Light guide based optical engine for light-valve-projection

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Abstract
We have studied several light guide concepts for light-valve projection engines. The aim of the light guide is to replace the array of lenses and mirrors in conventional transmission-type projection engines. Volume, cost and weight can be reduced, at a similar or better performance level. Results of a first prototype are discussed.

1. Introduction
A large part of current state-of-the-art projection devices is of the transmissive LCD type. The optical engine in such projectors usually consists of three LCD panels, one for each of the three primary colors, and an array of lenses and mirrors to split up and recombine these colors. Furthermore some components are required to obtain a homogeneous light distribution on the screen.

Some drawbacks of these types of projectors are the volume and cost associated with all the different components. We investigated the concept of light guides for optical engines, in order to improve the cost, volume and weight of transmissive type projectors. See figure 1 for a layout of such a projector.

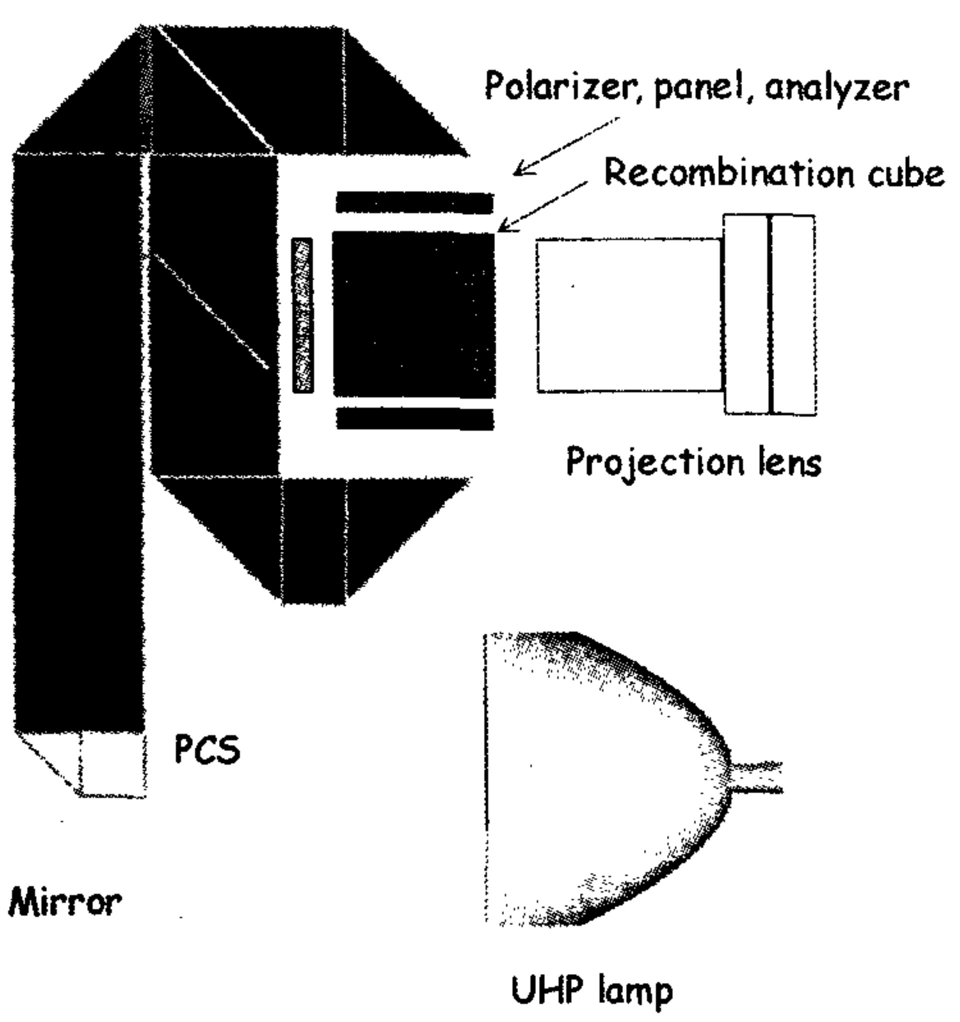

Figure 1 Layout of a light guide architecture

2. Description of layout
Figure 1 shows all relevant components of the setup. Compared to standard transmissive type projectors, some parts remain unchanged. This holds for instance for the dichroic recombination-cube, the LCD-panels, the polarizer/analyzer, and the projection lens. The light source used in our setup is a conventional 150 W UHP lamp with a F/2.1 elliptical reflector. All others components are replaced however by one single light guide – the 'heart' of this design.

This light guide is a glass rod, with a cross-section approximately the same size as the LCD panels. Light coupled into this guide at the front end will remain inside, due to total internal reflection (TIR). In this way the light guide serves several different purposes. Primarily it guides the light from the source towards the three different LCD panels. Two dichroic filters, placed inside the light guide, will split the white light from the UHP lamp into three primary colors.

Another purpose of the light guide is to provide a uniform illumination of the LCD panels. In standard transmissive type projectors, usually a relatively expensive fly-eye lens is used to obtain this uniform illumination. In our light guide, the principle of total internal reflection will ensure the mixing of light originating from all angles and positions within the source, thus providing a uniform illumination. The degree of non-uniformity is determined by several factors, in particular the length of the light guide. This is discussed in more detail in the next section.

Several components limit the amount of light that reaches the screen. As a high light output is of crucial importance, measures have to be taken to reduce these light losses. These limiting factors, and the measures taken to resolve them, will also be discussed in the next section.

3. Experimental setup and issues
When actually building the design as sketched in figure 1, several issues must be resolved. The most

important one is the potential loss of light in different components. To discuss this, we take a closer look at a number of components in the light guide set-up.

3.1. Coupling light into the light guide

As current LCD panels are in the order of 0.55" diagonal size, the light guide itself is also limited in size. Consequently, the entrance is also small, which limits the amount of light that can be 'squeezed ' into the light guide. Depending on the exact lamp configuration, about 30% of the light is lost here. UHP lamps with a small arc gap result in a better performance.

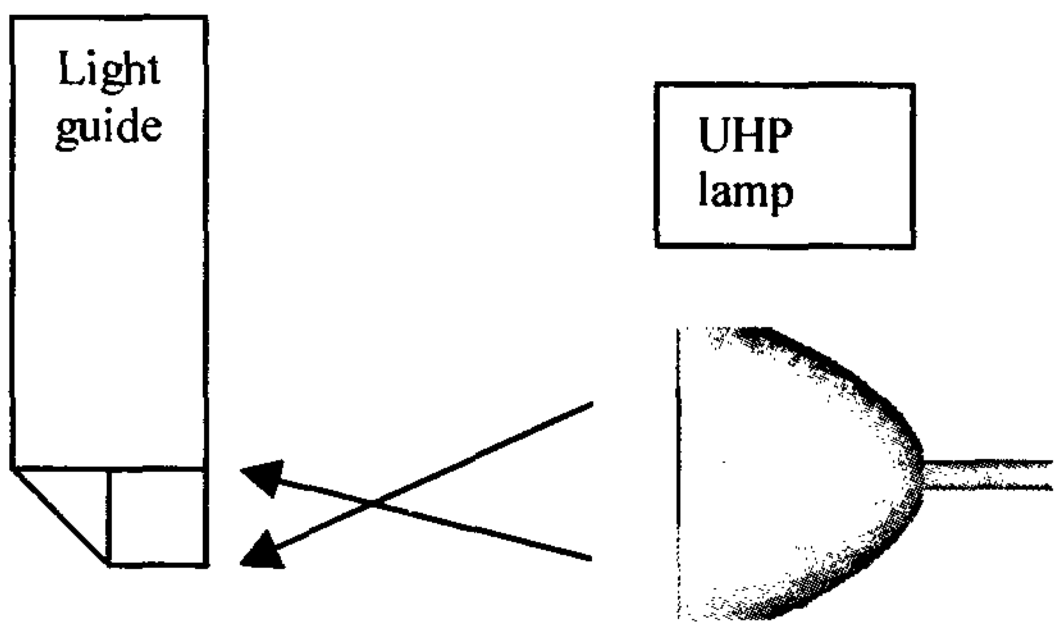

Figure 2. Coupling of light from the UHP lamp into the light guide.

3.2. Coupling the light into the LCD panel.

There are no optical components to image the exit of the light guide onto the LCD panels. Instead, proximity illumination is used. See figure 3.

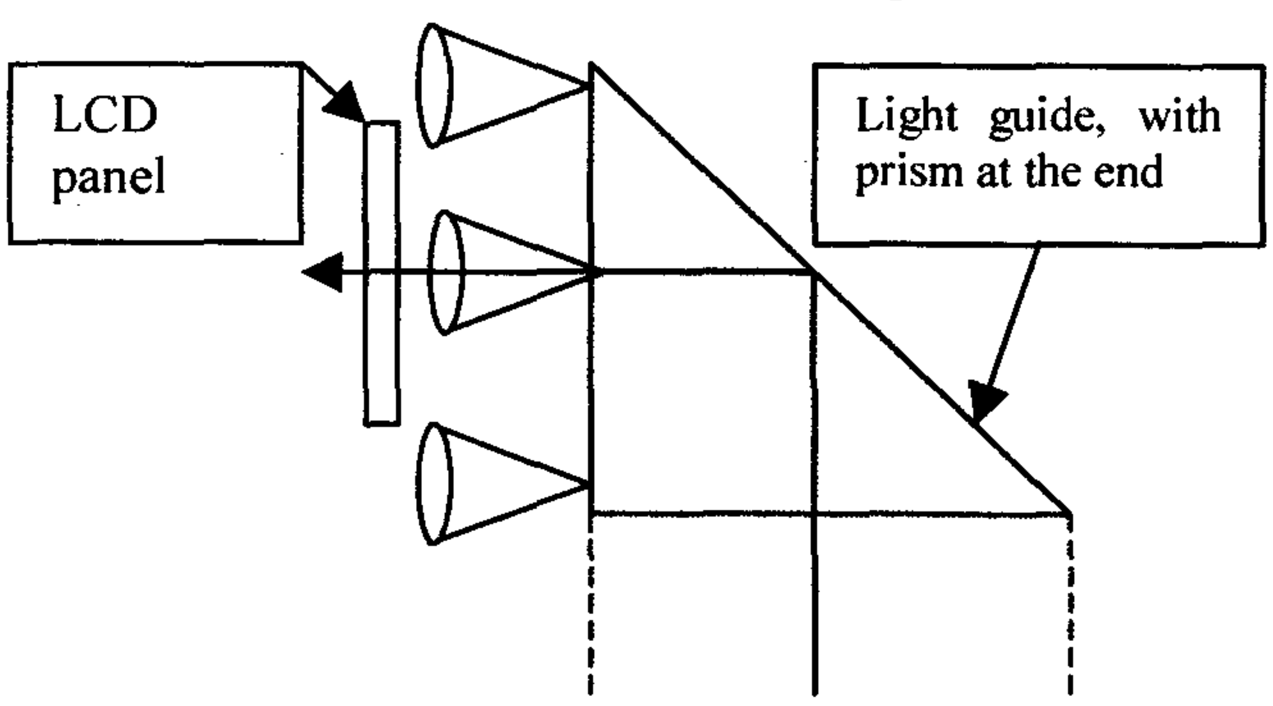

Figure 3. Proximity illumination.

Although the one light ray shown in figure 3 is perpendicular to the LCD panel, most others are not. These rays occupy several telecentric cones, which illuminate the panel. However, to obtain a uniform illumination the panel should be smaller than the cross section of the light guide. If not, the edges of the panel would be severely darkened with respect to the middle. The amount of light lost here is proportional to the distance between panel and light guide exit, and in our setup it is in the order of 20%.

3.3. Losses in the bending prisms

A certain angular spread is present in the light bundle inside the light guide. This is determined by the F-number of the lamp, and the refractive index of the glass. As a result, most rays will reflect from the glass-air interface of the prisms at non-perpendicular angles. See figure 4.

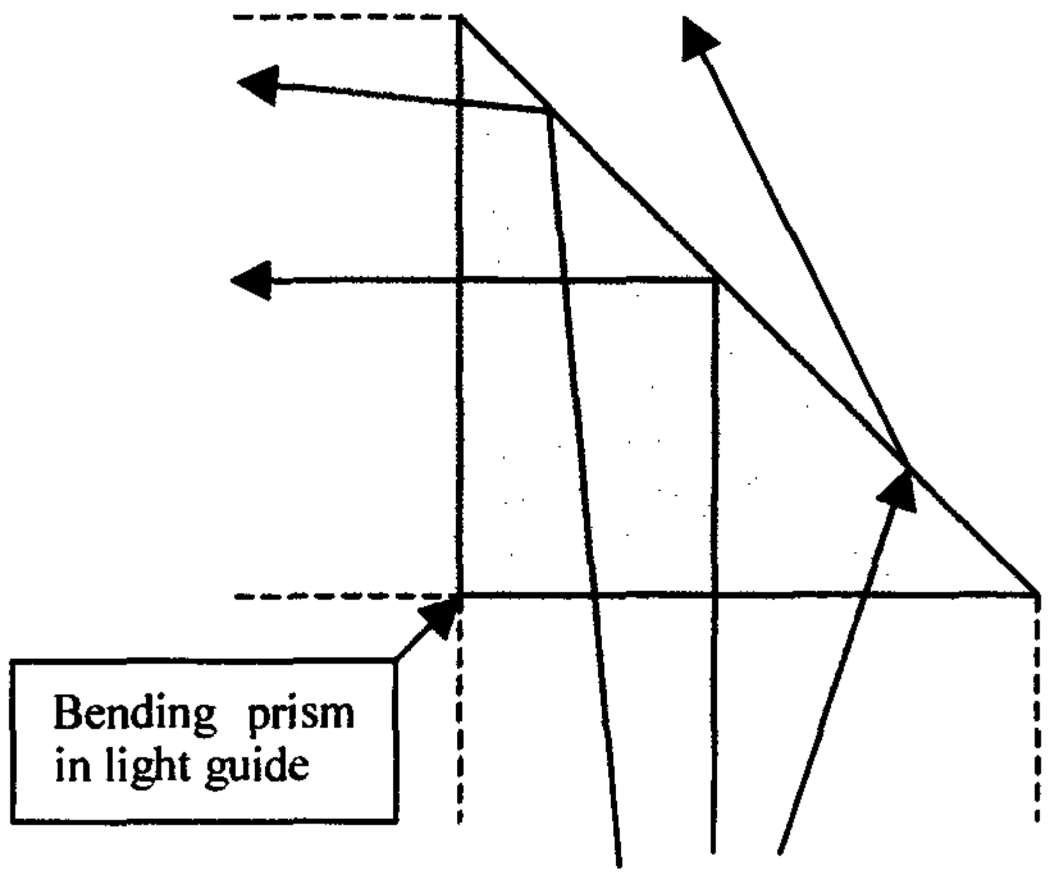

Figure 4. Light loss in bending prism.

Light rays that hit the oblique side of the bending prism with a relatively large angle, may be refracted out of the light guide, instead of being reflected by TIR. Using an appropriate combination of high index glass and a larger F-number lamp solves this problem. Calculations show that for a lamp with an F-number of 2.1 a glass prism with a refractive index larger than 1.6 is essential. SF1 glass fulfills this requirement: no light is lost at all. Applying a reflective coating also works, although some losses are inevitable.

3.4. Losses on the edge of the bending prisms

An additional possibility of light leakage is present near the prisms. Again this is due to the angular spread of the light rays. See figure 5.

Some light rays will cross the border between the prism and the rest of the light guide at quite a shallow angle. As a result they will hit the side of the light guide at an almost perpendicular angle. No TIR will

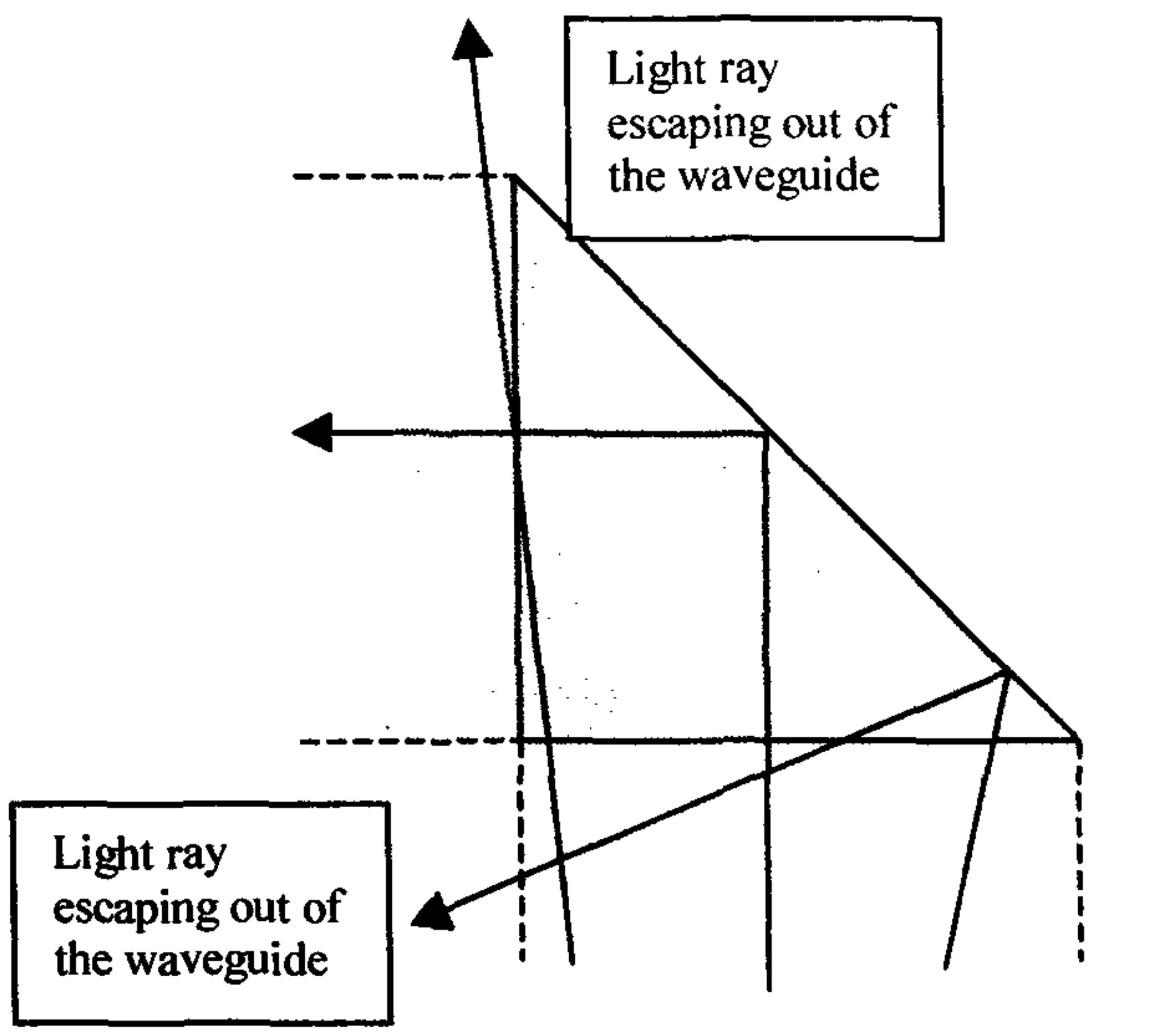

Figure 5 Light rays leaking out of the light guide.

occur, and the light will be lost. An elegant solution is possible however, by gluing the prism to the rest of the light guide with a low-refractive-index adhesive. See figure 6 for the effect of this measure.

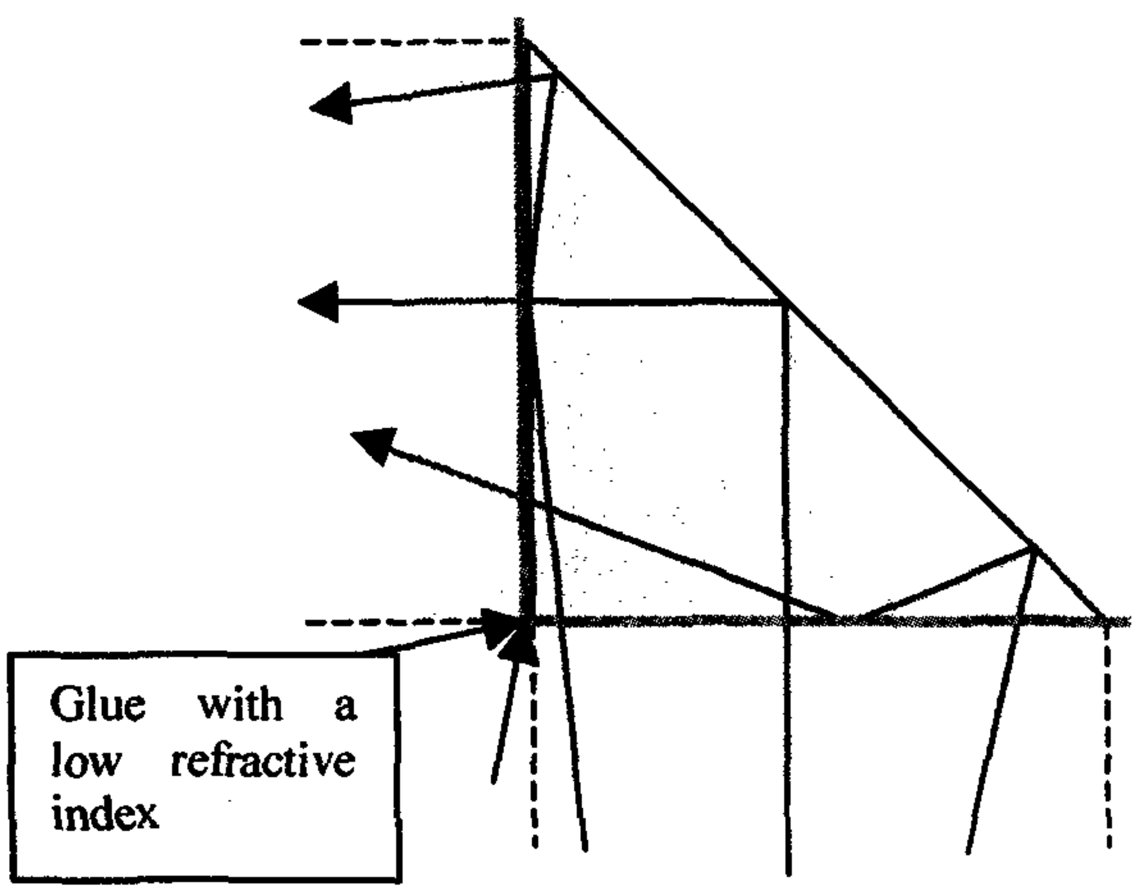

Figure 6. No light is lost when using glue with a low refractive index.

The required difference in refractive index between glass and glue depends on the angular spread of the light in the guide. With an F-number of about 2, and glass with a refractive index of about 1.5, the required difference is only 0.02.

3.5. Uniformity of the illumination

Apart from guiding the light from the source, the other main purpose of the light guide is to provide a uniform illumination of the LCD panels. Because of TIR, light originating from all angles and positions within the source will be mixed. The level of uniformity that will be obtained depends mainly on the length of the light guide, or to be more precisely, on the length versus width ratio. In a long and narrow guide more reflections on the sidewalls will occur, thus generating more 'virtual sources'. For our 150W elliptic UHP lamp, simulations show the uniformity as a function of the length versus width ratio. See figure 7.

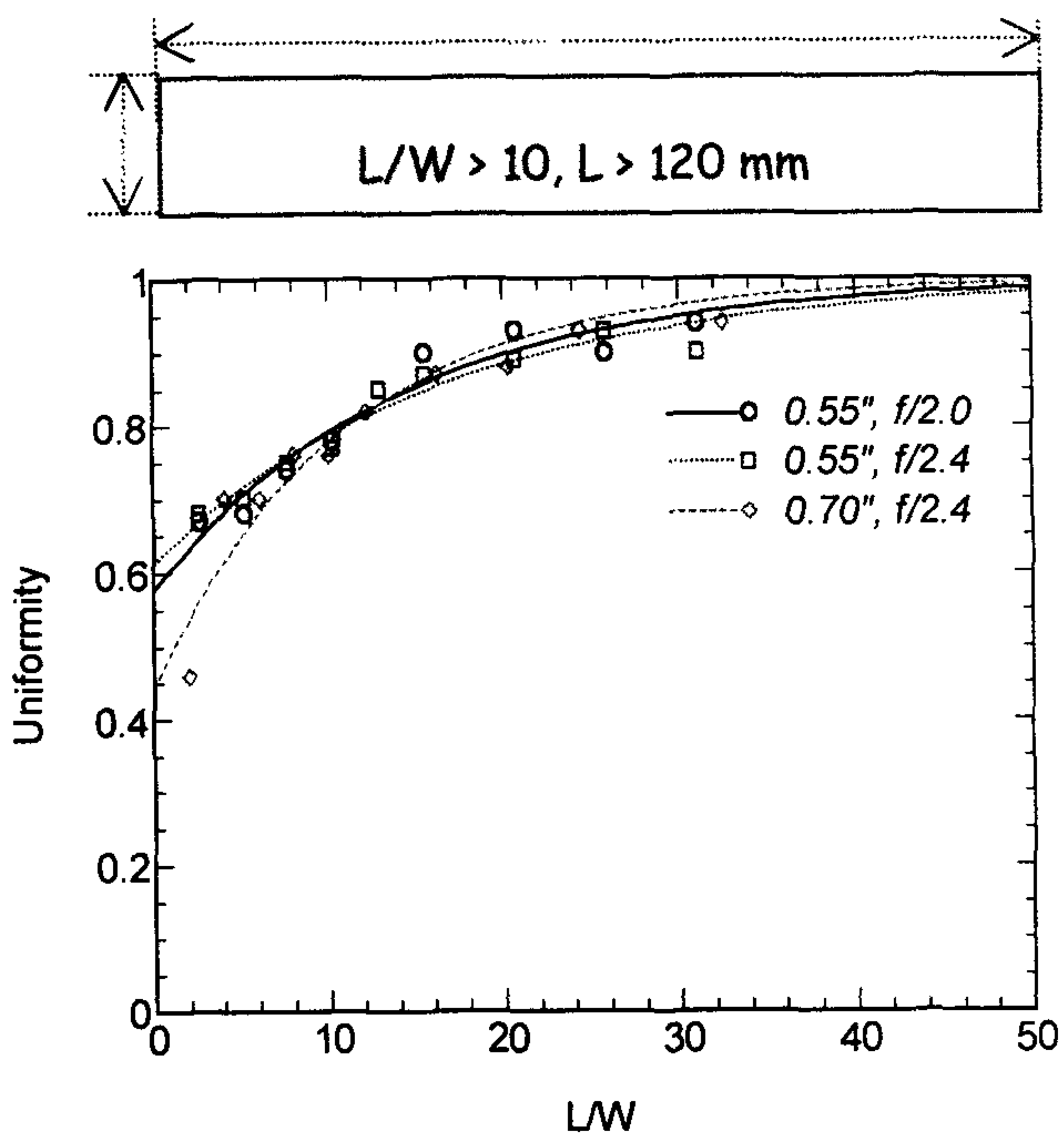

Figure 7. Simulated uniformity as a function of the length versus width ratio of a light guide.

4. Measurement results of prototype

A first prototype has been built, taking the considerations as mentioned above into account. SF1 glass has been used for the bending prisms, and BK7 glass was used for the straight sections of the light guide. No polarization conversion was used; the mirror and PCS like shown in figure 1 were replaced by a standard prism.

Some small loss factors are still present, partially due to ease-of-construction arguments. For instance, no AR-coatings have been applied to the entrance- and exit surfaces. This results in a loss of about 14 percent. Furthermore the integrated color filters did not exactly match the dichroic recombination cube.

The complete summary of loss factors is given in table 1.

Table 1. Comparison of the performance of the first prototype and a theoretical model

	Prototype	Achievable
Incoupling efficiency	0.70	0.75
Polarization loss	0.50	1.00
Polarization recycling	-	0.60
Outcoupling at prisms	1.00	1.00
Fresnell losses (2x)	0.86	1.00
Polarizer (cleanup)	0.85	0.85
Analyzer	0.90	0.90
Panel overfill	0.80	0.85
Panel (0.55", SVGA)	0.37	0.40
Colour fusion	0.90	0.95
Projection lens	0.90	0.95
Various losses	0.95	0.97
Optical throughput	**0.052**	**0.090**
Lumens from lamp (150 W)	**9000**	**9000**
Lumens on screen	**472**	**810**

Some of the parameters listed in table 1 have been measured directly, while others have been estimated on the basis of theory or indirect measurements. The final predicted result for the prototype of 472 lumen however is in good agreement with the actual measurement of 450 lumen. In the prototype no polarization conversion is applied. Depending on factors like panel size and lamp etendue, this might be beneficial.

The prototype as described above, including all the improvements discussed, is shown in figure 8. The resulting picture, played from DVD, is shown in figure 9. The outer dimensions, including the lamp, lamp-housing and projection lens, are just 16*15*5 cm, with space in between for e.g. a power supply.

5. Expected improvements

With relatively straightforward adjustments, the performance of the light guide can increase significantly. Most of these adjustments can be applied individually, i.e. not interfering with other changes. Adding AR coatings, and using a different lamp – to improve incoupling- will add some 30% extra light. Polarization conversion, as sketched in figure 1, will yield about 20% extra light. All together, an output over 800 lumen is possible, making this light guide a small, cheap and bright option for future projectors.

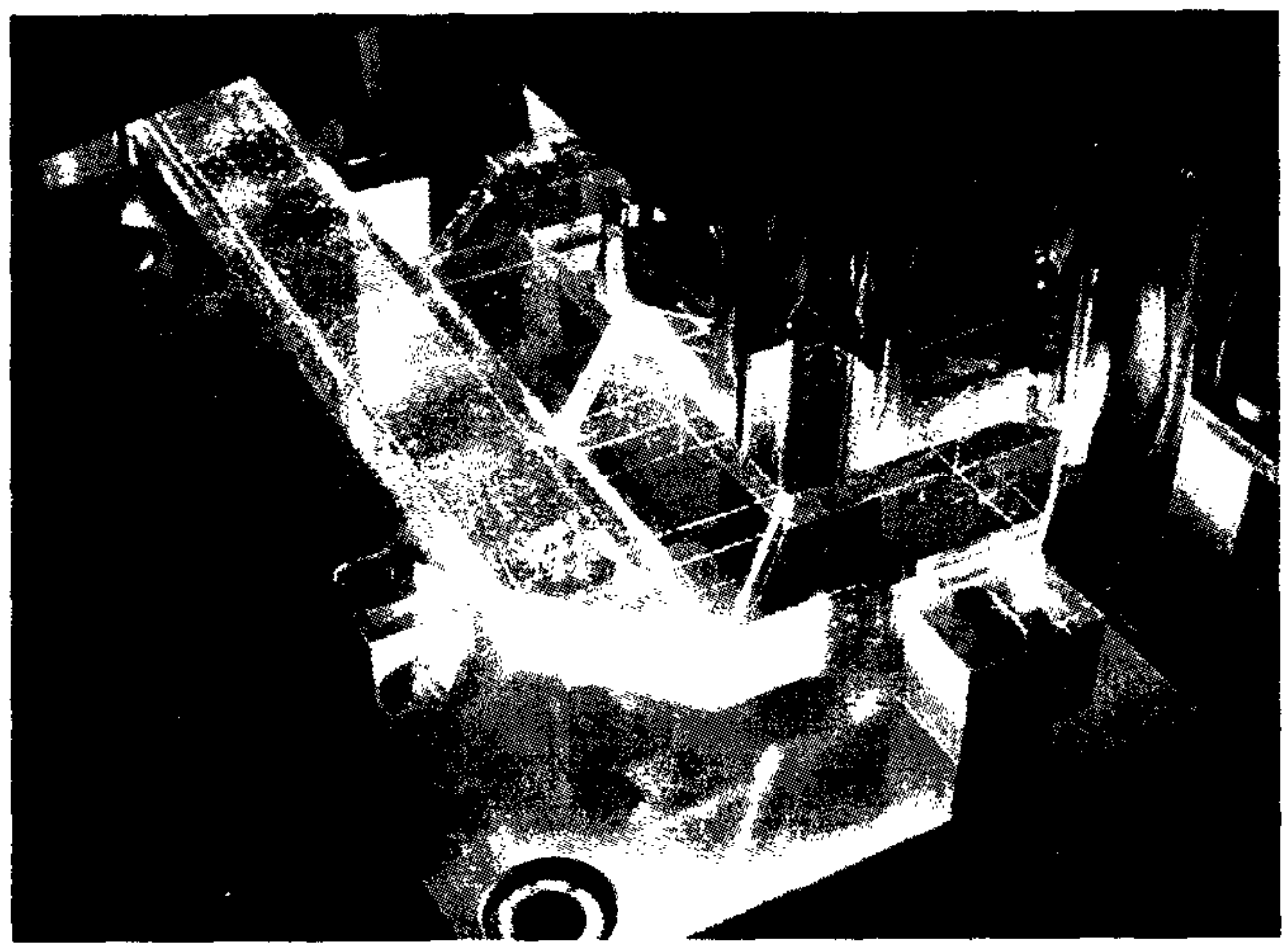

Figure 8. The actual waveguide

Figure 9. Sample picture from light guide based projector.

6. Acknowledgements

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