An Ultra Short-Focus Front Projector Using Reflective Projection Optics

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Abstract

As a result of improvements in the brightness and resolution of the front projectors used for the magnified display of information, the market for these compact and easily installable presentation tools has continued to show significant growth. In order to improve their performances even further, NEC Viewtechnology has developed a front-projection system that uses reflective lenses only to replace refractive lenses for the projection optics. The system configuration features four aspheric mirrors and achieves an ultra short focusing distance that enables projection onto a large 100-inch screen at a projection distance of only 0.65 meter.

Keywords

projector, ultra short focus, aspheric mirror lens, reflective optics

1. Introduction

The use of projectors in business environments has recently become a routine matter thanks to the possibility of presenting material that can be prepared neatly by using PCs. Moreover, projectors designed for household applications are achieving widespread acceptance for use in home theaters, etc.

In this paper as an example of an innovative technology that is currently attracting attention, we introduce the “WT610” projector, which adopts aspheric mirrors and an ultra short-focus projection system. This projector has been developed by NEC Viewtechnology as a world leading device[1, 2] (see **Photo**).

2. The Need for a Mirror-Based Reflective Projection System

The technical progress related to projectors is remarkable and the reduction of the projection distance is one of the key incentives of this trend.

Fig. 1 shows some of the advantages brought about by this reduction.

From the viewpoint of projector devices, the main development issue for minimizing the projection distance is to develop an ultra short-focus projection lens. However, reductions in the projection distance have not been achieved over the last few years. Usually, the projection lens is composed of about 10 single lens components in convex and concave shapes that are obtained by polishing the glass lenses. Aiming at achieving the required performance, the lens is composed of multiple components in order to control the projection distance and aberra-

Photo Ultra short-focus mirror projector “WT610.”

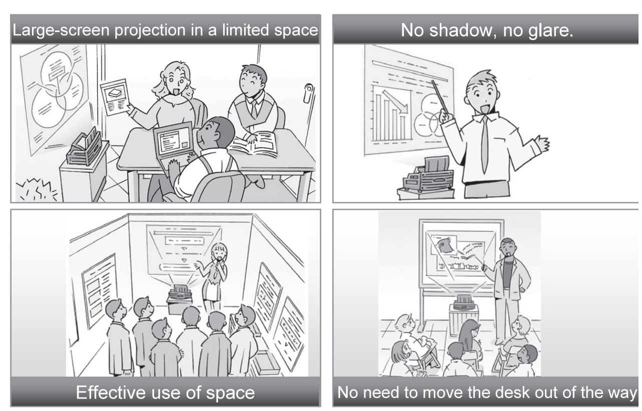


Fig. 1 The need for a reduction in the projection distance.

tion values, etc. at the specified levels. However, these performance standards are achieved only as a result of tradeoffs that affect the quality of other functions. Reducing the projection distance significantly causes degradation of the definition and compatibility has been very hard to achieve. An optical system combining reflective mirrors with refractive lenses[3)] was recently proposed as a solution to this problem. However, a completely reflective system that does not use refractive lens components at all is considered to be an ideal solution for obtaining a dramatic reduction in the projection distance and the correction of aberrations that may be caused by the reduction.

3. Basic Principles of the Reflective Projection System

Reflective lenses use mirrors (hereinafter referred to as mirror lenses) and are popularly used in the optics of telescopes including astronomical ones[4-6)]. The mirror lens features an absence of color aberration because it is free from the waveform dependency of refractivity that becomes basically important with refractive glass lenses. However, even when a reflective system is used, aberrations due to the mirror surface shape and other factors are produced, even when there is no aberration due to scattering by the glass used in the refractive lenses. It is therefore required that the mirror lens is designed to minimize such aberrations to levels that are acceptable for actual use.

In **Fig. 2**, (a), (b) and (c) show the mirror configuration Mn, focal distance fn (curvature radius rn), synthesized focal distance (Fn) and Petzval's sum for each mirror (pn) when the number of mirrors is 2, 3 and 4 respectively. Basically, the Petzval's sum indicates the total astigmatism values of the SM

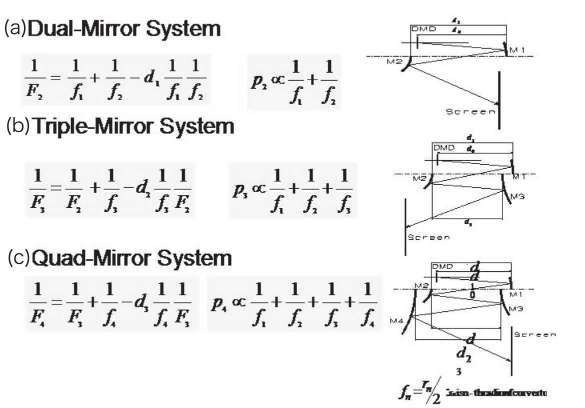


Fig. 2 Examples of mirror configurations and their focal distances and aberrations.

(Sagittal and Meridional) planes, and the importance of minimizing these values is a well known consideration in lens design[7)].

Our aim was to design an ultra short-focus mirror lens by respectively minimizing the Petzval's sum and reducing the number of mirrors to practical levels. In fact, to design it by considering the drop in contrast due to the scattering on the mirror surfaces and the drop in brightness due to reflectivity (R = R1 × R2 × ....). In order to achieve this aim we introduced an aspheric mirror surface shape because it is difficult to design the mirror surfaces spherically. The optimum asphericity of this design can generally be obtained by applying the following formula.

$$Z = \frac{ch^2}{1+\sqrt{1-(1+k)c^2h^2}} + \sum_{i=1}^{n} \alpha_i h^{2i}$$

where

$c = 1/r$ (r: the Radius of curvature)

$h^2 = x^2 + y^2$ (x,y,z: Coordinates with respect to the mirror's vertex)

Based on the above design principles, we optimized the intervals between mirrors, their number, their sizes and asphericity constants α by correcting aberrations so that the mirror lens could meet the required specifications and also by considering the possibility of mass-production.

4. Optical Designs and the Configuration of the Actual Products

Fig. 3 shows the model diagram of the optical configuration of the "WT610." Its display device is a single-plate DMD™, which is illuminated via a color wheel, on which RGB 3-color filters are placed by dividing the wheel surface angles, a rod integrator for use in making the illumination uniform, and an optical relay system. Only the image light that is reflected when each element of the DMD™ is ON, is incident to each mirror. The imaging system is composed of four aspheric mirrors. The mirror shape is concave with M1, convex with M2, concave with M3 and convex with M4.

Table shows the design values including the curvature radius r and asphericity constant α of the aspheric surface of each of mirrors M1, M2, M3 and M4. With this example, calculations are performed until the 16th-order aspheric term (even-number terms only). To improve the contrast performance, an iris diaphragm is inserted between M1 and M2 to screen the unnecessary light scattered from the M1 surface and the unnecessary

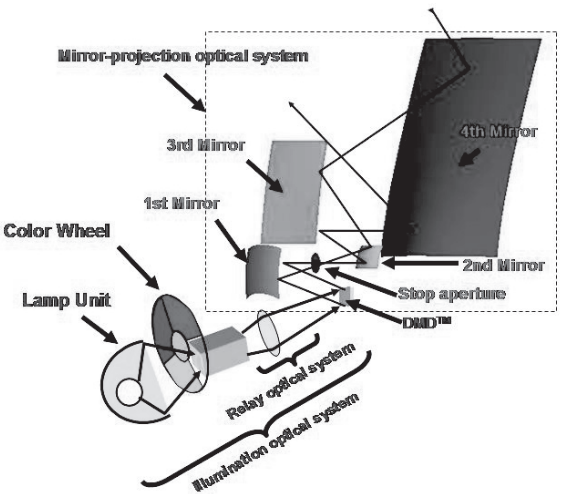


Fig. 3 Diagram of optical configuration model.

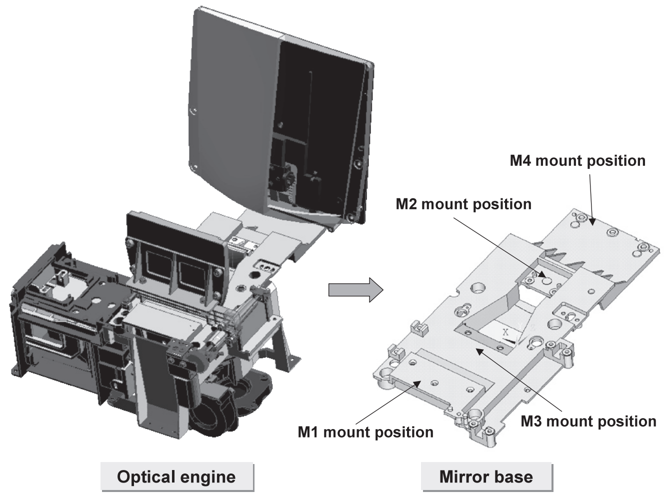


Fig. 4 Example of the optical engine configuration and base plate.

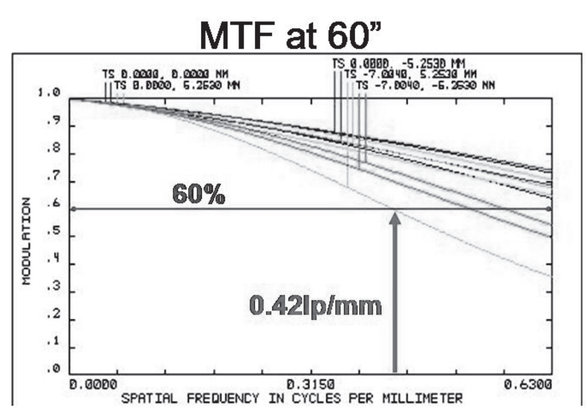
	M1	M2	M3	M4
r	134.97422	112.7408	-3435.339	132.2968
k	-5.263296	-83.78333	0.0	-7.00602
a1	0.0	0.0	0.0	0.0
a2	5.292E-07	7.072E-06	-5.672E-08	-1.775E-08
a3	-7.085E-11	-1.023E-08	2.067E-11	6.856E-13
a4	8.673E-15	1.640E-11	-2.409E-15	-1.720E-17
a5	-5.678E-19	-1.435E-14	1.503E-19	2.908E-22
a6	1.767E-23	6.015E-18	-4.780E-24	-3.014E-27
a7	—	—	5.713E-29	1.481E-32
a8	—	—	—	-7.663E-39

Table Design examples for mirror asphericity constant (α).

light derived from the off light that is reflected by other parts when the DMD™ is off. The diameter of this iris diaphragm is naturally determined by the F-number of the illumination or imaging system. This mirror lens moves M3 for the adjustment of focus in the optical axis direction. Therefore, M3 is designed to be nearly flat, with a curvature radius of 3,000m or more as shown in Table, in order to avoid the effects of movement during the various performances.

Fig. 4 shows the configuration of the optical engine of the "WT610." The mirror materials have been selected using a glass material for M1 and M2 and a plastic material for M3 and M4. Consideration has been given to compliance with the design specifications, effects of environmental temperature variations and support for the possibility of mass-production. The plastic material used is a low water-absorbing amorphous olefin resin material that can prevent warping or deformation under high temperatures. While the optical axis of the mirrors should be aligned, this mirror lens does not use refractive lenses that usually use lens barrels, so ensuring that the required 3D accuracy is achieved. In addition, it is also necessary to control the environmental temperature changes within the specified ranges. To meet both of these requirements, we adopted a configuration in which four mirrors are mounted on a single base plate, which is made of a BMC resin material featuring a low linear coefficient of expansion.

In addition, the actual product also incorporates a function for adjusting the interval between M1 and M2 because this exerts an important effect on the overall imaging performance and a function for flange-back adjustment of the DMD™. **Fig. 5** shows the MTF that represents the overall imaging perfor-



Each line of graph shows MTF curves at 5 grid points in right half image area. Calculation wavelengths are 650, 546 and 460nm.

Fig. 5 Optical simulation example of the MTF design.

mance (simulated values). This design makes it possible to maintain the resolution above the practical level of 60% when the pixel pitch of the DMD™ is 0.42lp/mm.

5. Projection Performance

Fig. 6 shows a comparison of the color aberrations at the product level of the same optical engine when either a traditional refractive lens or a mirror lens is incorporated. Since the optical engine adopts the DMD™ single-plate system and is not subject to the effects of deviations between devices of the different colors that occur with a 3-plate system as described above, its color aberrations are basically determined exclusively by the lens components. The aberrations are at the practical level even when the refractive lens is used as shown in (a) of this figure, but they are even better and the resolution is improved further when the mirror lens is used. The distortion of the projected image is also at the practical level, at less than 1.2 TV% even when errors and variances during fabrication are included. The brightness is also as high as 2,000lm.

6. Actual Usage Scenario and the Future Outlook

Fig. 7 shows examples of actual installations. Example 1 is in a small meeting room and takes advantage of the “anywhere” installation possibility and demonstrates the lack of shadows. The figure also shows the “WT615,” which is a new product that incorporates an electronic pen interface to offer both large-screen projection and an electronic blackboard function simultaneously.

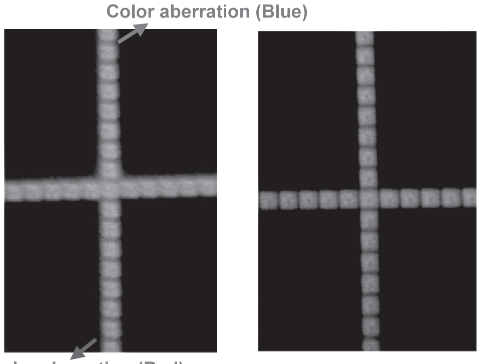


Fig. 6 Examples of the color aberrations of a refractive lens and a reflective lens.

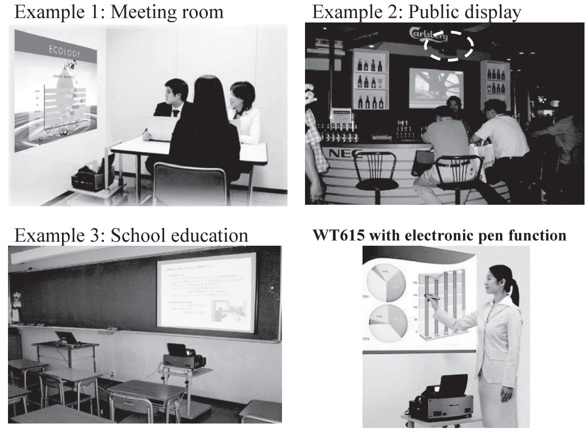


Fig. 7 Installation examples.

In the future, we will expand the mirror projector market and reduce the product price further as a result of improvements in the mirror design and processing technology.

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* DMD is a registered trademark of Texas Instruments, Inc.

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