewfinder uses a zoom objective to create an internal image that can be used with a reticle. The eye lens magnifies this intermediate image. A series of mirrors or prisms is used to get the proper image parity or orientation. Four or six reflections are needed for an eye lens on the back of the camera.

A good conceptual starting point for this design is the optical system of a single-lens reflex camera. The literature shows a variety of different prism/mirror combinations, but most seem to be variations on a penta or reflex prism, a Porro or Porro-Abbe system, or a Pechan prism. The main issue is packaging all of the elements within the relatively thin camera body. Since the reflections bend the light path through the camera, some extra path is created for these elements.

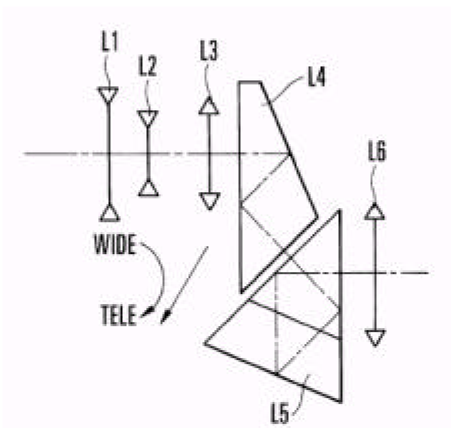
Some diagrams found in the literature:



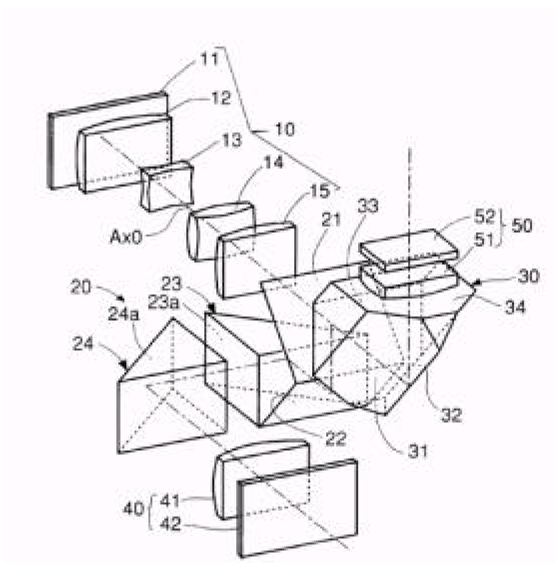
U.S. 6,266,490 Four reflection design. Prism 14a has a roof. The framing mask is #17.



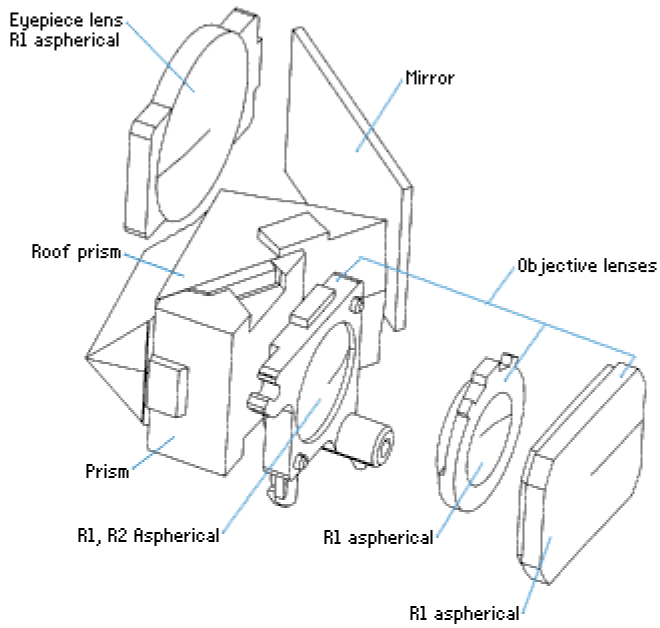
U.S. 6,266,490 Another four reflection scheme in the same patent. The zoom objective is #22, and #27 is the framing mask.



U.S. 6,141,159 A six reflection system with a roof on L5.

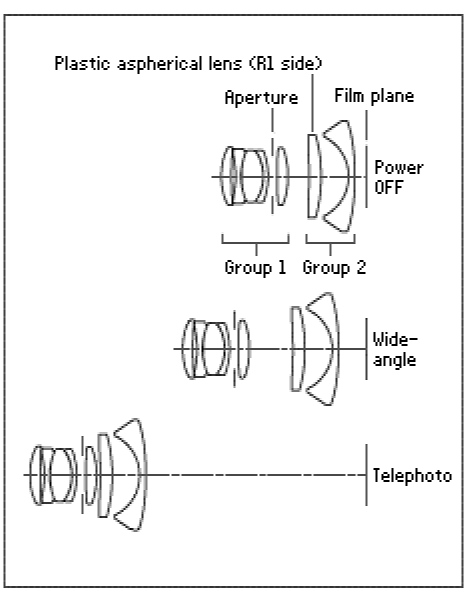


U.S. 6,018,417 A four reflection dual design that uses a beamsplitter so the image can be viewed either through the top of the camera or the back of the camera.



This figure is from a Canon technical report (IXY 230) that describes the zoom viewfinder in one of Canon's APS cameras. It includes the following text:

"In order to realize a sharp, clear viewfinder, the IXY 230 is equipped with a real-image zoom viewfinder that employs an air gap roof (focusing) prism developed for the IXY 220, and five aspherical lens surfaces. The air gap roof prism is a two-prism optical system with an air layer between the prism and the roof prism so that all the incident light to the first surface of the roof prism is transmitted while all the light reflected back to the first surface is reflected. The unique feature of this optical system is that the total reflection of the incident light is achieved without a vapor deposition surface. With this prism configuration, the number of reflections, one factor for image degradation, is decreased to four from six in conventional systems."



The report also has a diagram of the zoom camera lens. It is a two group telephoto zoom; the front group is positive and the rear group is negative. The two groups move to vary the focal length. The three configurations shown are storage, wide angle and telephoto.

Note the many similarities to the paraxial design of this problem.