New high efficiency interference filter characteristics for stereoscopic imaging

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ABSTRACT

Goal of this work was the optimization of brightness and colors performance of the interference filter system for 3D projection. Special emphasis was on avoiding, or at least reducing, the need for color correction, which was one of the reasons for low luminous efficiencies in the past.

On the base of datasets for various projectors (DLP, LCoS, LCD) and lamps (UHP and Xenon), the optimization for a high efficiency stereoscopic interference filter system was carried out. Focus of our study was on three by four (3-4) filter system. We also examined filter designs with higher numbers of transmission bands up to seven per filter. The results show that the 3-4 band filters design exhibits the highest efficiency of all inherently color balanced filter systems because of a minimum number of gaps between adjacent transmission bands. Results also revealed that Xenon lamp based systems and UHP lamp based systems have different optimum filters. However, differences are such small that it becomes possible to cover both systems by a unitary type of 3D glasses lenses

Keywords: 3-D stereo, 3-D, stereo projection, wavelength multiplexing, spectral division, interference filter

1. INTRODUCTION

Eyeglasses based stereoscopic technologies offer a cost efficient, robust and reliable way to provide 3D content for large venues. Besides polarization and active shutter technologies, the wavelength multiplexing approach is an upcoming technology platform in this field [1].

Since the introduction of the first full color wavelength multiplexing 3D projection display by Infitec beginning the last decennium using triple band filters for each eye there have been miscellaneous attempts to improve this specific 3D approach [2][3]. The key targets of all of these attempts are basically:

(i) Increase of luminous efficiency

(ii) No or less need of color correction

In this publication we want to present our recent work in this field, which aimed at finding optimum filter characteristics for different projector types. Optimization was done with respect to brightness, which is a predominant parameter in all 3D projection technologies and with respect to color, which comprises both, color balance and color fidelity. Figures of merits of the new filters are compared with those of the triple band filter system as well as with those of filters which resulted from other attempts presented in the past to improve the wavelength multiplexing 3D approach.

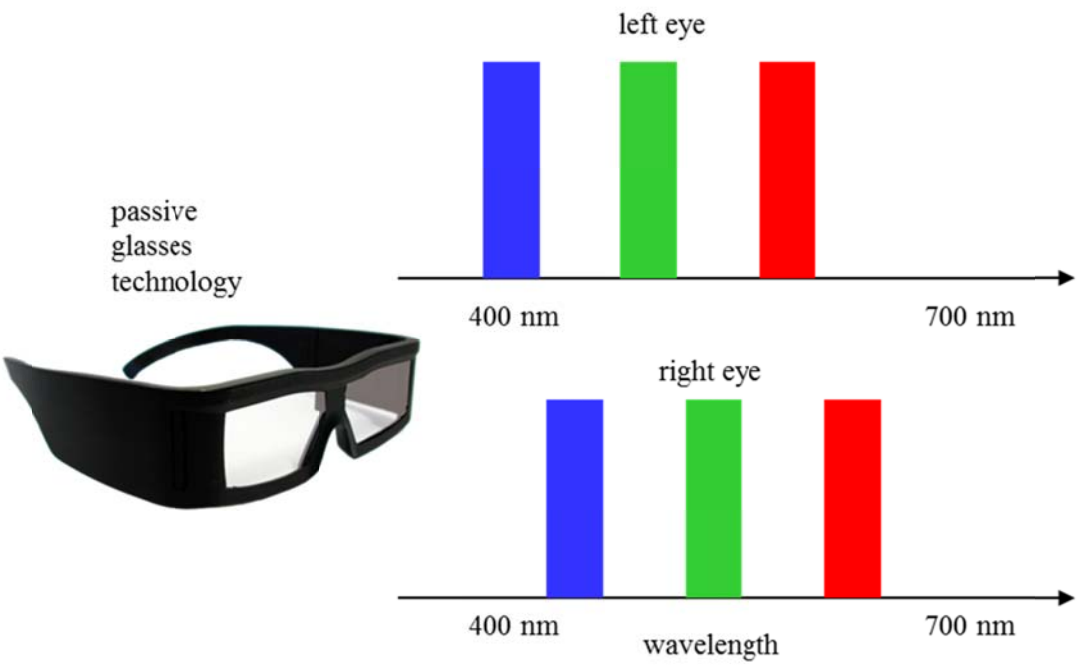

Figure 1: Wavelength multiplexing principle; left and right images are coded in spectrally independent wavelength bands.

2. TRIPLE BAND FILTER SYSTEM

The development of stereoscopic interference filter systems goes back to a Daimler Chrysler research project in the year 1999. Up to that time the only known spectral imaging technology was the anaglyph technology which uses, for instance, red and green filters for left and right eyes. Therefore, neither one of the eyes perceives a full color image. The INFITEC invention overcame this problem by using high quality interference filters which allow steep band edges and a high optical density in the blocking range. This way both eyes perceive a full color image and cross talk is kept at a minimum. 3D filtering was established by using triple band filters for both eyes (s. Fig. 1) because of the nature of the human eye, having three types of color receptors. Although the advantages, there is still a deficiency that results from the positions of the individual bands in the spectrum (s. Fig. 2). This causes significant discrepancies in the color triangles left / right (s. Fig. 3). In order to get balanced colors again, colors need to be corrected by a proper image signal processing. As a result of (i) filtering and (ii) color correction the final brightness is reduced to an average value of just about 12 % of the brightness before filtering (s. Fig. 4). The luminance differences of left and right filter may additionally be adjusted if desired [4].

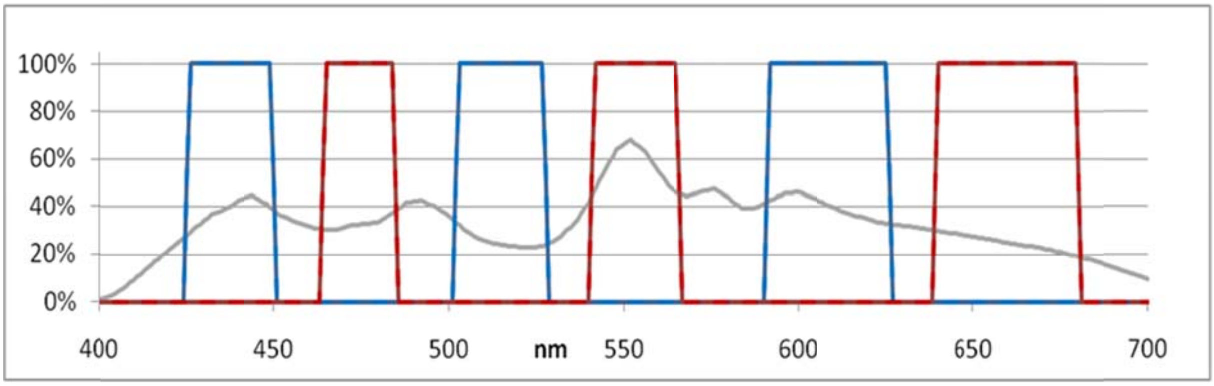

Figure 2: Standard 3-3 band filter configuration; blue line: left filter; red line: right filter; gray line: white UHP lamp spectrum

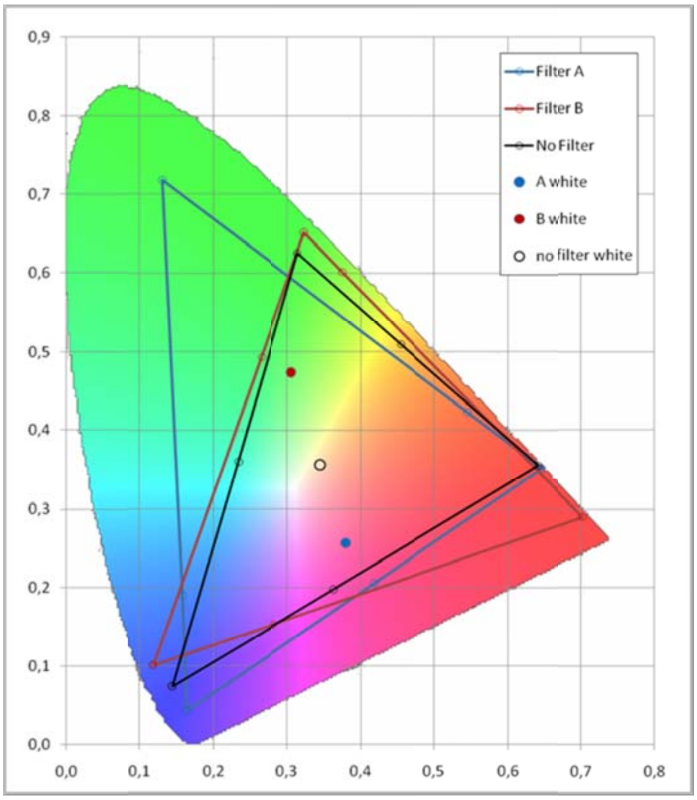

Figure 3: CIE 1931 x-y-diagram for 3-3 band system: black line: 2D gamut without filters; blue line: 3D gamut for left A-filter; red line: 3D gamut for right B-filter; circles indicate the corresponding white points

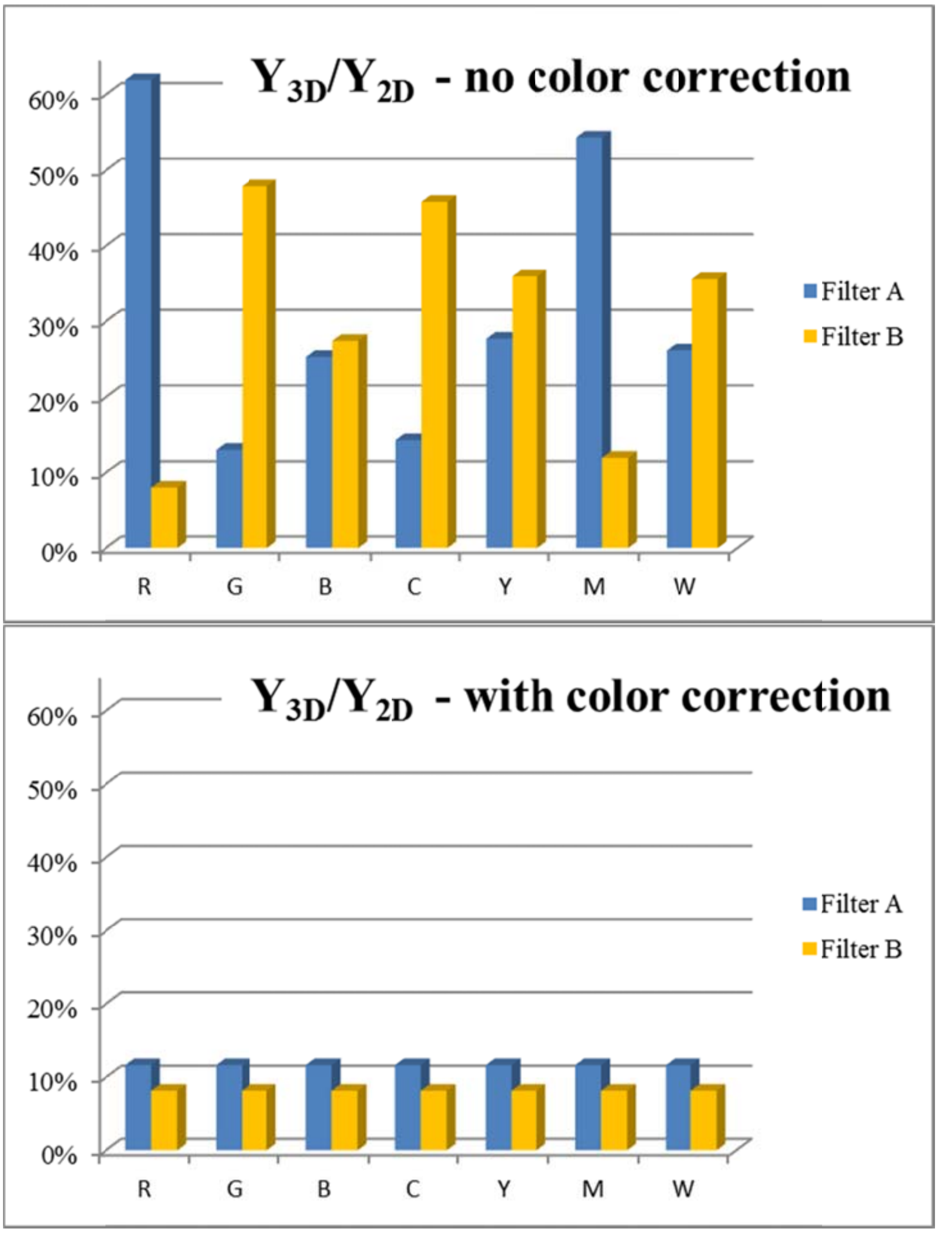

Figure 4: Luminance ratio 3D/2D for the 3-3 band filter for red (R), green (G), blue (B), cyan(C), yellow(Y), magenta(M), white(W)

3. THE 3-4 BAND FILTER CONCEPT

Our starting point for this new filter concept was color mesomerism, i.e. the phenomenon, that different spectra may cause the same sensation of color. Therefore, we subdivided the whole spectrum not in 6 sub-ranges but into 9, in order to assign in each primary color space one band to the one eye and two adjacent bands to the other eye (s. Fig. 5). Though this concept would basically result in a 3-6 filter system we can simplify the characteristics by combining bands at the green-blue transition and at the green-red transition to a uniform band, respectively. So, with this concept, we finally get a 3-4 filter system (s. Fig. 5).

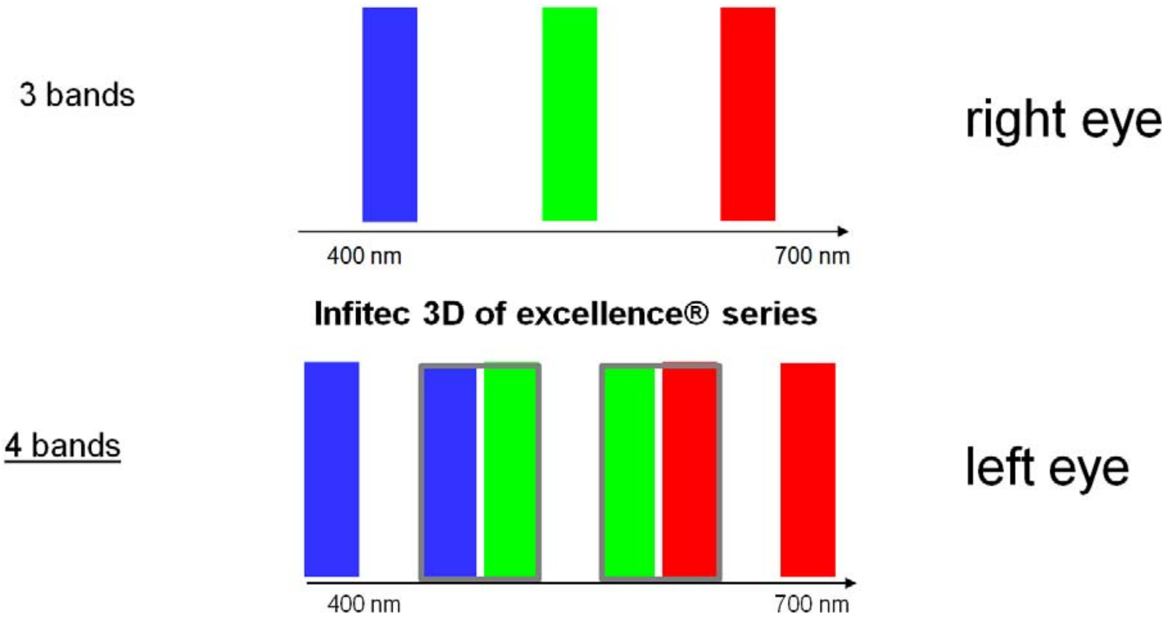

Figure 5: Infitec 3-4 band filter design concept

4. OPTIMIZATION METHOD

In order to find the optimum edges position of each band in the 3-4 filter system, we measured in a first step the spectra of projectors with various imagers and lamp types (Table 1). From these spectra, along with the filter characteristics, we calculated brightness and x, y color coordinates in the CIE 1931 diagram of each primary color. Then, filter characteristics were iteratively modified until optimum x, y values of the primary colors and the white point were established. This procedure was done for every projector.

Table 1: Spectral database for optimization

# Imagers	Lamp type	Manufacturer
1 DLP	UHP	Mitsubishi, Optoma, Projectiondesign, Sanyo, SIM2
3 LCD	UHP	Epson, NEC, Sanyo
3 LCoS	UHP	JVC
3 DLP	UHP	Barco, Christie, NEC, Panasonic, Projectiondesign, SIM2
	Xenon	Barco, Christie, NEC (D-cinema and simulation)
6 LCoS	UHP	LG

In a next step we compared the various filter designs obtained from this iterative scheme, where we found that there are basically two groups of filter designs. In each group there are only minor differences. As it would be hard in practice, to build a specific filter design for each projector, we decided to define just two different filter designs, which are associated to projectors using UHP lamps and to projectors using Xenon lamps.

In a final step, we defined filter characteristics for the 3D glasses lenses in a way, that the 3D glasses lenses cover both projector filter types (UHP and Xenon lamp). This was done in order to avoid the existence of different 3D glasses versions on the market in future. Fig. 6 shows the 3-4 filter design for UHP lamp projectors. The respective triangles in color space are very close to each other as well as to the triangle of the projector without filters (s. Fig. 7). Also, the white points are very close to the x = y = 0.33 point.

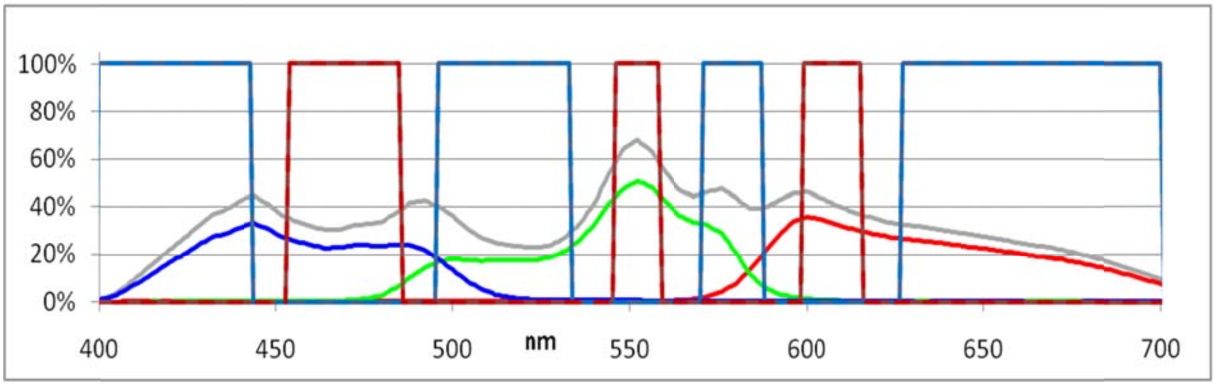

Figure 6: Optimized 3-4 band filter for UHP lamp system¸ bright blue line: left filter; dark red line: right filter; dark blue; green, red and gray line show primary color and white spectrum

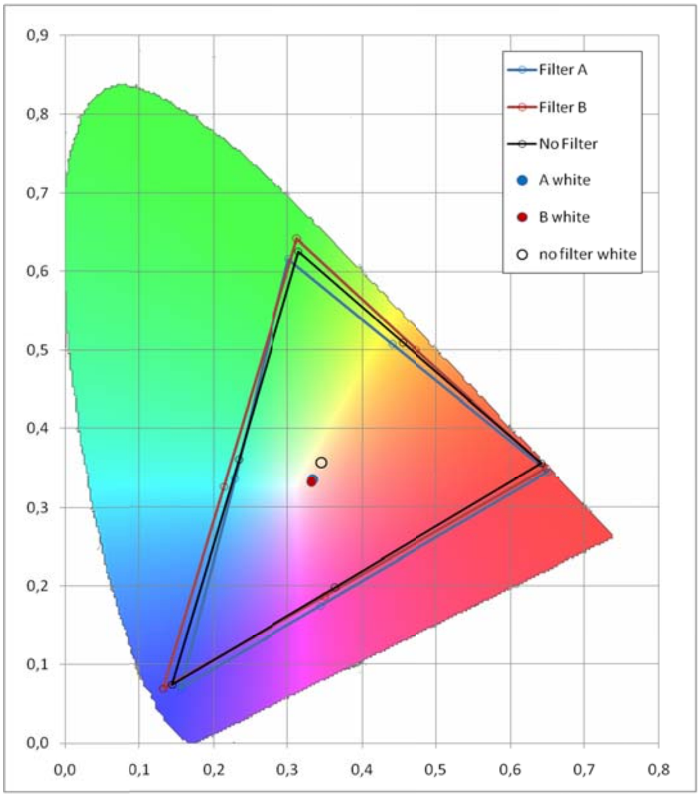

Figure 7: CIE 1931 x-y-diagram for the 3-4 system: black line: 2D gamut without filters; blue line: 3D gamut for left A-filter; red line: 3D gamut for right B-filter; circles indicate the corresponding white points

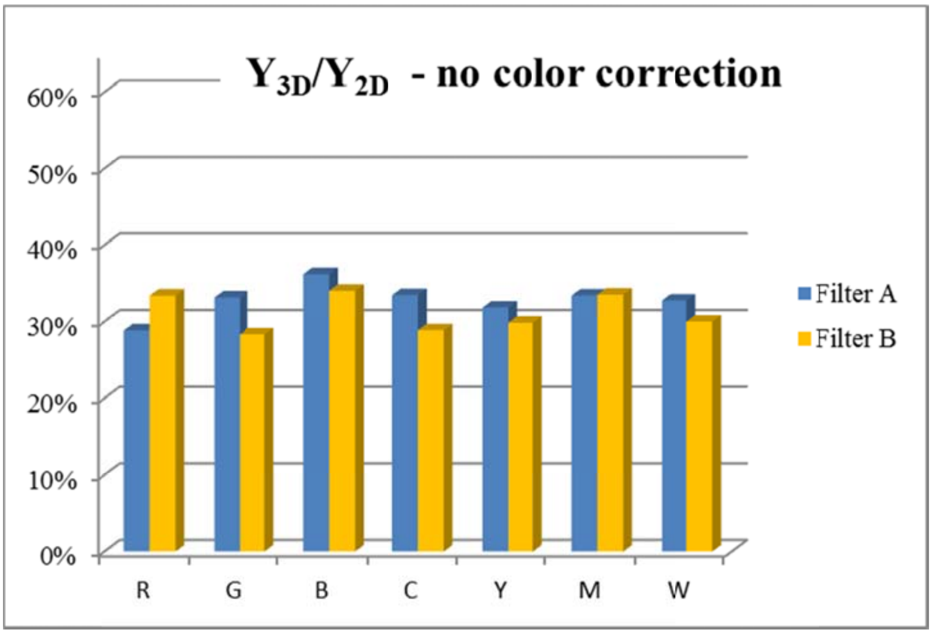

Figure 8: Luminance balance 3D/2D for the optimized 3-4 filter system

Fig. 8 shows the luminous efficiencies without any additional color correction for the primary colors, the complementary colors and for white for left and right, respectively. This example shows, that there is actually only minor need for color correction with the new 3-4 filters compared to the former 3-3 filters (Fig. 4).

Table 2 shows efficiencies for dual projector and for single projector / filter wheel systems with and without color correction.

Table 2: Transmission performance of Infitec 3-4 band filter system for a UHP lamp system

<table>
<tr><th colspan="3">Transmission</th></tr>
<tr><th>Static</th><th colspan="2">Filter wheel @ 45% duty cycle per channel</th></tr>
<tr><td>27,1%</td><td>L</td><td rowspan="2">Uncorrected average
11,2%</td></tr>
<tr><td>22,8%</td><td>R</td></tr>
<tr><td>23,8%</td><td>L white balanced</td><td rowspan="2">White balanced average
9,6%
L-R-Balance:
Y(L) = +26% Y(R)</td></tr>
<tr><td>18,9%</td><td>R white balanced</td></tr>
</table>

5. LUMINOUS EFFICIENCY IN N-M FILTER DESIGNS

Additional work was done to elucidate the question regarding efficiencies of filter systems with more than seven bands in total. Results show, that beyond the 3-4 system efficiencies decrease (s. Fig. 9). This is because the number of gaps increases with the number of bands and each gap contributes to a loss of efficiency. The only way to compensate this loss in n-m filter designs with high n and m numbers is to increase the steepness of band edges, which allows a reduction of the width of the gaps. As this may work in theory, in practice this is a dead-end strategy as the yield shrinks and the costs rise with increasing steepness.

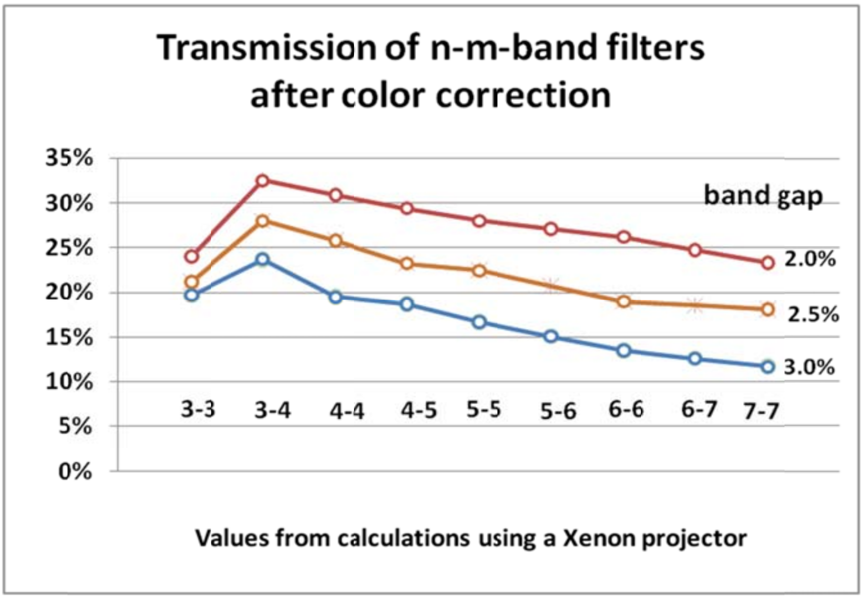

Figure 9: Transmission performance of m-n band interference filter systems for stereoscopic imaging

6. COMPARISON OF FILTER SYSTEMS

In our study we also evaluated the recent Panavision 3D filter system as example of a high n-m filter system regarding the efficiency. This assessment was done with a Xenon lamp 3-DLP projector. Table 4 gives an overview. Consistent to the results presented in the previous section, the 3-4 band filter system shows the highest efficiency.

Table 3: Luminous efficiency of wavelength multiplexing filter systems for a Xenon lamp system

	Luminous efficiency (incl. color correction)		
	Left eye	Right eye	average
Infitec 3–4 band filters (Xenon 3-DLP)	24%	19%	21,5%
Panavision 3D filters (Xenon 3-DLP)	21%	11%	16,0%

REFERENCES

[1] M. Pölönen, M. Salmimaa, V. Aaltonen, J. Häkkinen, J. Häkkinen, and J. Takatalo, "Subjective measures of presence and discomfort in viewers of color-separation-based stereoscopic cinema”, J. SID 17, 459 (2009).

[2] H. Jorke, A. Simon, and M. Fritz, “Advanced stereo projection using interference filters”, J. SID 17, 407 (2009).

[3] Arnold Simon and Helmut Jorke, “Interference Filter System for High-Brightness and Natural-Color Stereoscopic Imaging” SID Symposium Digest 42, 317 (2011).

[4] R, Patterson, A. S. Boydstun, J. A. Rogers, and L. M. Tripp, “Stereoscopic depth perception and interocular luminance differences”, SID Digest 40, 815 (2009).