

# Glasses-Free 3D Display for Cinema Applications Employing a MiniLED Display and Radial Parallax Barrier

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## Abstract

We describe a prototype glasses-free 3D display suitable for large audiences such as cinema or out-of-home advertising. This is based on designs originally developed in 1940's that used a radial parallax barrier to provide an optimum viewing plane (OVP) that passes through the eyes of seated viewers in the auditorium; this is an improvement over a conventional parallel barrier display where the OVP is parallel to the screen. The original principle is updated by replacing a projector behind the viewers with a miniLED display panel located behind the barrier.

## Author Keywords

Radial parallax barrier, miniLED display panel, centre of convergence (COC), optimum viewing plane (OVP).

## 1. Introduction

Supplying glasses-free 3D images to an audience who are located over an auditorium-sized area has special considerations that are not applicable to a display that is intended for monitor or television-type applications. One advantage of a cinema environment is that viewers are seated so that the seating arrangement can be configured such that each user's pair of eyes is in a 'sweet spot' that is determined by the display hardware. This is unlike a work or home environment like monitor or television applications, where the user/s viewing positions are not fixed. 3D cinema without glasses was demonstrated as long ago as 1941 in Moscow by Semyon Ivanov [1] This system sent the same stereoscopic pair to every viewer in the audience; this has the advantage of projecting the minimum amount of information;

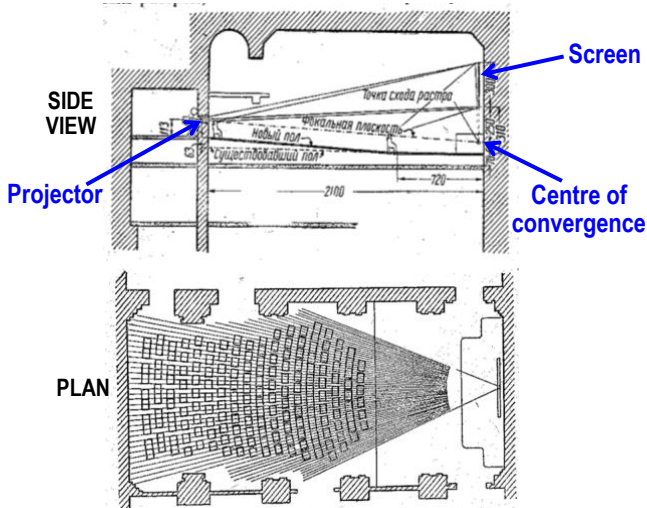


Figure 1 Extract from Ivanov (Ref [1]) Upper: Side view of auditorium showing projector behind viewers, Lower: Plan view showing radial seating arrangement.

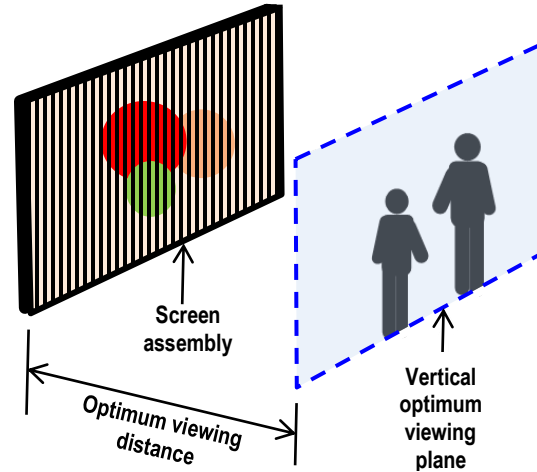


Figure 2 Conventional parallel barrier (or lenticular) with vertical optimum viewing plane.

however, it does not enable much freedom of viewer head movement, which caused some discomfort [2].

Other methods have been proposed over the years, notably those of Edmond Noaillon [3] and Francois Savoye [4]. Considerable work in this area was also carried out by the British-Hungarian Nobel Prize winner Denis Gabor [5], who is better known as the inventor of holography. However, it is unclear whether any of these methods ever materialized as a practical usable system.

## 2. Radial Barrier 3D Display Principle

The proposed method uses the hardware configuration used by Ivanov, developed in Russia in the early part of the twentieth century for cinema applications where the primary image source was a front projector mounted behind the viewers as shown in Figure 1 [1]. This worked reasonably well, but it never achieved widespread adoption. The display hardware produces 3D in a plane that is not vertical as illustrated in Figure 2, but is horizontal, or close to horizontal, as shown in a cinema environment of Figure 3.

The original system used a radial parallax barrier where the apertures radiated from a point below the centre of the screen, referred to as the centre of convergence (COC). The form of the barrier is shown in Figure 4 where the width of the apertures is considerably exaggerated for the purposes of clarity. A projector located behind the audience forms an image on a white screen mounted behind the barrier. A radial illumination pattern is formed on the screen and this is returned to the viewers via the apertures of the barrier.

Each of the apertures forms an illuminated strip on the screen and each strip reflects back to the viewers through several adjacent apertures. This produces multiple similar radiating view zone

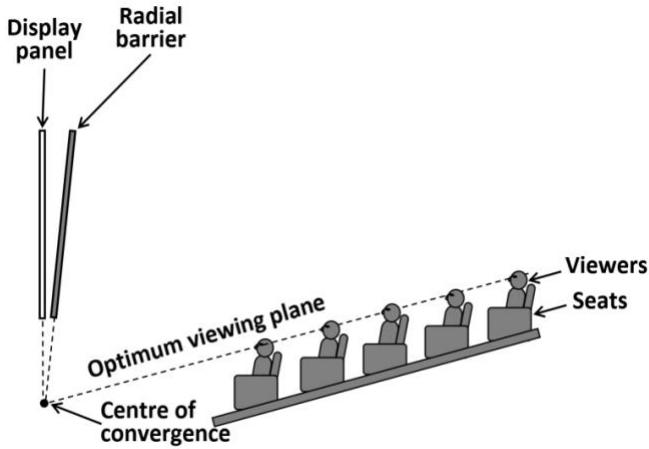


Figure 3 Side view of cinema configuration where the optimum viewing plane, the parallax barrier and the illumination pattern on the white reflecting screen all pass through the centre of convergence.

regions that are located at the OVP. The original cinema displays showed left and right image pairs; however, this restricts viewer head movement as the viewers' eyes must lie on either side of the boundary between the displayed left and right views. As this restricts the lateral head movement to a few centimetres, we have adopted the multiview approach so that several perspective views occupy the width of each viewing region. The viewing regions also radiate from the centre of convergence giving the seating arrangement as shown in Figure 1 lower.

In order to update this principle we use an emissive miniLED screen to replace the projector system of the original configuration. In the earlier systems, the rays from the projector passed through a parallax barrier and then reflected off the white screen behind it and passed through the barrier again to be returned to the viewers. Our simplified emissive LEDs screen reduces this to a direct light path. The principle of operation and an account of the history of glasses-free 3D cinema is found in a very informative White Paper by Blundell [6].

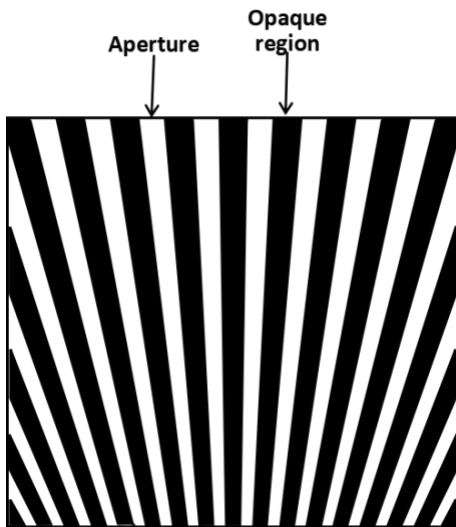


Figure 4 Radial parallax barrier pattern. In practice the pitch of the apertures will be smaller than this as they must not be visible. Also, the aperture ratio is lower than this .

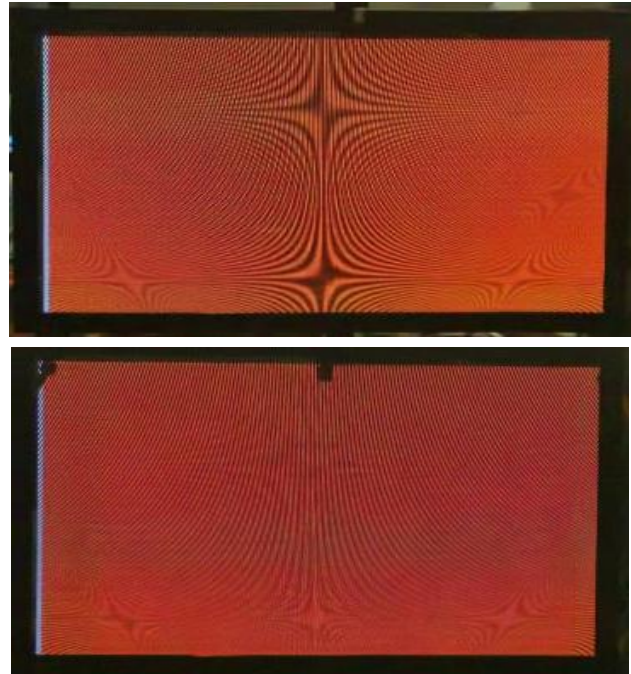


Figure 5 Upper- Effect of moiré without correction, Lower- Reduced moiré with diffuser in front of LED screen.

Although the radial barrier was a proven approach when used in a projection system, there are additional challenges that arise from the use of an LED screen in conjunction with a parallax barrier. The principal challenges are: mapping the original images to the LED screen sub-pixels, low luminance due to blocking of light by the barrier and, most importantly, the appearance of moiré patterning in the perceived images.

### 3. Method

The luminance of our LED panel is 1000 nits so a barrier with a 20% aperture ratio gives a perceived luminance of around 200 nits. This is satisfactory for cinematic use, but will be low for outdoor environments. If the aperture ratio is increased to allow more light to pass through, the inter-view crosstalk increases which causes more blurring for objects appearing away from the plane of the screen.

The initial tests on the prototype have covered Moiré, viewing field mapping and image quality. Due to the location of the display in our lab, it is difficult to carry out all tests at the typical viewing distances that the display is intended for. Nevertheless, much useful evaluation can be accomplished at around three meters from the screen. The barrier has a 20% aperture ratio with the pitch ranging from 2.5 to 5.0 mm over the height of the screen. Assuming a barrier pitch of 3.73 mm at the centre, and a human eye visual acuity figure of 1 minute of arc, gives a minimum viewing distance of around 13 m. Even if the screen was larger, but with the same barrier pitches top and bottom, it can be assumed that any moiré pattern on this small version will have the same shape but will merely be proportionally larger. However, it must be borne in mind that its appearance might be affected to a certain extent by the eyes' contrast sensitivity [7].

Moiré is where the barrier aperture and the LED sub-pixel patterns interfere and create visible patterns, as shown in Fig. 5 upper. This is a problem with the radial barrier as the aperture

angle ranges over 90° or more so any adjustment cannot be used to eliminate the pattern, as is the case for conventional parallax barriers. It merely shifts it to another position. The most serious moiré occurs at the centre line of the screen where the apertures are parallel, or almost parallel, to the sub-pixel pattern.

Moiré is notoriously difficult to predict and trial and error usually needs to be applied. In this case, we found that increasing barrier pitch from the original values of 1.6 mm minimum to 3.2 mm maximum made a considerable reduction to give the pattern in Fig. 5 lower..

The effect of moiré appears exaggerated when observations or photographs are made at 4 m distance, and patterns generally disappear at viewing distances above 10 m due to the contrast sensitivity characteristics of the human eye [7]. One fairly certain method of reducing moiré is with the use of a diffuser; usually one that diffuses in one direction only. However, diffusers must be used with care as they may also reduce the 3D effect. We experimented with a lenticular screen as these provide a convenient one-directional diffuser. Good results are obtained with a 200 lpi lens sheet with f-1.0 lenses having vertical axes and that is in contact with the front face of the display, as shown in Figure 5 lower.

#### 4. Results and discussion

Fig. 7 shows an image captured at 2.5 m. The total depth in this image is estimated to be in the order of 150 mm. Edges are comparatively sharp when compared to the barrier pitch of 5 mm at the top of the image. The screen is rather too small for a subjective performance assessment at 13 m, which is the visual perception limit of one minute of arc that corresponds to the so-called ‘Retina’ resolution. For the next stage of the work we will obtain more miniLED modules so that we can make a more meaningful assessment of the overall perceived quality of the display on a 110” screen.

The ultimate objective of the project is to provide glasses-free moving 3D images to a large audience who are located over the area of an auditorium. The screen size will be around several meters diagonal, the viewing distance in the range of several meters to tens of meters, and the audience size in the range of tens to hundreds. Our work has been expedited by the fact that SUSTech is located in Shenzhen and has close ties with many

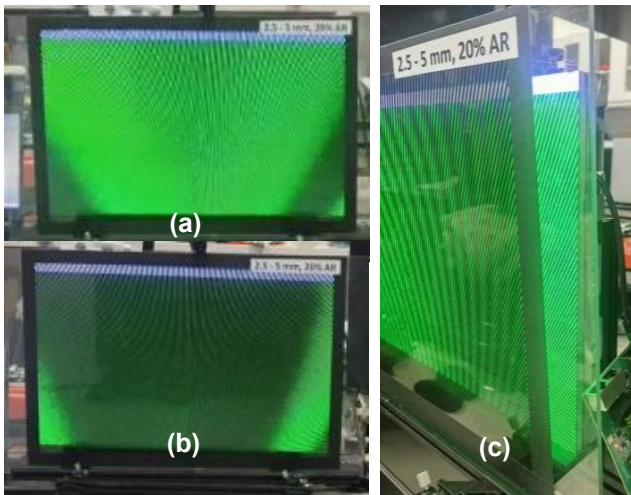


Figure 6 (a) Screen captured at X=0m, Y=1.5m, Z=3m, (b) Screen captured at X=0.15m, Y=1.5m, Z=3m (c) Close-up screen and barrier with test pattern.



Figure.7 Image captured at 2.5 m from screen. Note that some moiré might be seen when this figure is reproduced. However, when the screen is viewed directly at more than 4 m away, moiré is imperceptible.

LED display manufacturers. Consequently, we have built our first prototype based a state-of-the-art art 0.47 mm sub-pixel pitch RGB miniLED module. A single 600 mm x 340 mm module is sufficient at this initial stage as due to the barrier’s radial configuration, the range of aperture pitch from top to bottom can be the same as a full-sized version.

One anticipated problem could be from the change from stereoscopic (left and right view only) to multiview. Stereoscopic displays can show considerable depth where the displayed image can appear to fill a very large volume of space between the viewer and the screen and this can be demonstrated very effectively, particularly in large 3D LED displays where 3D glasses are employed. Due to the large viewing distance of typically several meters, the issue of accommodation/convergence mismatch [8] does not cause discomfort as it can do in some other viewing circumstances. However, when multiview is employed, the depth

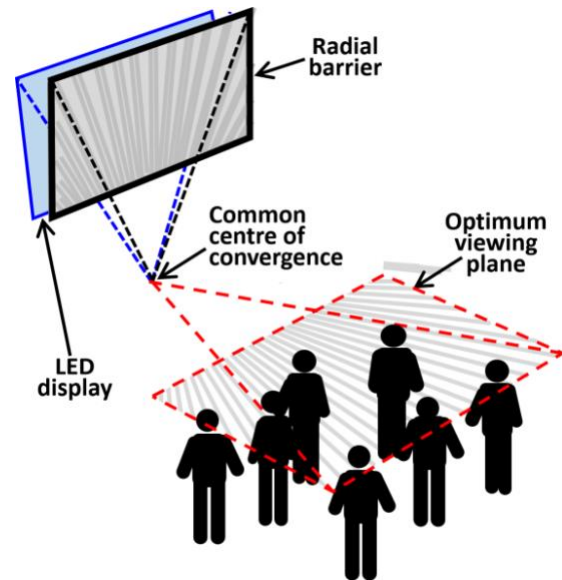


Figure 8. Setup in an OOH advertising application; in this the case the optimum viewing plane is horizontal and is at eye level. The centre of convergence is also at eye level.

of field of the displayed images is limited. We must determine whether multiview can provide images with sufficient depth to give a good experience for the users .

Another potential issue is the use of a parallax barrier where the light from the display is considerably attenuated. In a cinema application this is typically around 50 nits so this is unlikely to be a problem. In fact, it might be possible to reduce our current aperture ratio of 20% so that the depth of field is increased as we can benefit from the depth of field/aperture width trade-off.

If the display is to be used in OOH advertising then it is anticipated that a barrier might be unacceptably dim, so the use of a lens screen is under investigation. This will be challenging as this will require conical lenses, as opposed to the customary cylindrical lenses currently in use. Figure 8 shows a potential OOH advertising usage scenario.

## **5. Conclusions**

The development of naked-eye 3D display technology was relatively slow in the early days. This was mainly due the low resolution of the display panels at that time. Luckily, with the gradual improvement of panel resolution, especially the launch of 4K and even 8K displays in recent years, the commercialization of naked-eye 3D display technology has gradually become possible. Initial work in the area of large area glasses-free 3D displays indicates that it will be possible to achieve with good results. It remains to be seen whether it can become economically viable given the hardware costs that may be involved.

## **6. Acknowledgements**

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