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Aberration-corrected catadioptric magnifiers useful for simple microfiche readers

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Abstract. The present paper considers the magnifying power and aberration properties of three different catadioptric magnifying systems useful for application as simple hand-held microfiche readers. These are in the form of a plano-convex lens, a meniscus lens and an achromatic doublet lens and all their outer surfaces have been coated with a semi-reflecting film so that they behave like catadioptric elements. These can be designed to give magnification in the range of 15 × to 25 × with sufficient eye relief. Using such magnifiers, it is possible to read microfiche having frame sizes of 16 × 12 mm and 12 × 9 mm. The cemented achromatic doublet coated on the outer surfaces seems to give a very good image for use in microfiche reader.

Keywords. Microfiche reader; magnifier; catadioptric system; lens.

1. Introduction

Any hand-held instrument suitable for comfortable reading of microfiche having nominal frame size of 16 × 12 mm or 12 × 9 mm requires an optical system which is capable of producing visual magnification of 15 × to 20 × with sufficient eye relief. If the system is designed as an eyepiece with a very large magnification and to cover the field of view required and also with a reasonable eye relief, it becomes a very complicated lens system containing 6 or 7 individual lens elements. A complicated system for such purposes has been designed by Buzawa (1975) for a moderate magnification of 13 ×. In order to reduce the complexity of the system, several schemes were described by Weiss (1974), Murty *et al* (1980, 1983a, b). The basis of all these schemes is mainly to use the image formed by the reflection on a spherical surface. This enables one to use only very moderate curvatures for the surfaces and hence the aberrations tend to be very small. But to be able to use a reflecting surface on axis, we need to have some kind of beam-splitting arrangement. In the schemes by Weiss (1974) and by Murty *et al* (1980), this has been achieved by the use of cemented prisms with one of the faces made into a concave reflecting surface. In the schemes by Murty *et al* (1983a, b), on the other hand, this has been achieved by the use of semireflecting coatings on either side of a lens. It is much easier to mount the latter because it is rotationally symmetrical and also it is easy to provide for focussing. In this paper we compare the optical performance of three catadioptric magnifiers based on (i) a plano-convex lens, (ii) a meniscus lens and (iii) an achromatic doublet.

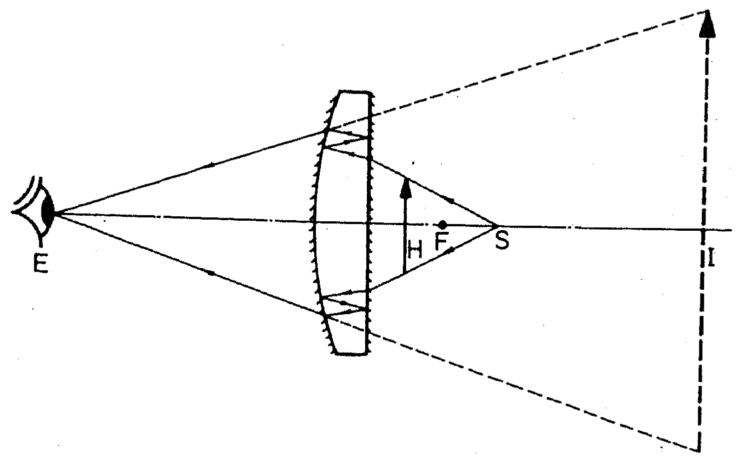


Figure 1. Schematic diagram showing the magnifying property of a plano-convex type of a catadioptric magnifier. The object transparency H is located inside the focus F and is illuminated by the source S. The eye is at E viewing the virtual image I.

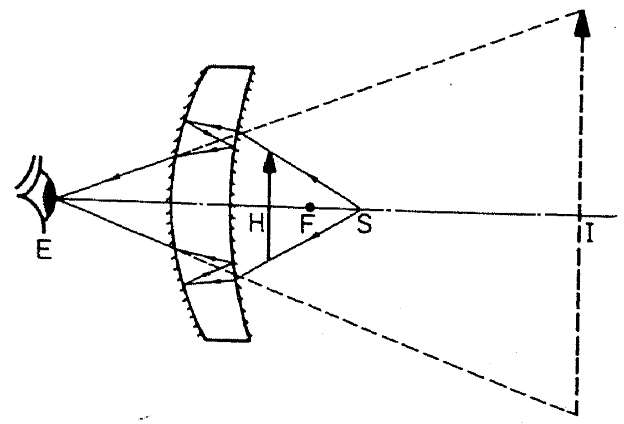


Figure 2. Schematic diagram showing the magnifying property of a meniscus type catadioptric magnifier. The notation is same as in figure 1.

2. Magnifying power

Figures 1 and 2 show the magnifying property of two simple catadioptric magnifiers which are in the form of a plano-convex lens and a meniscus lens respectively. The surfaces of the lenses are coated with partially reflecting layers. The object transparency H is situated inside the focal point F and is illuminated by a small source of light S. When the eye is located at the position E, one can see a magnified image I which is virtual. One may need to focus the image by slight movement of H with respect to F along the axis so that the virtual image is located at a distance of about 250 mm from the eye. One may note that the source of light is itself acting as the entrance pupil of the system and its image E is the exit pupil at which position the eye is to be placed to see the full field of view. As shown by Murty *et al* (1983b) the focal length of a thin lens used as a

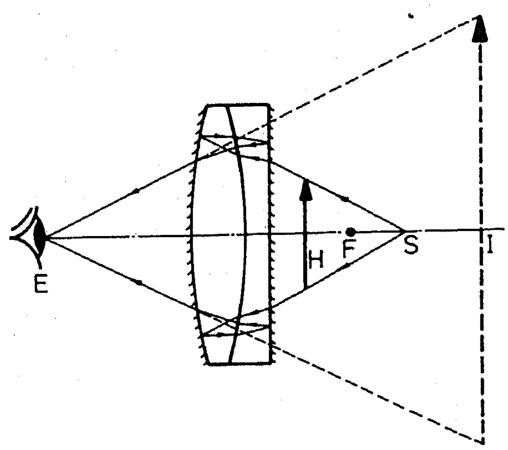


Figure 3. Schematic diagram showing the magnifying property of an achromatic doublet type of catadioptric magnifier. The notation is same as in figure 1.

catadioptric system by partially coating the two surfaces is given by

$$1/f_C = (3N-1)(C_1-C_2), \tag{1}$$

where C_1 and C_2 are the two curvatures of the surfaces, N is the refractive index of the material of the lens. The subscript c for f_C is used to denote that this focal length is for the catadioptric mode. If the lens is used directly then the focal length is given by the usual formula

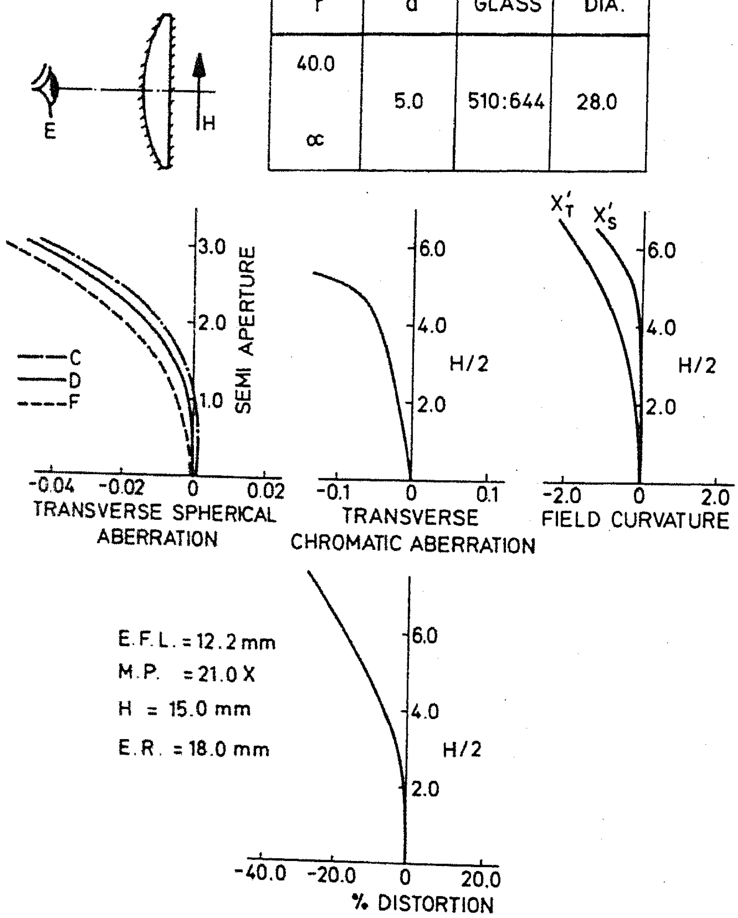
$$1/f_D = (N-1)(C_1-C_2) \tag{2}$$

where the subscript D for f_D is used to denote that this focal length is for the dioptric mode. Thus the catadioptric focal length is shorter by a factor of $(N-1)/(3N-1)$ compared to the dioptric focal length of the lens. Hence with very moderate curvatures, a very high magnifying power system is produced by the use of semireflecting coatings on the two surfaces of the lens. As an example, if a lens of focal length 100 mm is converted into a catadioptric lens, its focal length will be about 14 mm. Hence we get a magnifying power of about 19 × with such a lens.

Figure 3 shows the magnifying property of another conventional lens, namely an achromatic doublet, converted to the catadioptric mode by the same method of coating the outer surfaces with semireflecting layers. Unlike the previous situation, the focal length in the catadioptric mode is not easy to be expressed simply but can be computed by the use of paraxial ray tracing. However, the shortening of the focal length will be by the same order of magnitude. We shall now, in the following, analyse the three different types of the catadioptric magnifiers.

3. Aberration properties of the three magnifiers

The three catadioptric magnifiers illustrated in figures 1, 2 and 3 were designed for a magnifying power of about 20 × and the frame size of the microfiche transparency has been assumed to be 12 × 9 mm so that the diagonal of the field is about 15 mm. The magnifying power and eye relief of all the three systems were computed by the use of



r	d	GLASS	DIA.
40.0			
	5.0	510:644	28.0
∞			

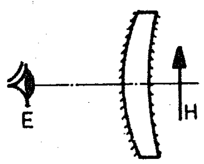
Figure 4. Diagram showing design data, magnifying power, equivalent focal length, eye relief, object size and aberration curves for the plano-convex type of catadioptric magnifier. All dimensions are in mm.

paraxial ray trace. The aberration properties have been computed by the use of finite ray trace.

Figure 4 shows the design data and aberration curves of the plano-convex type catadioptric magnifier. It may be seen that the eye relief is quite large. The field curvature and distortion are somewhat large at the full field. The plano-convex lens has less chromatic aberration than the equivalent lens used in the dioptric mode. But still the axial colour is not completely corrected and hence the lateral colour appears at the edge of the field to some extent.

Figure 5 shows the design data and the aberration curves for the meniscus type catadioptric magnifier. It may be seen that the distortion and the field curvature are improved to some extent while the colour remains about the same as before. This is because both systems use the same glass and the colour is basically independent of the shape of the single lens.

Figure 6 shows the design of the magnifier using an achromatic doublet converted into a catadioptric magnifier. The achromatic doublet is the type with the crown element being equi-convex and the flint element being plano-concave. In this case, one may note that the distortion and field curvatures are considerably improved and that



r	d	GLASS	DIA.
25.0			
	4.0	510:644	28.0
50.0			

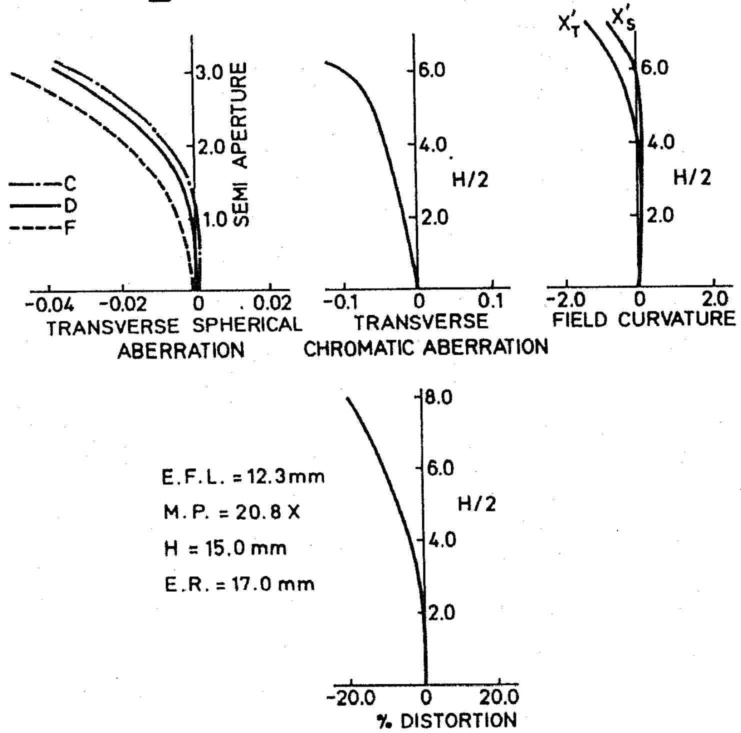
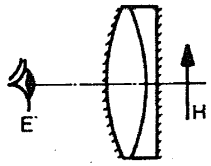


Figure 5. Same as in figure 4 except that these refer to the meniscus type catadioptric magnifier. Note the improvement of field curvature and to some extent distortion.



r	d	GLASS	DIA.
36.0			
	7.0	519:604	28.0
-36.0			
	3.0	620:362	28.0
∞			

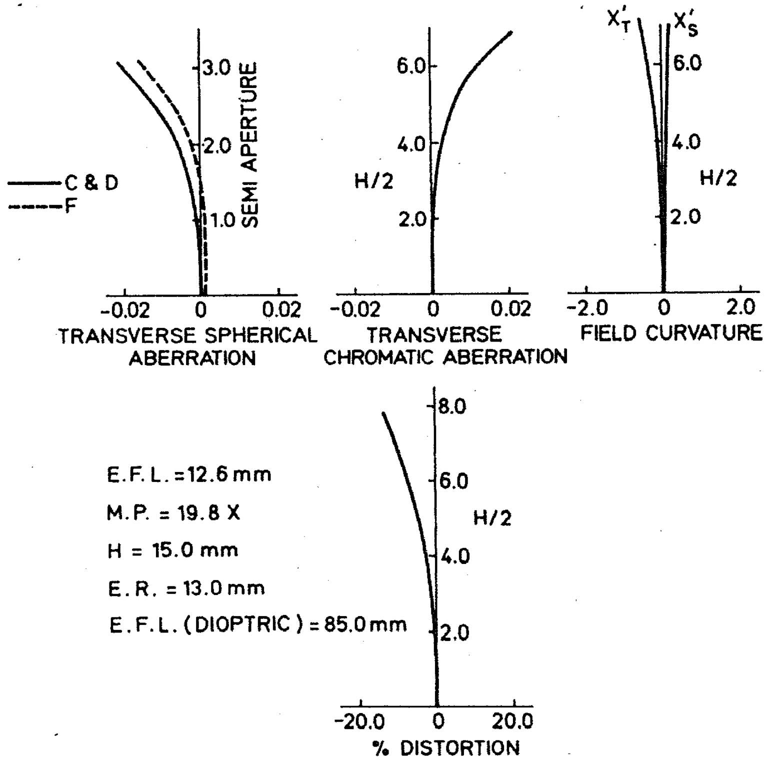
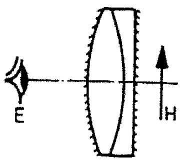


Figure 6. Same as in figure 4 except that these refer to the achromatic doublet type of catadioptric magnifier. Note the general improvement of the aberrations.



r	d	GLASS	DIA.
51.8			
	5.0	519:604	30.0
-51.8			
	2.5	620:362	30.0
∞			

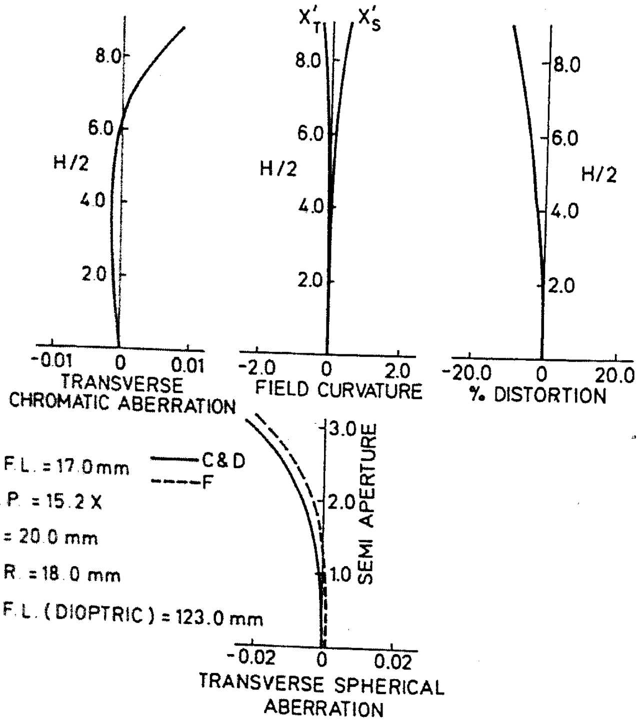


Figure 7. Same as in figure 6 except that the magnifying power is 15 ×.

the colour also has improved considerably. The reason for the choice of only one radius of curvature for the lens is to make it as simple and cheap to manufacture.

All the three catadioptric magnifiers whose design data and aberration curves are shown in figures 4, 5 and 6 are made of spherical surfaces of moderate curvature and their apertures are equal. Their eye reliefs are also reasonably large. Comparison of the aberration curves shows, however, that the system based on the achromatic doublet in figures 3 and 6 seems to be very good to be used as a magnifier for reading microfiche. When the microfiche frame is of size 16 × 12 mm, the magnification can be about 15 × and a design for this using the achromatic doublet is shown in figure 7.

4. Experimental observation

All the catadioptric magnifiers shown in figures 4–7 were fabricated and tried for viewing microfiche. For this purpose, a simple hand-held instrument has been

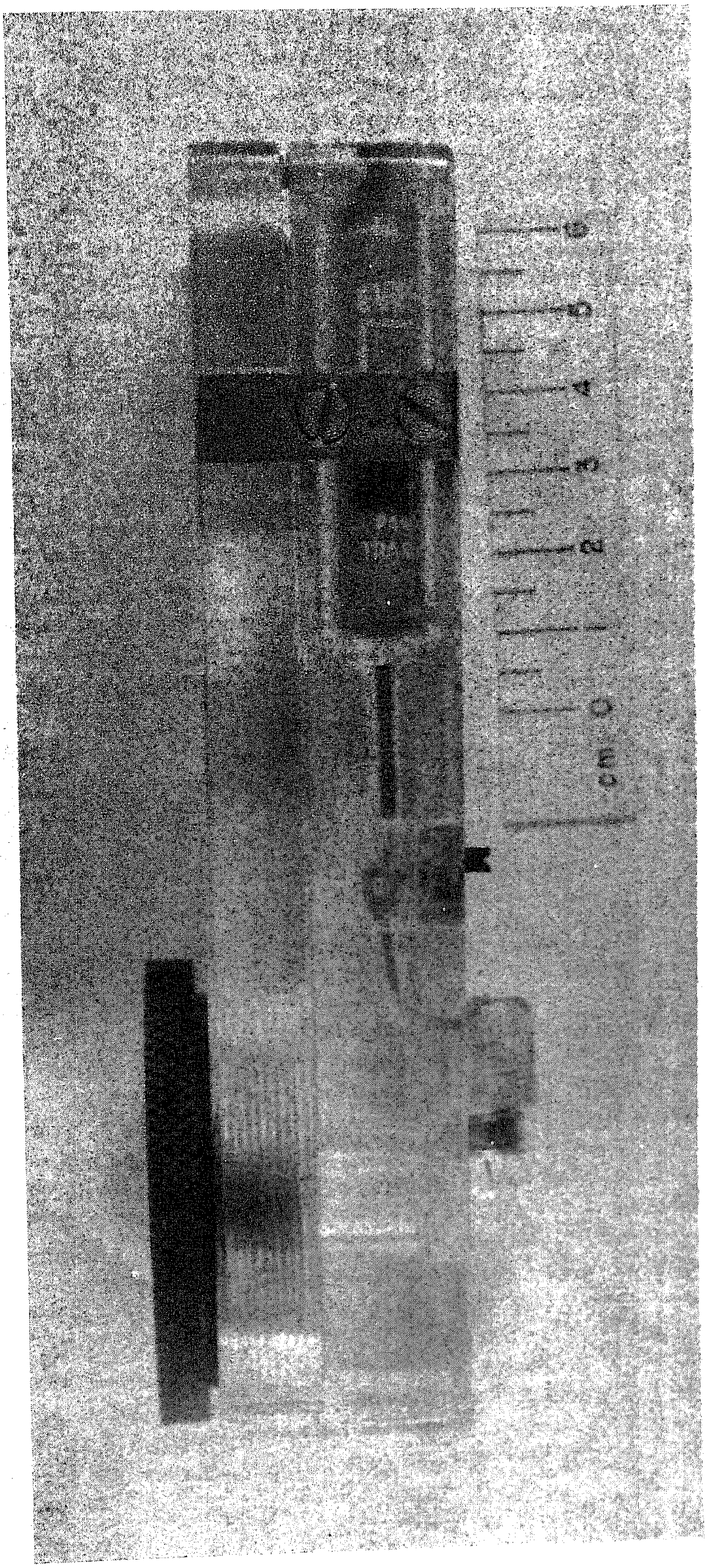


Figure 8. Photograph of the hand held microfiche reader.

fabricated with a provision to replace one lens by another. The light source is a small lamp with a small filament and a spherical glass envelop such as the one used in flash lights. It is operated by two small 1·5 V cells. The lamp and the cells along with a switch form an integral part of the microfiche reader. The reader is shown in the photograph of figure 8. The outer surfaces of the lenses were coated with about 50 % reflecting layers of aluminum even though chromium would have been better for the sake of durability and ruggedness. All the three systems give very sharp images in the central part of the field. The single element systems of figures 1 and 2 show some colour at the edges of the field but it does not detract from reading the material comfortably. Similarly, the plano-convex system shows field curvature and distortion but it is not a detriment for reading purposes. The meniscus system has much less field curvature and distortion but the outer field is slightly coloured. The image with the achromatic doublet system is very good from all points of view and hence can be recommended where the extra cost is immaterial. In fact, one can build one's own microfiche reader with a lens purchased from any of the optical houses selling standard optical components and then getting it coated suitably. In fact, we have purchased commercial achromatic doublets with focal lengths in the range of 75 to 125 mm and coated them to convert them into the catadioptric type magnifiers. They work quite nicely for the purpose.

This type of magnifier is also quite suitable for viewing enlarged images of 35 mm slides. The full field can be viewed at once at magnifying power of about 7 ×. Such a system may be easily constructed by the use of an achromatic doublet of 50 mm dia and 250 mm focal length. After the coating of the lens, it will act like a lens having a focal length of about one-seventh of its value.

References

Buzawa M J 1975 *Proc. Int. Lens Design Conference*, Haverford College, Haverford, Pensylvania
Murty M V R K, Das N C and Shukla R P 1980 *Opt. Eng.* **19** 915
Murty M V R K, Das N C and Shukla R P 1983a *Opt. Eng.* **22** 149
Murty M V R K, Das N C and Shukla R P 1983b *Opt. Eng.* **22** 373
Weiss H 1974 *Opt. Eng.* **13** 550