

# Holographic 3D Displays from SeeReal: Developments, Improvements, Progress

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## Abstract

*In 2007 SeeReal had demonstrated the first large real-time holographic 3D display based on tracked viewing windows. Subsequent work has led to advanced concepts for overcoming limitations of the prototype. This paper describes the current state of SeeReal's developments and its progress in practical realization of these advanced solutions.*

## 1. Introduction

Until recently large real time true holographic 3D displays had been far from reach. Even sophisticated designs were limited to small reconstruction volumes and were not capable of real time calculation. This situation changed in 2007 when SeeReal Technologies demonstrated its concept of tracked viewing window holograms <sup>[1]</sup>. This concept drastically relaxed requirements for pixel pitch of the display and of computation power that had been severe obstacles before. At SID 2007 a large 20" holographic display with real time calculation even taking into account hologram generation based on user interaction was demonstrated. Improved versions of the prototype were shown to the public at the FPD 2007 and Finetech 2008 exhibitions. These prototypes were still monochrome but in the following also color versions were realized <sup>[2]</sup>.

The prototypes were intended to demonstrate the principle and feasibility of tracked viewing window holography and the possibility to realize large holographic displays made from off the shelf components, an option that was thought to be impossible before. On the other hand these prototypes still had some limitations that made it unfavorable to get to a product by only doing straight forward enhancement of the components. These limitations included low brightness of the reconstructed 3D scene – prototypes had to be shown in a dark room environment, limited tracking angle – that means

limited freedom of movement for an observer, and a bulky appearance of prototype – size and weight were comparable to a CRT but not to a flat screen monitor.

Advanced design concepts in order to overcome the limitations of the prototype and being more suitable for products were developed subsequently some part of them already published <sup>[3]</sup>.

This work deals with current progress of SeeReal's developments which means refinement and also experimental verification of advanced concepts for the realization of a holographic display product.

## 2. Results and discussion

Basic units of the holographic display system are: backlight, spatial light modulator, tracking optics, position finder as well as software/hardware for content generation/real time hologram calculation. Due to limited amount of space this paper will focus only on part of these components.

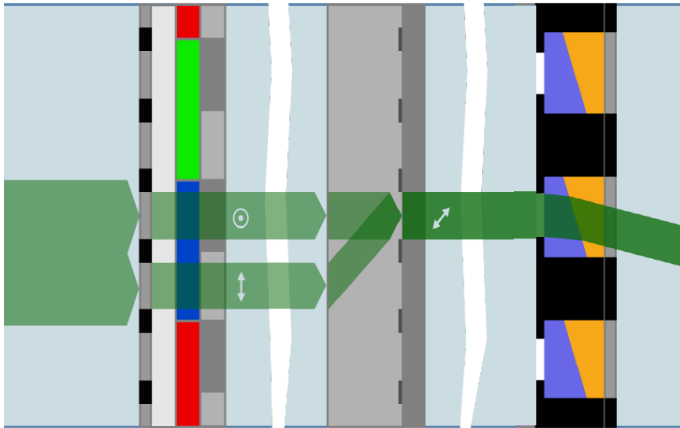
Flat backlight designs optimized for coherent applications have been developed but will be described elsewhere.

Spatial light modulator: Computed holograms include complex valued information, that means amplitude as well as phase data. Common LCD displays modulate intensity -which is proportional to the square of amplitude. A minor modification can change an LCD towards being a phase modulating display. But this still does not give the possibility to address both parameters amplitude and phase independently in a single LCD. A straight forward set up would be a sandwich structure of two LC panel but this has some disadvantages.

SeeReal has found a better solution, that we call beam combiner. From a single phase LCD with the beam combiner near field superposition of light from each pair of two pixel of that LCD is done.

A complex number is coded into a pair of 2 SLM phase pixel. Similar to a two-beam interference in an

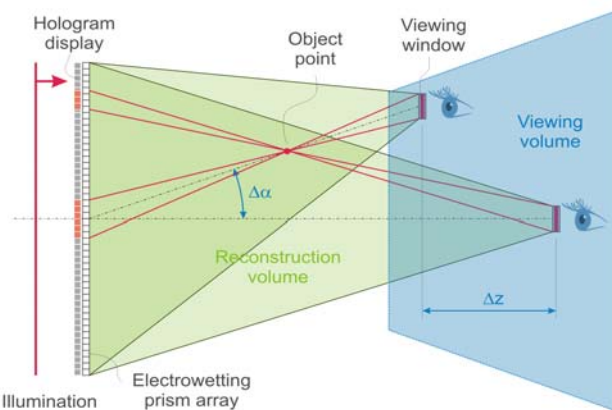
interferometer an amplitude is coded by the difference of phase values of that pixel pair, whereas the phase is coded by a common phase offset of both pixel.



**Fig. 1. Schematic: hologram display sandwich with phase SLM, beam combiner and EW tracking**

There exist several options how to actually set up this beam combiner. Part of them is based on polarization. The layout is schematically illustrated in the left part of Fig. 1. A structured half wave plate is placed after the phase SLM in order to get orthogonal polarization for light from each pixel of a pair. One polarization state is deflected inside the beam combiner but again made parallel at the output. An aperture and a polarizer are used at the output.

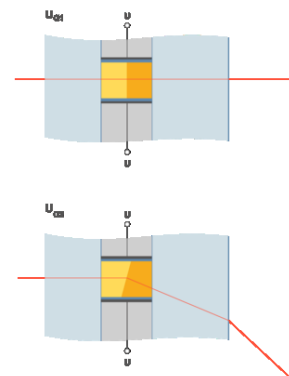
A suitable material for the beam combiner may be a birefringent plate. It has been experimentally verified that it is possible to get birefringent plates of sufficient thickness from oriented polymer materials. Another solution is a pair of volume gratings which are designed for polarization sensitive deflection in combination with a spacer layer.



**Fig. 2. Eye tracking and reconstruction volume**

Tracking, which means using optical components for locating the viewing window at the current eye position, is an essential part of the holographic display as it allows for freedom of movement of the observer in front of the screen. This is illustrated in Fig. 2.

SeeReal has now diversified its concepts for tracking leading to solutions optimized for particular applications. Tracking based on electro wetting the concept that was presented at SID 2008<sup>[3]</sup> is thought to be especially well suited for a multi user configuration and large tracking range – as required in TV applications. A PC desktop or notebook application most of the time will be single user and a smaller tracking angle in 3D mode is acceptable as long as there are no restrictions in 2d mode. For such a system there exists a simpler tracking solution which is even more cost effective and closer to current LCD fabrication technology. This will be described in a future publication. Progress of electro wetting tracking is described here.



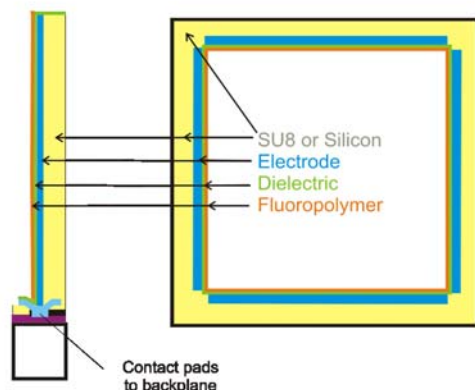
**Fig. 3 Principle of electro wetting prism**

Fig. 3 shows the principle of an electro wetting prism, which contains 2 liquids the interface angle of which can be changed by applying a voltage. In such a way light deflection under a variable angle can be achieved.

Lens and prism elements based on electro wetting were developed a few years ago<sup>[4][5]</sup> and variable focus lenses are now available as a mass product. Also some types of electro wetting displays are already there<sup>[6]</sup>.

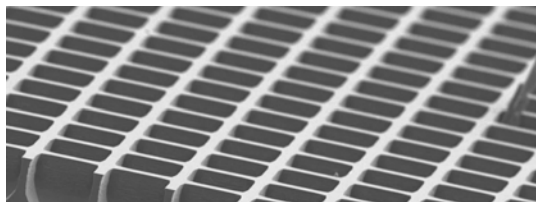
However these commercial displays as well as previous laboratory stage prism arrays<sup>[7]</sup> were merely limited to a relative small number of relatively large pixels. Therefore fabrication of electro wetting prism arrays with a small cell pitch in the range of 30-60 μm and a large number of cells – although based on known principles - means the need for improved

design in order to get the desired feature size and complexity. Some important steps for practical realization of such arrays have been successfully performed now.



**Fig. 4. EW cells composed either SU8 or Silicon side walls, an electrode layer, a dielectric layer and a fluoropolymer layer**

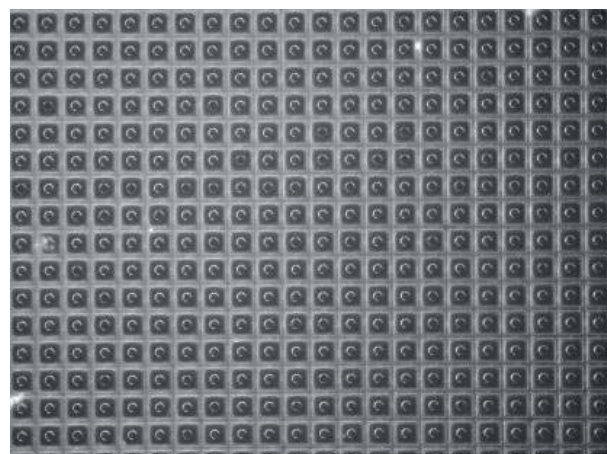
Fabrication of arrays with a cell pitch as small as  $50 \times 50 \mu\text{m}$  has been verified. Fig. 5 shows such a fabricated sample.



**Fig. 5. Fabricated sample of electro-wetting cell array with  $50 \mu\text{m}$  cell pitch.**

Another important issue includes precise filling of small cells with well defined liquid volumes in order to get a constant fill height. In contrast to an LC display electro wetting cells are divided by side walls. At least for one of the liquids there is no exchange of volume between different cells possible after filling is completed. So each cell has to be filled individually with exactly the same amount of liquid. It was verified that it is possible to fill cell arrays with the required precision in the pico litre range. Figure 6 shows a filled array.

Although at the current stage verifications have been done still with small size samples this already shows the feasibility of precise small-pitch large-cell number arrays.



**Fig. 6. EW Cells filled with liquids (top view)**

The achievable observer tracking range depending on cell parameters of the prisms has been investigated by simulations in detail for various configurations. For horizontal as well as vertical tracking with a single prism both deflection angles are no longer independent. But this makes it even easier to get large angles in a diagonal direction. Phase SLM, beam combiner and EW prism elements are shown in Fig. 1. Input apertures of the prisms can be made smaller than output apertures helping to reduce truncation.

Cell parameters limiting the tracking range have been analyzed by simulations. One of these parameters is the electro wetting saturation angle. Above a certain voltage level there is no further change in electro wetting angle. Prism angle and therefore deflection angle of the cells may be limited by saturation. Saturation depends on material parameters of the electro wetting cells.

In the experimental work material configurations and cell parameters have been optimized in order to get a low saturation angle down to  $45^\circ$ , which means large prism angle and therefore large tracking range.

The impact of electro wetting tracking on holographic scene reconstruction has been investigated by simulations. Effects like brightness variation for different display positions due to effects like beam truncation and beam squeezing by the cells have been analyzed. Methods to reduce this brightness variation by cell apodization or a change in fill factor have been found.

Simulations have led to a refinement of concepts for further improvement of electro wetting tracking whereas experimental work has made important progress in proving feasibility of this tracking solution.

**Hologram calculation:** The possibility of real time generation of large holograms was already demonstrated back in 2007. Nevertheless in the meantime calculation speed was further improved up to 100 fps on the current prototype.

**Content generation:** With SeeReals real time holo calculation it is possible to convert 3d stereo data to holograms. This gives access to existing 3d content.

This has been practically demonstrated on the current display prototype by using WOWvx videos from the Philips WEB site. WOWvx is a stereo format that uses content plus depth map.

These scenes are stored in their original file formats and converted to hologram in real time when played. The content looks pretty good while being somewhat shallow. The latter is partially due to the original low parallax (depth). Stereo data have to be limited in depth range to the accommodation vergence mismatch in stereo, whereas holography can use a natural depth range. Nonetheless, these are “real life” videos showing scenes as animals, water or a Toyota commercial. Despite the fact that Philips discontinued development of its 3D products the demonstration shows how easy it is to convert 3D stereo content to holograms.



**Fig. 7. 2D photo of color hologram on current prototype (camera focusing on planets)**

SeeReal’s holo-player is also able to show transparent surfaces and considers occlusion data. With the transparency feature it is possible for an observers eyes to focus correctly either to a (semi)transparent object at the foreground or at another object behind this first one. This feature is unique for holography

The player is also able to playback 3D video sequences produced in a SRT proprietary format.

With this concept on one hand it is easy to use existing 3d content, on the other hand it is also possible to generate special content with superior features unique to holography.

### 3. Summary

SeeReal’s results demonstrate the feasibility of key components such as for example electro wetting prism arrays for holographic 3D displays. This verification is an important step towards a display product.

The ease of processing existing 3D stereo content for real time hologram calculation has been demonstrated. Availability of content is important for launching of new 3D display products

### Acknowledgement

*Fabrication of EW samples and of beam combiner samples has been done in cooperation with external partners.*

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