56.2: Achromatic Space Variant Retarder for Micro-Display Based Projection Systems

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Summary:

Rear Projection TV (RPTV) offers low cost and high definition images, but suffers from inadequate form factor for the cabinet design. Slim RPTV design with small depth and low chin (distance from stand to image lower edge) are available and offer a second chance for RPTV to compete in the battle of flat screen displays. For slim RPTV with a low-cost, refractive Fresnel screen, the angle of incidence of the light beam reaches 70° and induces large Fresnel losses. In order to correct this issue and to increase brightness uniformity and light flux, we designed a space variant retarder (SVR) to be located in the imaging arm of the Slim RPTV. This paper describes the concept and the experimental results.

Fresnel Losses within a Slim RPTV:

Slim RPTV optical design is mostly based on very wide angle projection. Only one part of the field of view is used (upper part in Figure 1). The beam folding is then performed inside the cabinet with very small depth. Figure 1 shows a non-folded beam for a slim RPTV design. The system of Figure 1 uses a combination of projection lens and aspheric concave mirror designed by Optinvent. This system reduces not only the depth to 7" for a 61" screen, but also reduces the chin to only 5.5".

The incidence angle on the Fresnel lens varies from 10° to 70°. For high-temperature poly-Si (HTPS) and liquid crystal on Si (LCOS) based projection systems, the beam incident on the Fresnel lens is linearly polarized. In the configuration of Figure 1, the losses from the Fresnel lens vary with incidence angle and could reach 30%, reducing screen brightness uniformity. Figure 2 shows the Fresnel reflection efficiency for incidence angle in the 10~70° range.

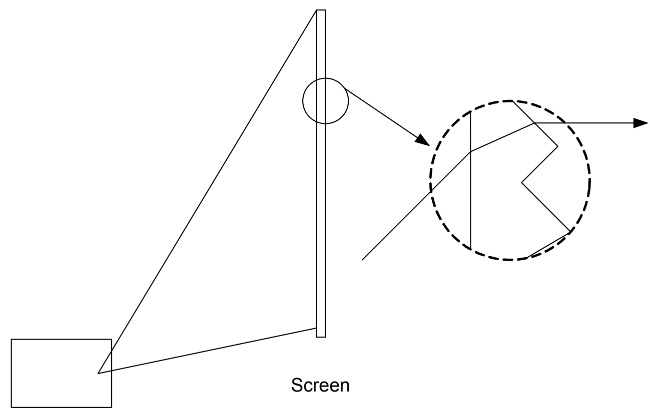

Figure 1: Projection system configuration for Slim RPTV.

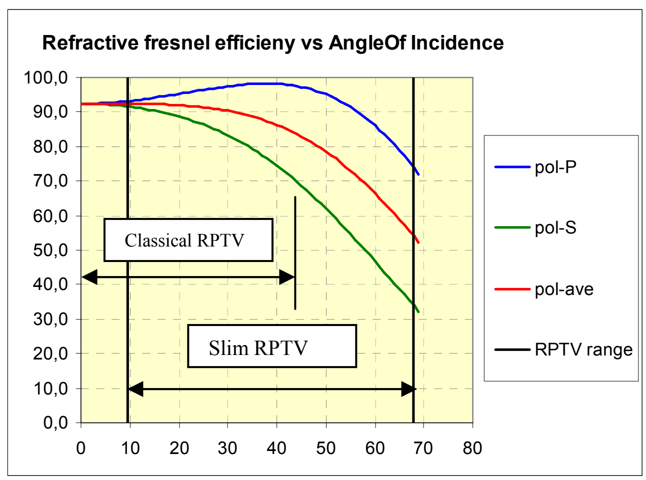

Figure 2: Efficiency of Fresnel reflection for incidence angle in the 10~70° range.

Figure 3 shows the desired direction of polarization of the incident beam that minimizes the Fresnel reflection. To do so, the polarization state at each point of the Fresnel screen should be parallel to the plane of incidence (p-polarized). It is not possible to reduce Fresnel losses with an incident beam having the same polarization state over the field. An incident beam with a polarization orientation parallel to the short side of the image induces strong losses in lower right and left sides of the image.

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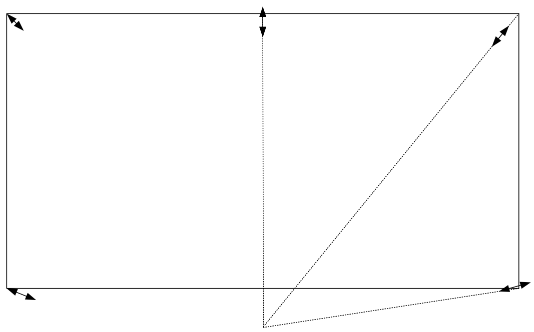


Figure 3: Polarization direction desired at screen level.

An incident beam with polarization in the perpendicular direction induces strong losses in middle top and bottom of the image. Here there is a conflict: it is not possible to reduce brightness non-uniformity without correction of polarization at each point of the field. In order to correct the polarization state at each point of the field, we need an SVR and a free location in the optical system for an intermediate image to do the correction on the polarization direction. This is what we have done in the imaging arm of our wide angle projection system.

Space Variant Retarder (SVR):

The SVR component employed here has been designed to achromatically rotate a uniform linear input polarisation state into an output linear state radially-oriented about a point on the component's surface. This type of SVR may be called an achromatic m=1 vortex retarder, and is a half-wave retarder whose fast-axis (FA) varies as illustrated in Figure 4 (m=1 is the polarization vortex mode of the output state). The output polarization state at each point corresponds well with the desired state for minimal loss at each point on the Fresnel screen. Figure 5 shows polarization state out of the SVR when input polarization state is uniform, linear and parallel to the short side of the component.

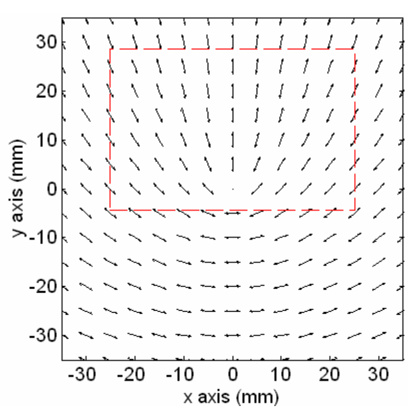


Figure 4: Modeled retardance FA orientation for m=1 vortex SVR. Region to be used in slim RPTV is outlined in red.

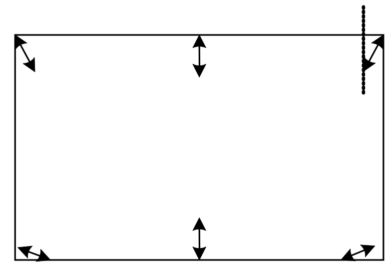


Figure 5: Polarization state out of the SVR component.

Others have demonstrated SVR's for generating radial polarization, made by active TN LC cells having spatially varying twist angle [1], [2]. However, those SVR's have some disadvantages, which can include: lacking broad achromatic performance, presence of defect lines, complicated fabrication, and stability of the LC alignment. Also if rubbing alignment is used, a greater potential for introducing defects exists.

The present SVR design and fabrication was performed for Optinvent by JDSU. The JDSU team developed an experimental SVR with achromatic performance for a wavelength range of λ=420~680 nm. This is based on JDSU's Hybrid Liquid Crystal (HyLC) photo-aligned liquid crystal polymer (LCP) technology. This technology offers a high degree of customization for making birefringent components, and is compatible with high-volume production [3]. The general fabrication technique used for creating LCP retarders with spatially-varying orientation and the advantages over other technologies are discussed in [4]. The SVR component is depicted in Figure 6. It consists of an achromatic half-wave retarder with a continuously spatially-varying orientation coated on a glass substrate, which is bonded to a second glass substrate. Broadband AR coatings are on the external surfaces.

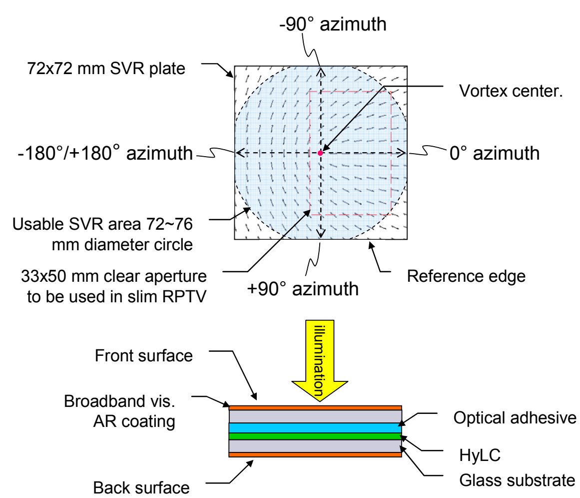


Figure 6: Schematic of the SVR structure.

Experimental Results:

Prior to using this SVR inside a projection system, we characterized the polarization response of this component. The SVR was placed between a polarizer and an analyzer. The output intensity pattern is shown in Figure 7 for the analyzer parallel, 45°, and perpendicular to the polarizer. Note that the bright fringe follows the analyzer direction. Intensity of the bright fringe represents the efficiency of the polarization conversion. Its "whiteness" indicates the achromatic performance (the yellowish appearance comes from the polarizer/analyzer).

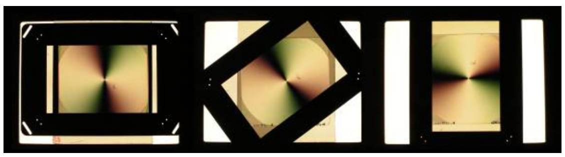


Figure 7: SVR between polarizer/analyzer: parallel, 45°, and perpendicular.

The spectral polarization conversion performance of the SVR measured at various azimuthal locations approximately 30 mm from the vortex center is reported in Figure 8. This shows high spectral conversion efficiency over the 420~680 nm band at all measured azimuths.

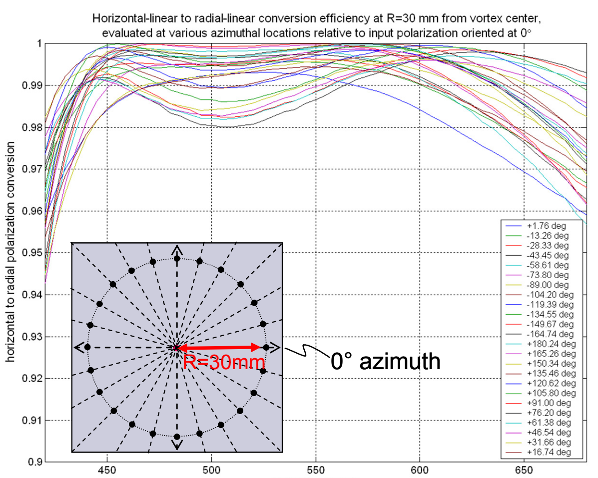


Figure 8: 0°-linear to radial-linear spectral conversion efficiency measured at various azimuthal locations.

Integration inside Slim RPTV:

The SVR was integrated into an existing Slim Rear projection TV, developed by Optinvent. Figure 9 shows the experimental setup with the SVR integrated into the slim projection system. Figure 10 shows the overall cabinet design and the location of SVR component, placed just after the projection lens inside the imaging arm.

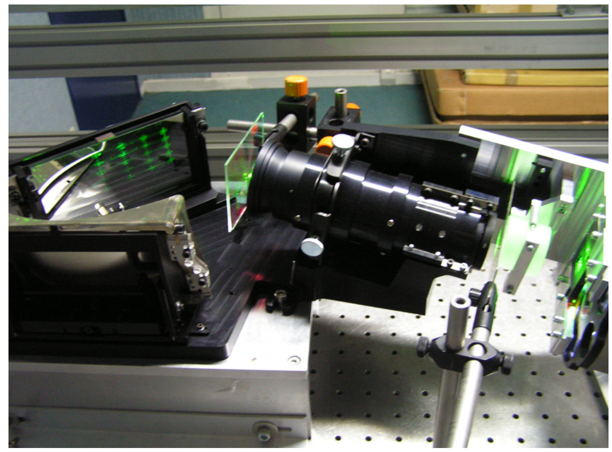


Figure 9: Experimental setup used to measure SVR Brightness improvement Inside Slim RPTV.

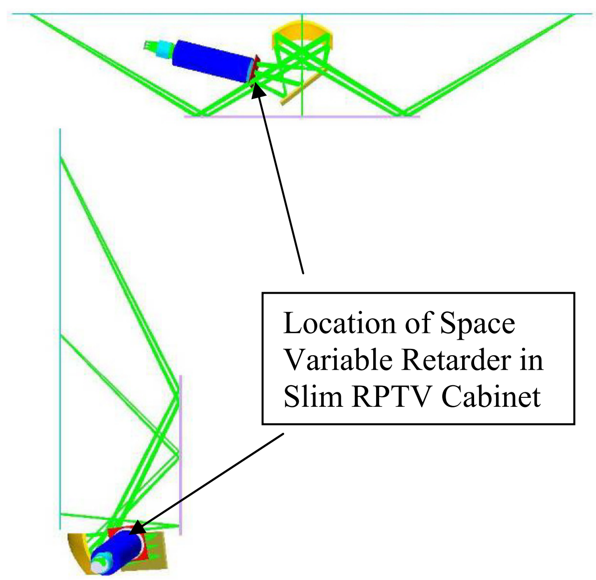
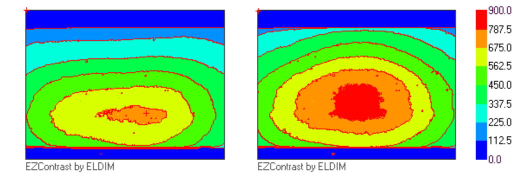


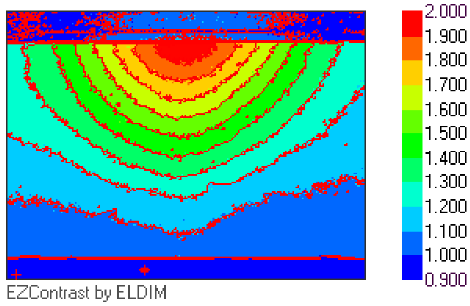
Figure 10: Location of SVR inside Slim RPTV Cabinet.

Brightness and Uniformity Results:

The measured pattern of screen brightness (illuminance) is shown in Figure 11 with and without the SVR. We also calculate in this figure the average brightness and the brightness uniformity. The ANSI uniformity value improves considerably from -30% to -22% (lower magnitude means higher uniformity).



WITHOUT SVR	WITH SVR
Av Brightness: 441nits	Av Brightness: 555nits
ANSI uniformity:-30%	ANSI uniformity:-22%



Measured Brightness Improvement Factor with SVR

Figure 11: Top left and right are respectively Slim RPTV brightness uniformity without and with SVR. Bottom is the brightness improvement factor.

The overall brightness level is also greatly improved with the SVR. The calculated total illuminance improved by 1.25x (up to 2x at the top of the screen). Figure 12 shows the measured improvement to be well correlated with theoretical predictions. The theoretical curve is calculated from Fresnel coefficients for parallel and perpendicular directions of a polarized beam incident on screen Fresnel lens.

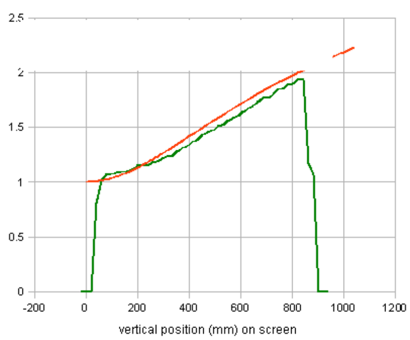


Figure 12: Comparison between theoretical brightness improvement Tp/Ts (Red curve), and measured brightness improvement (Green curve) vs. vertical screen position with SVR component.

Conclusions:

We have developed a new component for the projection display market that can improve brightness and uniformity for Slim RPTV systems using polarized light. This system could be applied to LCOS or LCD based micro-displays (MD) where the light source is a UHP lamp. This component would also be useful for all MD based systems, including DLP, if laser (polarized) sources are used.

References:

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