46.2: Optical System of Ultra-Thin Rear Projector Equipped with Refractive-Reflective Projection Optics

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Abstract

An ultra-thin DLP™* rear projector composed of a refractive-reflective projection optics and an off-axis hybrid screen has been designed. The projection optics has extraordinarily large projection angle of 136 degrees with very low distortion, which is also applicable for a video-wall monitor as well as a stand-alone display. Results of prototype projection systems using the technology will be presented.

1. Introduction

Rear projectors are a popular method of displaying large images under bright ambient light conditions. Also, compact projector cabinets are strongly desired, and efforts to reduce cabinet size have been reported [1, 2, 3, 4, 5]. Most of the previous works employ refractive projection optics and their projection field angle as well as their layout of the optical components had been designed to realize a thin and/or short pedestal cabinet. However, refractive lens design becomes increasingly difficult in controlling distortion, lateral color aberration and astigmatism under wide field angle and compact size of the lens constraints. Recently, Kanayama et al. [4] proposed a projection optical system, which is composed of a refractive lens and an aspherical mirror; however, their projection optics specification and layout is not sufficient to reduce the cabinet depth and height simultaneously. To solve this problem, we have designed extremely wide-angle projection optics and a novel bending optical layout of an optical engine. Also, an innovative screen system, which makes excellent images from the projected light of large incident angle, has been developed.

2. The new optical system

2.1 Layout of the projector

Figure 1 shows a schematic diagram of the new optical system. A bent mirror facing an aspherical mirror bends light emitted from a refractive lens horizontally. This horizontal layout of the refractive lens and a DMD™ including other illumination optics makes the height of the cabinet very small. The convex aspherical mirror expands the projection angle of the reflected light and directs the light upwardly to a plane mirror located at the back of the cabinet. In order to make the cabinet thin, the plane mirror is positioned parallel to the screen.

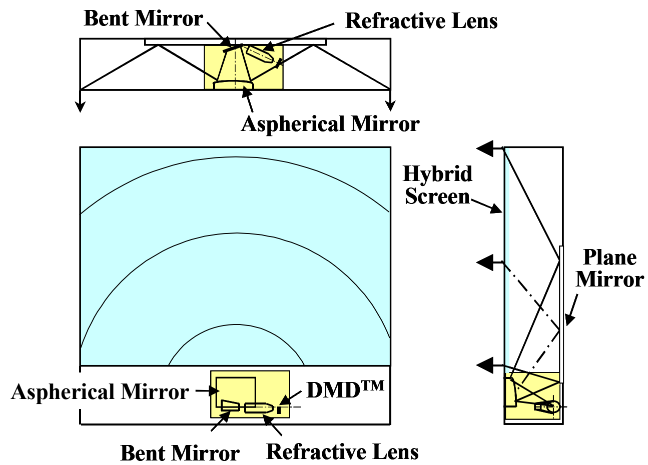

Figure 1 Optical layout of the projector

2.2 Projection optics

A non-telecentric projection optics which can project the DMD image located vertically off-axis field area is designed. A convex aspherical mirror, which is located after the refractive lens, expands the projection angle. This refractive-reflective optical layout is very useful for realizing an extraordinarily large projection angle of 136 degrees with small distortion. Figure 2

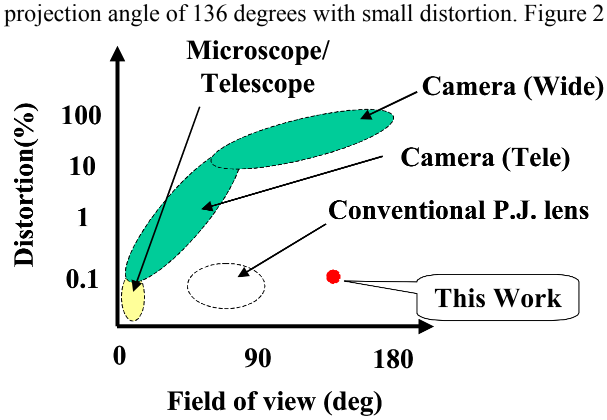

Figure 2. Novel projection optics: positioning

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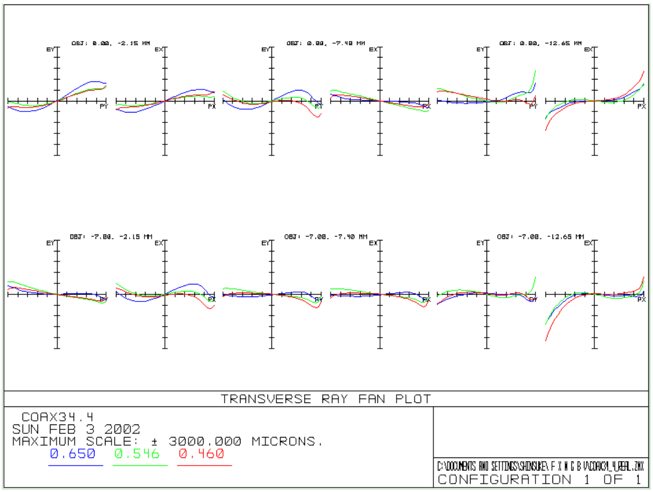

Figure 3. Transverse ray aberrations on the screen side. Each EX/EY graph shows aberrations at 6 grid points in the right half image area of 60-in. diagonal. Calculation wavelengths are 650, 546 and 460nm. Nearly negligible lateral color aberrations as compared to a pixel pitch of 1.2mm are seen.

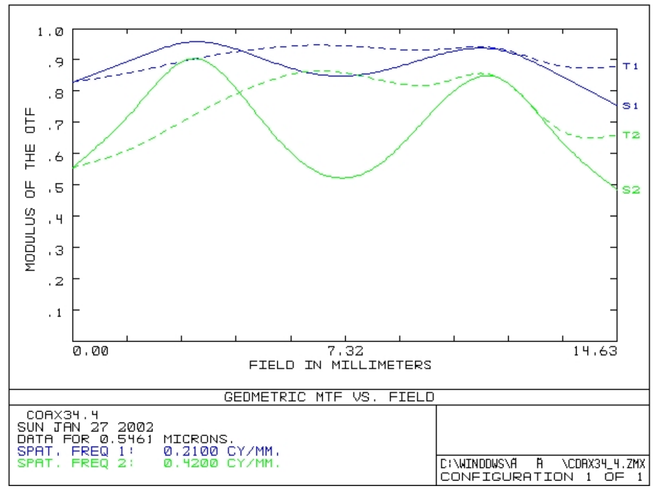

Figure 4. MTF vs. field characteristics on the screen side. Calculation is done at spatial frequencies of 0.21 and 0.42 mm^{-1}, wavelength of 546.1nm. Note that field between 0mm and 2.1mm is not used. Due to the small color aberration as shown in Fig. 3, little degradation occurs even if multiple wavelength MTF is considered.

shows positioning of this optics in a map of field angle vs. distortion. It shows that the new optics has opened a new design area, which attains low distortion and ultra wide-angle simultaneously.

Figure 3 shows transverse ray aberrations of the three primary colors calculated on screen side. As the aspherical mirror has a strong negative power, lateral color aberrations are kept small within the projection angles. Figure 4 shows an MTF vs. field characteristics of green wavelength. The spatial frequency of 0.42 mm^{-1} on screen side corresponds to a length twice the pixel pitch of 1.2 mm. This graph shows the optics can provide an excellent resolution suitable for digital based contents display.

2.3 Optical engine

Figure 5 shows the outline layout of the optical engine. A single DMD is illuminated by a mixing rod and relay lens optics [6]. A rotating color wheel composed of angular segmented dichroic filters generates three primary color beams of red, green and blue. The DMD is shifted downwardly more than half height of its image area in order to emit the projected light upwardly from the projection optics.

Light flux generated by an ultra high-pressure mercury lamp is collected by a parabolic reflector and focused by a condenser lens unit to an incident end face of the mixing rod. The luminous intensity angular distribution of the illumination beam focused by the condenser lens is unaffected by the mixing rod. Therefore, the well-known “dark central cone” distribution of the illumination beam due to a shadowing effect by a lamp electrode sleeve creates an apodization effect on the entrance pupil of the projection lens. This apodization can be useful for improving the resolution of the projected image.

Table 1 shows the characteristics of the DLP optical engine. The extraordinary large projection angle makes the short projection distance of 410mm for making an image of 60-in.

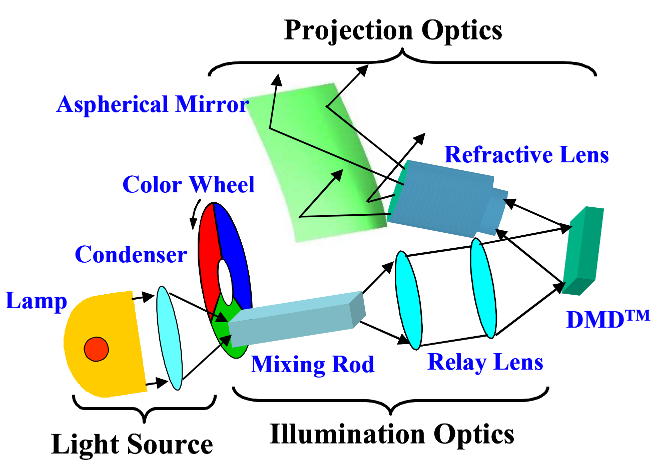

Figure 5. Outline layout of the optical engine

Table 1. Characteristics of the optical engine

Projection optics	**Refractive-Reflective hybrid system**
Projection angle	**136 degrees**
Projection distance	**410mm from the aspherical mirror**
Entrance pupil	**Non-telecentric**
Illumination optics	**Mixing rod/ Relay optics Non-telecentric**
Optical output	**500 ANSI lumen @ 120W lamp**
Contrast ratio	**2000:1 (on/off)**

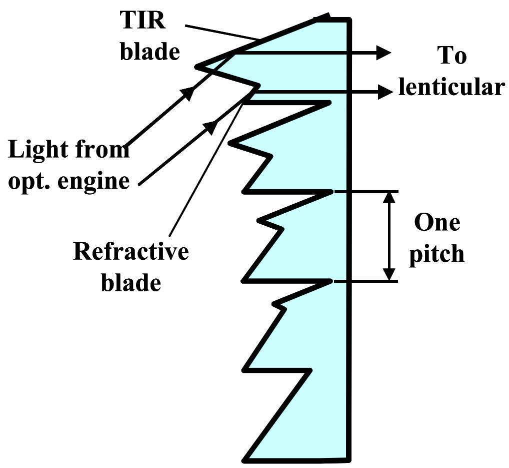

Figure 6. Cross sectional view of the hybrid Fresnel lens. Width ratio of the refraction and TIR blade in a pitch is changed gradually as the incidence angle increases.

Table 2. Outline specifications of the prototype single rear projection display

Screen	**60-in. (4:3) Hybrid Fresnel lens & Lenticular**
DMD™	**0.69-in. diagonal, single chip, Tilt angles of +/- 12 deg.**
Pixel number	**1024 x 768 (XGA)**
Lamp	**Ultra high-pressure mercury 120W**
Cabinet size	**1201(W) x 1243(H) x 260(D) mm^3**

diagonal. Matching of the light beam between the illumination optics and the projection optics on the small entrance pupil of the projection optics produces the high light output of 500 ANSI lumens and excellent contrast ratio of 2000:1.

3. Hybrid screen

A vertical cross section of the hybrid Fresnel lens screen is shown in Figure. 6. It is composed of a refractive blade and a total internal reflection (TIR) blade in one pitch and deflects the projected light to the screen normal direction. The width ratio of refractive and TIR blade is modulated gradually according to the radius of the blade circle in the screen plane shown in Figure. 1. This modulation is useful for avoiding visible boundary lines between two types of blades and provides an even transmission distribution throughout the image area.

A lenticular lens, which is not drawn in Figure 1, located in front of the hybrid Fresnel screen creates an image with wide viewing angles.

4. Specifications of the rear projector

Table 2 shows outline specifications of a prototype single projection display. The novel optical layout of the ultra-wide angle projection optics discussed above makes a 60-in (1524mm) diagonal XGA display with a depth of 260mm and height of 1243 mm. Also, the width of the screen border of the top, left and right sides can be designed very thin for video wall applications. Photo. 1 shows the appearance of the single experimental rear projection display with a real image from a PC source of XGA resolution.

5. Conclusions

Due to the new optical system, cabinet size can be thinner and lower than any proposed ones. The 260mm depth at 60-in. diagonal screen makes this display just like a "Projection Panel", which is adequate for digital signage applications. In the large screen FPD market, PDPs are currently the most popular. But the DLP projector has superior characteristics of "no burn in", which is a serious issue of PDPs when used as public information displays. In addition to the "no burn in" characteristics, this DLP

Photo 1. External appearance and displayed image of the prototype rear projector

projector has features of small distortion, high resolution, small lateral color aberration and small borders around the screen. Therefore the new optical system, which compensates for the PDP disadvantages, is suitable for high information content video-wall applications as well as a stand-alone monitor.

6. Acknowledgements

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