# Reflective Electro-Wetting Displays for Out of Home Display Applications

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***Abstract***

*Digital out of home displays are a very attractive medium to communicate with the public. LED displays have found many applications in this application, however general usage of LED displays is hampered due to their light pollution and power consumption. This creates a unique opportunity for reflective digital displays. Etulipa has developed reflective displays based on electro-wetting display technology and is now field-testing their first reflective display, the electronic changeable copy board for text-based messages. In parallel the matrix-based display has been developed. The panel housing of this matrix solution has been optimized for narrow seems for both black-and-white and full color displays, which creates the opportunity to bring the full color reflective electro-wetting display to the market.*

## 1. INTRODUCTION

Out of Home (OOH) displays are excellent media for companies and organizations to interact with its targeted audience. Examples of such displays vary from bus stop information signs to digital posters to large billboards of 14 foot by 48 foot. The global trend to urbanization is one of the key drivers towards a continuously increasing spending on out of home advertisement. An example that corroborates with this trend: in 2017 the OOH advertisement budget in the USA increased with 4.6%, twice the increase of the GDP growth [ref 1].

The public is used to timely updates in news, information sharing and entertainment as experienced on their mobile devices. The availability of display technologies with high light emissivity created the opportunity to display digital out of home (DOOH) content, which enabled advertisers to communicate timely and intimately with their audience. These trends have resulted to a constant increasing fraction of the DOOH budget going to digital forms of advertising. [ref1, 2].

The outdoor sun has a demanding requirement on the display technology due to its illumination of up to over 120,000 lux at noon at a clear sky. Objects in the environment reflect this intense light leading to luminances of many thousand nits. Any light emissive display that cannot produce a comparable luminance, will be washed out in the day light. This requirement on luminance limits the application of LCD technology typically to semi-outdoor environments, where the LCD screen is shielded from direct sun light, for example in gas stations.

LED screens for DOOH applications are specified with a luminance of at least 5000 nits which makes them the most suitable for general usage in the outdoor environment, but they have two characteristics that limit widespread implementation. Firstly, the emissivity causes light pollution in the evening and night time. This light pollution severely limits the permits that are given for raising digital display constructions. In addition, power consumption is very high, averaged over a day LED screens use in the order of 250 Watt per $m^2$. Note that the power consumption can go above 800 Watt per $m^2$ in bright sun light to keep the display readable.

Reflective displays do not have such issues. The brightness automatically scales with the amount of light falling onto them and the power consumption is extremely low because emissive light does not have to be created. These characteristics makes them ideal candidates for DOOH applications. However, the challenging requirements for the application of reflective displays DOOH made limited wide spread implementation up to now.

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## 2. REQUIREMENTS

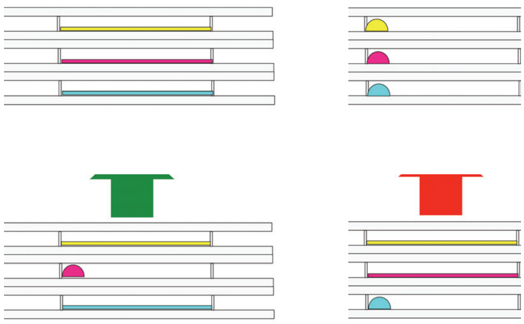
The key technical requirements for implementation of a reflective display technology are discussed below. In addition, it always has to be taken into account that any solution has to be commercially affordable for the application.

### 2.1 Requirement 1: Capability to display bright colors

Bright and saturated colors are experienced when the surface of a reflective display reflects a particular part of the spectrum of visible light. Light emissive display technologies can use a combination of specific light sources, like LED's or can create colors by using an RGB filter. Increasing the strength of the light source behind the light filter causes an increase in the brightness of a particular color. The quality of a color from a reflective display is created purely by the amount of light and the spectrum of that light reflecting from the display. An RGB filter limits the surface that is used in the reflection, and thus creates washed out colors. Reflective displays based on diffraction will have a reflective color that tends to be angular dependent.

Etulipa uses Cyan-Magenta-Yellow electro-wetting display technology to create reflective displays with bright colors. Sub millimeter areas, called electro-wetting cells, are created between two glass plates. Each glass plate has a conducting ITO layer and the electro-wetting cells are filled with a colorless electrolyte and a small amount of a colored oil. One of the ITO layers is covered with an electric barrier which has hydrophobic characteristics.

The oil wets this hydrophobic surface, creating a colored layer, as shown in Fig 1a. In presence of an electric field the electrolyte wets the hydrophobic surface and consequently, the oil layer in each cell will change into a small droplet, indicated in Fig 1b. Each cell acts as an optical stop, creating a situation of seeing a reflected color (Fig 1a) or seeing the white back reflector (Fig 1b). By stacking three of these sets with oils colored cyan, magenta and yellow bright colors can be made by individual switching of the cyan, magenta and yellow layers on or off, as indicated in Fig. 2. A demonstration of the color capability of Etulipa's technology is shown in the screen shot in Fig. 3.



*ig 2. Three optically coupled electro-wetting-display ipanes can create any color. As example: From left o right all closed (all light aborbed) leads to black; ll open (all light reflected) leads to white; magenta pen and cyan and yellow closed leads to reflection f green; and cyan open and magenta and yellow losed, leads to reflection of red.*

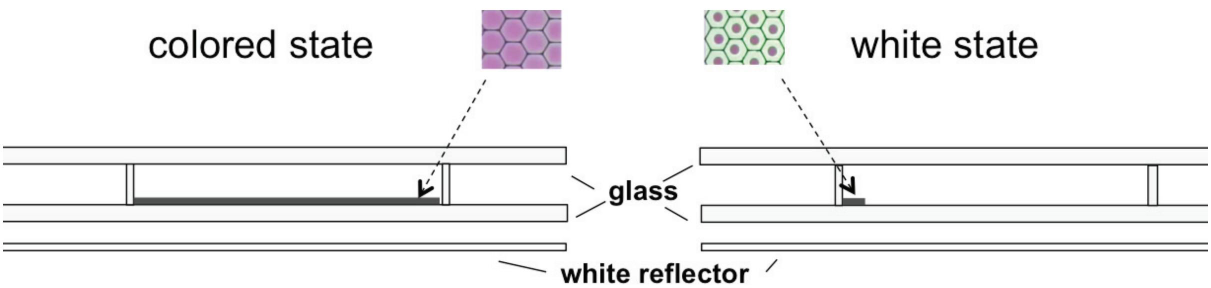



*Fig 3. Still [ref 12] demonstrating high contrast in the demo in the top right, and full saturated colors in the demo in the center under extreme sunny weather conditions.*

### 2.2 Requirement 2: Video speed

There are many applications for reflective displays, as mentioned above. In several cases video speed will not be necessary. They will require change of content once a day, for example a digital electronic changeable copy board (eCCB), or change of content once a minute, for example on information screens at bus stops. Video speed is not necessary in such cases. The switching speed needs to be such that the viewer experiences a smooth transition from one content to the other.

On the other hand, displays with the goal to share information for commercial purposes, third party advertising, have to show full color images and high-speed video. Etulipa's electro-wetting display technology is capable of producing that required high-speed video. Switching times of the individual droplets can be tuned down to 10 milli-seconds. An example of a demonstrator of an outdoor display with video content is shown in [ref 4] Etulipa's youtube channel.

### 2.3 Requirement 3: Reliability

Reliability has many aspects. Obviously critical items for OOH displays are:

- Outdoor air temperatures in commercially interesting areas can vary from -40 °C in the winter up to over 40 °C in the summer. In addition, the sun causes induced heating. Even in display housings optimized for temperature control, the induced temperature can still be at least 22 °C higher [ref 2 Mil Std], leading preferably to storage and operation specifications of -40 °C to over +70 °C. Testing for compliance with these conditions include, high temperature, low temperature, temperature shock and temperature cycling tests. General reference documents like Mil. Std. 810G [ref 3] can be used for guide lines.
- Humidity can be managed by applying IP65 or higher specified enclosures, either on low level, like individual displays or panels or by creation of an IP rated screen assembly.
- An assembly has to withstand vibrations. Firstly, vibrations caused by transport to the construction site, and secondly, vibrations caused by wind and passing traffic. The first type is a one-time event, and appropriate packing can help the product to survive these conditions. The latter vibrations will act upon the product for the complete life time, which is typically 7 to 10 years.
- Light fastness is a property describing how resistant material is to fading due to day light or sun light. Light fastness depends on the strength of the sun, and thus on the geographic location. A requirement on the amount of fading of a display that has a commercial life time of 7 to 10 years implies test times over 6 weeks in test equipment that generates light comparable to the sunlight. [ref 5].

### 2.4 Requirement 4: Seamless experience

DOOH emissive displays build up from individual LED matrix panels result in large seamless screens. Single LCD displays build together to form large displays always have seams, which may detoriate the viewers experience of the shown images. On the other hand, a person reading text from a single display does not experience a perception of low quality due to the edge. Also, reading text from a big distance, for example from changeable copy boards as shown in Fig 4 and 5, is not impeded by presence of seams.


*Fig 4 (left) traditional changeable copy boards.*

*Fig 5 (right) reflective digital changeable copy board prototype from Etulipa.*


That leads to the conclusion that the relevance of seams is determined by a) the content to be presented, and b) the size of the display in relation to the human's field of vision, or preferred viewing angle PVA [6]. When a screen has to show large images, or video content and it is build-up of individual panels and more than one panel fit within the PVA, then seams present between panels deteriorate the image quality.

Commercially affordable digital display solutions define a pixel pitch, optimized for the typical viewing distance. Ideally, this pixel pitch is chosen below the resolution of the human's eye [7] such that the viewer does not experience any pixelated image. Obviously, a seamless experience implies that high quality screens have to be designed also with seams with a dimension smaller than can be distinguished by the eye of the viewer at the typical user distance to the screen. Etulipa designs reflective matrix panels with pixel pitch of 10mm. A high quality seamless experience is guaranteed by design of seams with dimensions up to maximally 1/3 of the pixel pitch.

Etulipa's first digital reflective matrix display is developed for retail customers to present messages and information. The format is the typical CCB (4 ft by 8 ft) which allows customers to easily exchange the passive CCB with a digital version without any construction hassles. The system can work off-grid. The low power consumption can be provided by a solar panel. A first prototype is shown in Fig. 6.


*Fig 6. Prototype design of Etulipa reflective digital matrix panel display with seams with dimensions maximally 1/3 of pixel size.*

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