

2022 Update Notes

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2023 Update Notes

Outline

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Transparent OLED

Transparent LED

Spinning Fan Persistence of Vision Displays

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Laser Projector filming techniques

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Head mounted displays

Projection on Static Transparent Material

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Volumetric Projection

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Projection on water droplets

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Fiber Optics and Acrylic

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Computational Caustics

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Wood Veneer and LED

Others

PDLC

SPD

Electrochromic Glass

LCD

{% embed url="https://vimeo.com/105175961?embedded=true&owner=403780&source=vimeo_logo" %}
description: Paint that can light up and change color when a current is applied to it.

Electrochromic Paint

Plasma Combustion

Other Experiments

Light Leaks

Wedge Display

Lickable Display

Liquavista Electrowetting Displays

Deconstructed LCD

Colloidal Bubble Display

Parallel Reality Display

Phases by AV&C

Robotics and Displays

Overview

CRT

Vectex Displays

Eggcrate and other Numeric Displays

Eggcrate

Nixie Tubes

Others

Pyrotechnics and Other Curiosities

Pyrotechnics

Eidophor Projector

Holograms

Autostereoscopic Displays/3D TV's

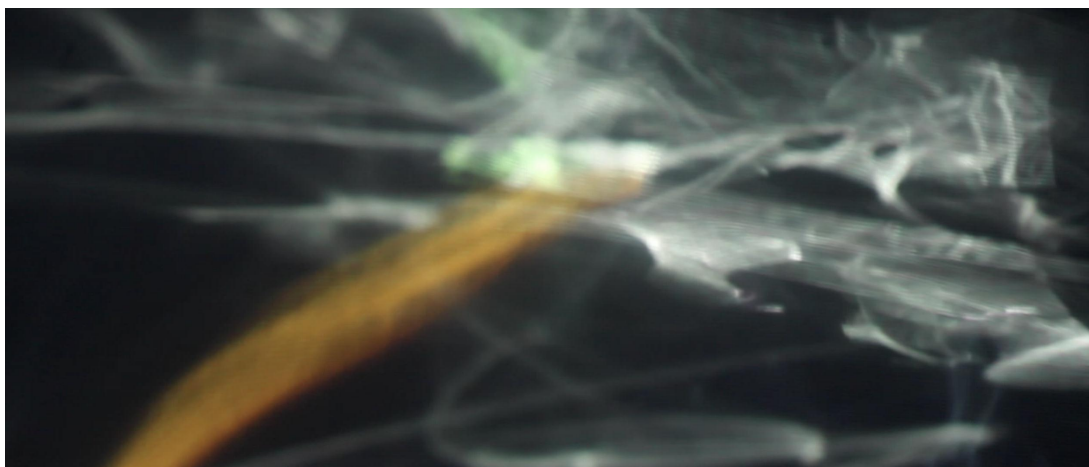
LED TV's

3D LED Displays and Forced Perspective

DIY Notes to Remove the Polarizer from your Monitor

Notes on DIY Transparent screens

2022 Update Notes



(Original version from [Blair Neal](#))

This article was originally created and hosted on Medium, but its length on a single page made it very unweildy to keep it updated with fresh content. Additionally, most of the information is from the original writeup from 2015 and needs a pretty serious update as many things have changed in 7 years.

This update will be ongoing and some sections may be more updated than others. Gitbook may not be the final resting place but it seems like the best approach for now.

🌟 If you're on Github: This page is auto generated by Gitbook and is more readable at the link here, especially for things like embedded videos.

If you're on Gitbook, the link to the Github for this article is here. Please contribute if you'd like!

If your project or image is featured here and you would prefer me to remove it, please send me a message/email/etc (contact info on my website). Additionally, if you have something you think needs to change or be added, please submit a pull request and I'll add it in.

Additions for 2022 compared to the original 2015 version:

- Moved to github/gitbook
- Re-organized content and added a new outline
- Added new content and examples to almost every content page
- Added separate sections for Legacy, Technique, and Experimental approaches
- Added the following sections compared to the original, and dozens of new examples and videos. Most of the original categories also have many new subcategories within that weren't originally included.
 - Switchable Glass
 - Drone Displays
 - Many new Transparent displays and transparent OLED updates
 - Electrochromic Paint
 - Scanning Fiber Optics
 - Lasers and video projection
 - Laser Diodes
 - Many new Lightfield displays (Looking Glass, Solidlight, Fovi, Leia)
 - Architectural E-Ink
 - Ferrofluid
 - Acoustic Levitation
 - High Refresh Rate Displays
 - Cathode Ray Tube
 - Eggcrate and numerical displays
 - Pyrotechnics and other curiosities
 - Misleading terms
 - Touchscreen notes
 - XR and Virtual Production
 - ...and more?

This is currently using Gitbook's free plan. If there is enough interest, I could set up a tipjar or something for this project and open it up as a paid project with multiple contributors and the ability to export the entire thing as a formatted PDF.

Notes on Contributing Updates

Content contributions are encouraged and welcomed! Please submit a pull request and I'll get back to you.

Categorizing:

While there are a ton of top level categories and a bit of inconsistency in how I'm organizing, I'm going to do my best to keep things in certain places. If you have a display technology that only has a single example, it will most likely be a better fit for the "Experimental" category instead of just the alternative display category.

In my (rough) categorization:

- Alternative Displays: mostly commercial products and things you can buy or rent right now
- Techniques: a combination of a commercial product and a fabrication/optical technique
- Experimental/Other: this is a catchall for one-off art projects and lab/research experiments. Not a clear line between this and the technique section - open to suggestions on clearer delineations.
- Legacy: mostly for things that are discontinued or no longer used

Images:

I'd like to reduce the reliance on external images hosted that could eventually disappear. Please include images in the repo - just make sure they aren't overly large (<10-5mb please, aim for a compressed jpg if possible)

Gitbook works a little differently with images and they are stored in the .gitbook asset directory and have relative paths. See this example from the page in /Alternative Displays/Lasers and Laser Projectors.md

```
![Matthew Schreiber's Focal Point](../.gitbook/assets/Ontario.jpg)
```

Content Embeds:

One important note is for embedding content, Gitbook uses a custom format for embeds - html/iframe would also be fine, but for consistency I've mostly stuck with Gitbook's formatting which looks like this:

```
{% raw %}  
{% embed url="https://www.youtube.com/watch?v=WxgVYCxShvA" %}  
{% endraw %}
```

Note the odd spelling of "endembed" instead of embedded when adding a comment beneath an embed. Ideally adding a comment for what the video is will be hugely helpful later whenever youtube videos aren't visible.

```
{% raw %}
{% embed url="https://www.youtube.com/watch?v=D1pa3UX89GA" %}
Rollable OLED {% endembed %}
{% endraw %}
```

2023 Update Notes

To add:

- Transparent OLED with black pixels <https://www.flatpanelshd.com/news.php?subaction=showfull&id=1673336078>
- Stacked RGB pixels: <https://news.mit.edu/2023/vertical-stacked-color-microscopic-leds-0201>
- Royole Flexible tree display and flexible panels - <https://global.royole.com/us/rotree>
- Rollable LG tv
- PJ-Link 3D LED TV Display - actuated LED panels
 - : https://www.youtube.com/watch?v=CNYp_R1sriw
 - https://www.youtube.com/watch?v=19I453Vj_60
 - Wayfinding leds: <https://www.youtube.com/shorts/tWAruYoVHc>
 - Mechanical overview: <https://www.youtube.com/watch?v=Swt6U6aD2OY>
- One Plane Displays or projection displays
 - <https://www.industrialalchemy.org/articleview.php?item=511>
- Nixie tubes to vintage area?

Already added since 2022:

- **UV activated materials (photochromic pigments and paints)**

description: This is an overview of everything that is covered in the following sections.

Outline

- **Introduction**
- **Brief Notes on Standard Displays**
 - LCD/Standard displays
 - LED
 - Projector
 - OLED

• Displays

- Transparent
 - Transparent LCD
 - Transparent OLED
 - Transparent LED
 - Spinning Fan Displays/Persistence of Vision
 - Electroluminescent Displays
- Modified LCD Polarizer
- Volumetric Displays
 - Mechanical/Persistence of Vision
 - Layered screens
 - Volumetric LED
 - DIY
- Electronic Paper/E-Ink
 - Standard
 - Sculptural/Architectural
- Flexible Displays
 - Flexible OLED
 - Flexible LED
- Lasers and Laser Projectors
 - Laser Projectors
 - Laser Projectors and Video Projection
 - Laser Projectors and film techniques
 - Laser Diodes and other approaches
 - Lasers and photosensitive surfaces
- Light Field displays
 - Looking Glass
 - Solidlight
 - Leia Lightfield
 - Fovi3d
 - Multilens Displays
- Head Mounted Displays (VR/AR/Mixed Reality)

• Techniques:

- Pepper's Ghost
- Projection on Static Transparent Materials/Scrims
- Projection on Water or Fog
 - Water Screens
 - Fog Screens
- Volumetric Projection
- Diffusion and Distortion
 - Artistic Approaches
 - Fiber Optics
 - Ulexite/TV Stone
 - Computational Caustics
 - LED through wood veneer
 - Low Resolution Diffusion
 - Others

• Experimental/Artistic Exploration/Other

- Physical/Mechanical Displays
 - Flip-dot
 - Split Flap
 - Other Mechanical Approaches
 - Interactive Haptics
 - Ferrofluid

- Switchable Glass
 - PDLC
 - SPD
 - Electrochromic
 - LCD
- Drone Displays
- Electrochromic Paint
- Scanning fiber optics
- Acoustic Levitation
- Plasma Combustion
- High Refresh Rate Displays
- **Legacy/Vintage Curiosities**
 - Cathode Ray Tube
 - Eggcrate and numeric displays
 - Pyrotechnics and other curiosities
- Closing Notes
- **Appendix and Other References**
 - Misleading terms
 - Hologram
 - Autostereoscopic Displays/3D TV's
 - LED TV's
 - 3D LED/Forced Perspective
 - Touchscreens
 - XR/"Virtual production"
 - DIY LCD Polarizer Removal
 - DIY Transparent Screens
 - Acknowledgements and Other References # Standard Displays Overview

Before we talk about "alternative displays" we should briefly cover what could be considered more standard displays. The main 3 categories are things like standard TV's and monitors (that have many subsets within them), LED video walls, and projectors.

Standard Monitors

Image Source

Image Source

These can be a range of different technologies like LCD, OLED, and many others. Currently, the most common display is the Liquid Crystal Display or LCD and it is in most laptop screens, desktop monitors, commercial TV's and so on. LCD's have a backlight, a rear polarizer, a glass layer with electrodes and liquid crystals that react to electrical changes, and a front polarizer. Each pixel has a set of 3 sub pixels with red green and blue color filters that can be combined at different levels to recreate their millions of colors.

Technologies like Quantum Dots (such as in Samsung QLED line) promise to improve LCD's color reproduction and accuracy by allowing more precise tuning of light wavelengths. Plasma displays were contender for LCD for a while, but they have become less popular. Pixels in plasma displays are individually lit which result in a deeper contrast compared to LCD's.

Organic Light Emitting Diode displays or OLED displays operate in a similar principal to Plasma and are now almost as common in consumer TV options as LCD displays. OLED has a lot of interesting properties since it can be made smaller and thinner than LCD or Plasma, this means that flexible displays and transparent displays are a much more viable option with OLED. OLED is still quite expensive in comparison to LCD's at the moment, but this will change as the market shifts. MicroLED is another technology that works in a similar fashion but is still fairly new.

Standard monitors are affordable for most applications, are high resolution which makes them ideal for applications when the view is standing up close, have a decent color and dynamic contrast range, accept a variety of inputs, and are long lasting. Consumer displays are also typically two dimensional and flat, even if displaying 3D content with glasses or another method. Their brightness is suitable for primarily indoor applications. Brightness of these is generally measured in nits or candela/sq meter — most laptop screens are around 300nits at maximum. For outdoor applications, you have to source specially made outdoor monitors that are weatherproof, can withstand a variety of temperature fluctuation, and have a considerably higher brightness rating — some available ones can do 1500 nits or more which would be almost painful to look at up close in an indoor setting.

Of course, these displays have their limitations. They are only viable up to a certain size for a single unit. Most of the largest max out at 120in or 305cm of diagonal image. Past this, they must be tiled together to form a larger video wall, and there are inevitable lines or bezels between adjacent units. Even those larger video walls start to reach a limitation at a certain point where Projectors or LED video walls are a more economical choice.

The color and dynamic range of these monitors appears to be decent, but it is actually not as good as you might expect— we are missing out on a whole range of visible colors. Most standard displays are also locked at 60hz refresh rate (the speed that the screen is redrawn every second) which is perfectly fine for most applications like movie watching, but things like gaming monitors have started jumping to 240hz or more. Even though our brain's visual refresh rate is about 60hz (a huge oversimplification), there are some intriguing things that can be done with a higher refresh rate. Imagine scrolling this page up and down and having it look as natural as a piece of paper moving up and down instead of the commonly jittery experience. There are also researchers looking into using high frame rate or high temporal resolution displays to do things like turning normal displays into higher resolution displays — here is an incredible survey of a range of options with computationally augmented displays.

LCD's Explained

{% embed url="https://www.youtube.com/watch?v=VamqtyatBss" %}

OLED's explained:

{% embed url="https://www.youtube.com/watch?v=xAMhX3Drq14" %} # LED

Image Source

Image Source

LED Video Walls are another common option for displaying digital art on a large scale (also called LED Displays — not to be confused with LED Monitors where the light source is simply the LED backlight). These are usually comprised of individual tiles that are linked together and driven by a special display driver box that addresses the tiles from a standard monitor input. The tiles are generally either single all-in-one RGB LED's or larger individual R,G and B LED's that are placed close together.

The primary specification of an LED wall is its pixel pitch, measured in millimeters. If you are viewing a wall close up, you want a low pixel pitch — some can get very small, even in the 0.9mm range and smaller these days. Larger pixel pitch such as 16mm to 20mm is perfectly acceptable if your viewer is really far away from the screen because their eye won't be able to discern individual pixels as easily. LED displays are also one of the only display types that can be viewable in direct sunlight. Some of them are 3000nits or more of brightness, which explains why they are the display of choice in places like Times Square.

LED video walls have a wide variety of models and applications. Some are used as jumbotrons in stadiums, as high end storefront signage, or are used as sculptural stage elements. Some move towards the spectrum of lighting elements and are extremely high pixel pitch. These large pixel pitch tiles can be used almost as “transparent” elements because when the audience is far away, they are able to see through the frame — as in this video wall. Stage lighting examples are the LightSlice, Vanish, and the Saber. Some manufacturers also provide custom LED tile work and can do more unusual shapes like spheres, curves, triangles and more.

The primary drawback of LED walls is cost, although the prices have been dropping rapidly in the past few years as these become more commonplace. Most LED walls for events are typically rentals due to the large cost of purchasing and the labor to install them. They do last a long time in the case of purchasing, but even a modest sized wall at a high resolution can run into the hundreds of thousands of dollars very quickly. The cost of installation (for rental or permanent) can also be an additional hurdle since you typically need an experienced technician to set them up and get the pixel mapping established. Some stage designers will overlay a black or dark grey rear projection material or even acrylic overtop of the LED's to soften them and provide a more diffuse look. When using an LED video wall for applications that require very close viewing distances, content design should be considered very carefully. LED walls can be so bright that using content on a white background in an indoor setting can feel a bit like staring at the sun - most walls used indoors are typically set at only a fraction of their potential brightness.

Because of some of the cost and special considerations involved in installation, most people will often work with an AV integrator to facilitate the acquisition of the electronics needed for the LED wall, the media systems planning, the physical installation plan, and the installation itself. There are many options for integrators and different levels of involvement, but to name a few sources of LED product and integration options in the US, you can look at companies like Fuse Technical Group, DetailLED Solutions, Creative

Technology Group, Electrosonic, and Diversified to name a few. Some places are more suited for permanent installation versus rental and you often need to find the right fit for your project.

{% embed url="https://www.youtube.com/watch?v=h8imXrmm-yw" %} LED Walls: A Beginner's Guide {% endembed %} # Projector

I have covered projectors in depth in [another article](#) (it is from 2014, so it needs an update as well) so I won't go into detail with them here.

It is important to remember that they are not much more than a fancy implementation of a light source, an imaging element and a lens. They are best for darker environments, but they tend to be the most economical choice for large scale imagery. It is also easier to blend multiple projectors together more seamlessly. # Overview

This area covers a wide range of technologies that could be considered alternative displays compared to the standard ones. They are often niche products or artistic approaches. As such, many are very expensive when compared to standard ones.

After this section, there is a slightly different category of "techniques" that is more of an unusual application of a standard display. There are plenty of crossover ideas between the two, so I wouldn't consider either as a strict line. # Transparent

- [Transparent LCD](#)
- [Transparent OLED](#)
- [Transparent LED](#)
- [Spinning Fan Displays/Persistence of Vision](#)
- [Electroluminescent Displays](#)

Transparent LCD

{% embed url="https://vimeo.com/50200308?embedded=true&owner=3549383&source=video_title" %} https://vimeo.com/50200308?embedded=true&source=video_title&owner=3549383 {% endembed %}

LCD's are a transmissive technology (in contrast to Plasma or LED that are emissive technologies). This means that light passes through a medium to get to your eye. The backlight that is used for LCD's is meant to provide a strong and very even field of light that gets passed through the actual liquid crystal/polarizer element. Essentially, the backlight is a flat light box that you can fade up or down, but it doesn't have much else to do with creating the image itself.

A liquid crystal element can function perfectly fine on its own, without a proper backlight. This means that an LCD can effectually work as a transparent monitor if you are keeping some sort of light source between the screen and the viewer.

A common usage is to put an object in a box with a strong, even light behind it, and have at least one side of the box be a transparent screen. This allows you to superimpose sharp graphics that appear to float overtop of the object inside. The Hypebox is a commercial product that is built around this idea of a transparent screen that has a strongly backlit box behind it for placing different products. This can be combined with a standard touch screen for interactive transparencies. Also, since LCD's do such a good job at blocking light, when they are displaying black they are nearly impossible to see through (when facing front on), providing a unique reveal effect. A bright point light source can be put behind them to use the LCD as a sort of projection mask — resulting in a variation on a normal projector (your projected image will probably be fuzzy without focusing lens elements though).

```
{% embed url="https://vimeo.com/133062810?
embedded=true&owner=994292&source=video_title" %}
```

Some artists and studios have also been able to source custom LCD elements that are closer to the LCD's that are used in old pocket calculators with only a few elements that can be turned on and off. Pieces that come to mind are Hypersonic's Patterned by Nature and Iris by Hybe.

A challenge with transparent LCD's is sourcing usable ones. There is a DIY route — but the visual results aren't great. Only a few commercial vendors supply these screens, and because it is a specialty item, they tend to be more expensive than comparable screens with backlights. You may also be limited by certain available sizes — making it difficult to scale these to a large application. Even if the screens were tiled together, at least one edge needs to have the driver board on it, so its not as easy to tile them together like normal LCD walls. The color reproduction with these transparent LCD's tends to be a little duller than the vibrant colors you're used to. Their transparency can be cloudier compared to regular glass since the polarizer and liquid crystal layers are sandwiched in there as well. I've found that black, white and gray content is the most striking on transparent LCD's.

Transparent OLED

```
{% embed url="https://www.youtube.com/watch?v=2wgLUDKSaTg" %} LG
Transparent Display {% endembedded %}
```

Compared to transparent LCD, transparent OLED's, however, are a different beast. OLED is an emissive technology and therefore does not require a backlight. This means that brightness and color reproduction will be much better compared to transparent LCD. Their brightness still isn't going to rival a normal display, so they aren't ideal for any sort of outdoor use or in a brightly lit space. Also, in contrast to a transparent LCD that works somewhat equally on both the front and back, for now, transparent OLED is only visible on one side since the emissive element is designed to point in one direction.

Transparent OLED's are still very useful for a lot of creative applications like being applied to a storefront window without blocking the view or applied onto a mirror so that graphics can be superimposed on top of the mirror. You can also position a camera directly behind them when doing magic mirror

digital effects. You can stack multiple OLED's in front of each other for a layered effect, but there is a caveat. There is a significant darkening effect that occurs when looking through the panels, it's like a few stops of a neutral density filter — so when you stack them, they get darker and darker as you go backwards. There is also a larger display driver that comes off the back about 8 inches down the long side on the models I have seen, so this limits your ability to layer them closely together for a volumetric display.

Transparent OLED's used to be available for a short time in the mid 2010's and then kind of disappeared from the market for some time. Some of the rumored reasons for this are that the displays produced back then had some serious manufacturing issues that led to them being very expensive and difficult to produce. They also had a limited or unknown lifespan and it was difficult to rely on them for permanent installations. As of 2022, [LG](#) and [Planar](#) currently offer transparent OLED solutions that top out at 55" 1920x1080p displays. The cost of transparent OLED is still considerable since it is a niche product - some estimates are in the \$20,000-\$25,000 range for a single 55" display.

Also, be wary - while there may be other providers of transparent OLED, they are usually using Samsung or LG components. Some potential rental sources of some old transparent OLED I've come across are [ABCComRents](#) and [Oxygen Eventworks](#). These screens can also be made interactive with different touchscreen approaches.

Transparent LED

There are a few different approaches to Transparent LEDs that are out there in the market.

The most common and slightly cheaper solution are products that essentially have rows of LEDs on very thin metal strips that are mounted in large frames. There are resolution limitations with these solutions because of their construction and the need for gaps to create the "transparent" effect, but they are great solutions for stage shows and architectural installations. [Roe's Vanish](#) line is an example of this type of a product.

Transparent LED strip example with Roe Vanish
Transparent LED strip example with Roe Vanish

The other transparent LED solution out there uses LEDs that have been mounted on special glass panels. These LEDs are powered and controlled using very thin, nearly invisible electrical leads on the glass. There are limitations on the pixel pitch, brightness and resolution with these products, but they provide a fairly convincing transparent effect. Due to brightness and resolution limitations, they are best used on large scale architectural installations and intended primarily for evening and nighttime viewing as opposed to full daylight.

See also: [Muxwave transparent LED](#)

[GLAAM's G-Glass](#) product is one example of a commercial product in this space:

{% embed url="https://www.youtube.com/watch?v=9NT1ww4nMis" %}

Spinning Fan Persistence of Vision Displays

There are a lot of products out there for these kinds of “holographic” spinning fan displays that could be considered a different type of “transparent” display. Hypervsn comes up the most often for a single and multiple unit system. These products use a spinning mechanism and a strip of LEDs on each fan blade. When the fan spins fast enough, the LED’s draw each frame and the persistence of vision illusion allows a user to see an image that appears to float in mid air.

By their nature, these displays are still just perceptually flat and not true 3D, but with the right content they can provide some convincing visual tricks. One nice element of these displays is that they are scalable in the sense that multiple units can be linked together to create larger images.

![Hypervsn Wall

](../gitbook/assets/03_556x400_00159.jpg)

{% embed url="https://www.youtube.com/watch?v=8ZuoRWRzS_c" %}

Artists such as TUNDRA have found other interesting applications of these technologies by layering them with different content, such as in their piece *Row*

{% embed url="https://vimeo.com/535964694" %}

There are also other ways to create the same persistence of vision effect using lateral motion. In the experiment video below, an engineer experimented with quickly vibrating a thin strip of “FlexLEDs” up and down to create a rough sketch of how this could work.

{% embed url="https://youtu.be/wM_Byrv9iBI" %}

Electroluminescent Displays

These are similar to old LCD displays for calculators in that they are somewhat fixed in the images they can display as they rely on illuminating special layers of material as opposed to individual pixels. One provider is Lumineq.

Lumineq Electroluminescent Display
Lumineq Electroluminescent Display

{% embed url="https://www.youtube.com/watch?v=d16Y6QDN3Gg" %}
Lumineq Demo Video {% embed %} # Volumetric Displays

There are many types of volumetric displays and various ways we could classify them. Below we’ll cover volumetric displays that use the principles of using mechanical or persistence of vision illusions to create images, and

another version that uses layered screens to create a sense of volume. In a separate section we'll cover [light field displays](#) that have another take on this whole approach.

- [Mechanical/Persistence of Vision](#)
- [Layered Screens](#)
- [Volumetric LED](#)
- [DIY](#)

Volumetric Displays (Mechanical/Persistence of Vision)

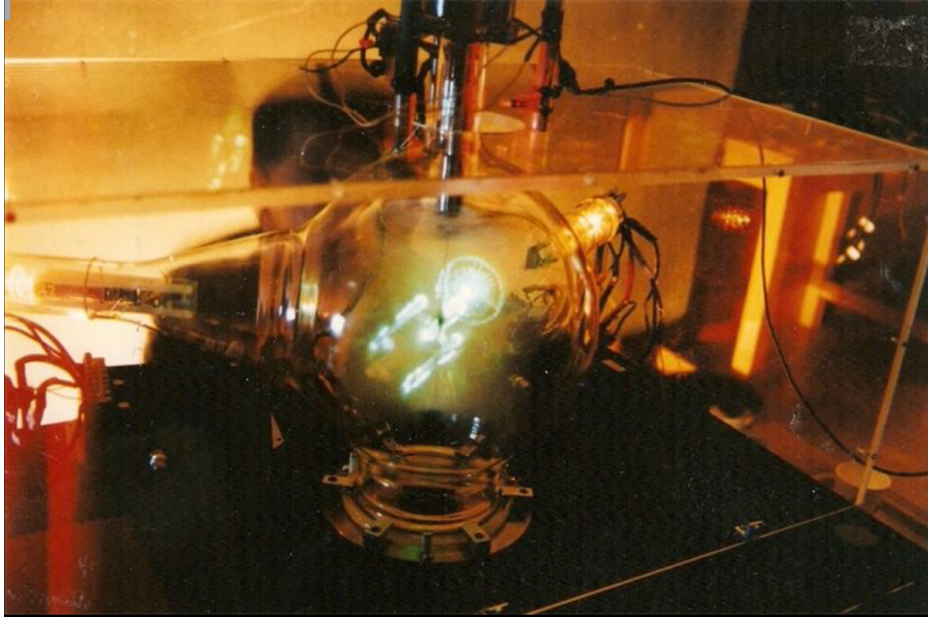
{% embed url="https://www.youtube.com/watch?v=I7vgha_N5s8" %} viSio Volumetric Swept Volume Display — [Source](#) {% endembed %}

With [Volumetric Displays](#), there are a couple different flavors, and in this section we'll cover displays that work with the principle of persistence of vision, and are also known as swept volume displays. Volumetric Displays have been discussed in science fiction for decades and have been researched extensively since the 1960's. [Here](#) is a 1969 paper from Bell Labs on a technique that uses a loudspeaker to vibrate a reflective mylar sheet in sync with a CRT to make an image volume.

This type of volumetric display usually uses a 2D display element in addition to a mechanical apparatus to move the display quickly enough (either laterally or radially) to give the illusion of volume. You can buy persistence of vision (POV) LED toys at carnivals and festivals that are the same basic idea that is found in the more complex setups discussed below. Crayola even made a toy a few years ago called the [Digital Light Designer](#) that let kids draw on one of these displays in real time. There are also more sophisticated LED based setups such as the [viSioor](#) [voLumen](#) that are mentioned in the links section.

These volumetric displays allow for one of the best impressions of 3D physicality and presence because the viewer can walk around and view different angles of the same image. The downside is that their mechanical nature makes them difficult to scale to larger displays with finer resolution, and the fact that they are moving so quickly can make them quite dangerous in certain situations. Some techniques can also be difficult to capture reliably or smoothly on video because the refresh rate may be out of sync with the camera's frame rate.

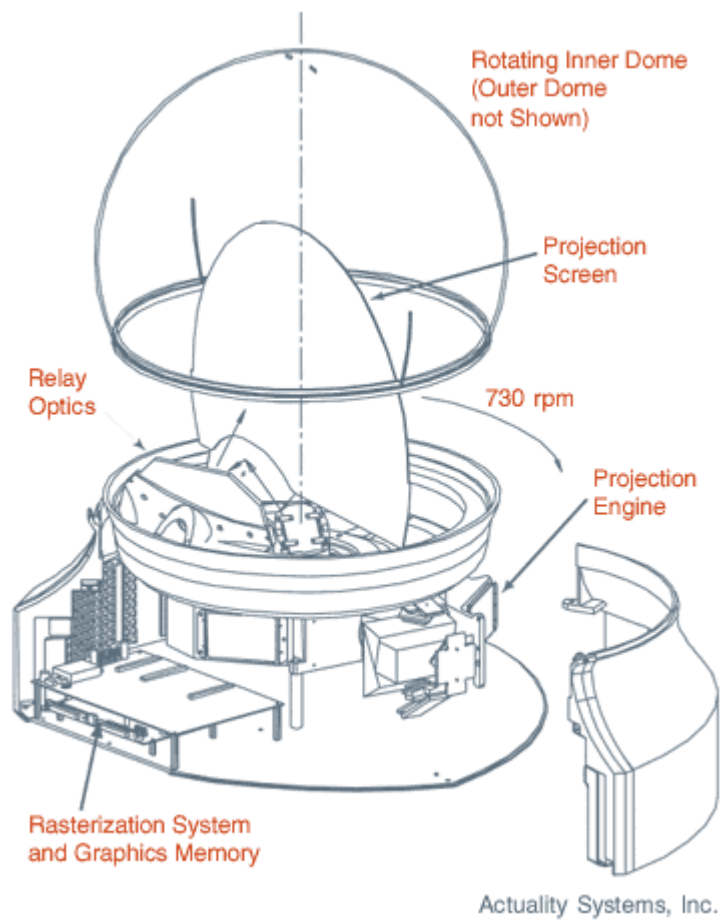
There have also been attempts at combining mechanical motion with more sophisticated displays like CRTs, projectors or LCDs. One of the earlier successful examples of these screens is [Barry Blundell's](#) volumetric cathode ray tube work. He did some experiments in the 1990's that used a specially designed glass tube, a spinning phosphor plate and multiple electron guns. [Here is a video](#) of that display in action.



Barry Blundell's Cathode Ray Sphere -Source

The Perspecta by Actuality Systems came in 2001 and followed a similar approach, but used specialized projectors and a rotating screen instead of electron guns. Here are some stats on the capabilities of the early version of the Perspecta:

"This computation is performed on a high-end NVIDIA GPU within the Volume Rendering Unit, and the results are stored in the Core Rendering Electronics (CRE). The CRE drives three Texas Instruments DMDs (Digital Micromirror Device) at approximately 6,000 frames per second with these slices, which are projected onto a diffuse screen that rotates at 900 rpm. The result is a crisp, bright, 3D image that can be viewed from any angle."[\[Link\]](#)



Perspecta Diagram — Source

A more recent version of this type of display is the Voxon VX1 (\$9800USD). Their former product was the Voxiebox. These displays use a high speed scientific projector and a rear projection platform that is moved up and down extremely quickly. The movement of the platform, the refresh rate of the projector and the content that is being drawn are all synced together by software. As the platform moves, a different slice of a 3D image is projected. As these slices are projected, the viewer's brain assembles them into a persistent volumetric image.

{% embed url="https://www.youtube.com/watch?v=IQvkn9-ghhs" %} Voxon VX1 {% endembed %}

The Z axis resolution of the Voxon display is primarily limited by the frame rate of the projector and the lateral motion of the projection platform. There are also challenges with scaling this display to a considerably larger size for a number of reasons. Moving a much larger platform up and down a greater distance at a rapid pace isn't outside of the realm of mechanical possibility, but it would be a different engineering challenge to make this display several meters wide and move up and down a few meters multiple times in a second. A larger platform also requires a brighter specialized projector, which comes at its own cost.

Voxon VX1
Voxon VX1

Perceptually, the Voxon style of display is suited to some particular visual aesthetics — it is better at showing certain types of graphics than others. The projected light is additive on each slice, so while one surface appears solid, it also combines with the light behind it — this is similar to the issues faced by volumetric projection in the other section. This makes very dense imagery move towards the white end of the spectrum as different slices add together for the viewer. Vector style imagery with points and lines tend to be more successful ways to represent solid shapes.

Another more artificially focused example of a mechanical volumetric display is Benjamin Muzzin's piece Full Turn. Benjamin took 2 LCD panels, stuck them back to back and spun them at very high speeds. The power and video signals were passed in using a specially designed slip ring. The bottom ring is fixed and has one end of a cable attached to it. The top layer spins with the LCDs and maintains electrical contact via metal brushes that run in circular channels. As the LCD spins faster than the refresh rate of the screen, it allows it to render volumetric images that move and shift. In comparison to the Voxiebox, this particular implementation presents a different challenge when trying to form coherent 3D images because of the radial motion as opposed to lateral motion.

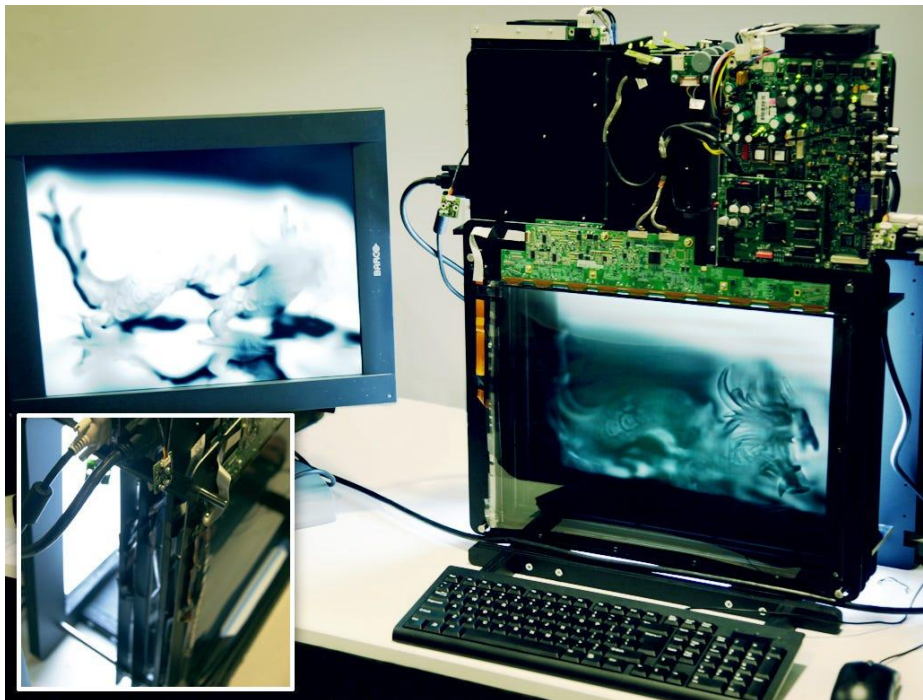
{% embed url="https://vimeo.com/74735651" %} <https://vimeo.com/74735651> {% endembed %}

Volumetric Displays (Multiple Layered Screens)

{% embed url="https://youtu.be/sVv1oc14X1w" %} Tenex Solid State Volumetric {% endembed %}

There are a few different types of this type of volumetric display. One type is known as a Light Field Display or a Polarization Field Display and uses a series of layered LCD's (or other transparent media) to create an illusion of depth via parallax. This is a simplified explanation because there are a lot of nuanced variations on this concept. The Nintendo 3DS is a well known version of this type of display — it uses 2 stacked LCD's — the bottom one alternates dark bands so that each eye sees the version of the image that is intended for it.

By stacking each display on top of the other, you are able to create volumetric effects with 3 dimensional content, or more slipping parallax effects with 2D content. The depth resolution is limited by how many displays you can stack on top of each other. It also becomes more difficult to backlight all of the stacked displays so that everything is visible. Each display, its components and polarizing film will cost a little bit of luminance and clarity for the viewer. If the screens are far apart, there is also the possibility of internal reflection between two adjacent screens that can impact the contrast.



MIT Media Lab's Polarization Field Display — Source

When using this type of display technique to show content, there are a few different approaches and challenges. The most straightforward method is to chop up your images into different depth layers so that you can achieve parallax by displaying each layer on a different screen. This is similar to the method of hand drawn cel animation where the background landscapes are on a different layer than the characters. To achieve more of a 3D volume effect with this method, you would have to incorporate viewer eye or head tracking into the display software in order to display multiple viewpoints in real time. The screens are also only viewable on 1 or 2 sides of a cube, instead of 4 or 5 sides. Your Z-dimension is constrained by how many displays you can stack on top of each other. Blending colors across multiple screens is also a challenge. Stacking dark colors will turn muddy at the end

and stacking red green and blue won't necessarily make white as with other additive light methods. Color filters also impact the brightness, and some [projects](#) use grayscale monitors instead.

{% embed url="https://vimeo.com/266093174" %} RENDER from WOW uses multiple layered OLED's {% endembed %}

Getting a video signal to each display is another technical challenge, depending on how many layers you are trying to drive. If you have 6 stacked displays at 1920x1080 — you need to be able to render six 1080p streams at once and keep them all synced together.

[LightSpace Technologies](#) has a display that was formerly known as the Depthcube that uses a high speed projector and a series of about 20 LCDs that are used as optical stops, so that each layer of depth can be halted at the correct location. By using special antialiasing techniques, the physical space between the layers can be smoothed so it doesn't feel so stepped. Here is a [writeup](#) with more technical details on how it works. This display has been in development since the early 2000s and has been commercially available at an unknown price point. The primary use case of one of these displays has been in engineering or medical applications. Here is a [video](#) of it in action.



Depthcube Diagram and Image — Source



Depthcube Diagram and Image — Source

There are some versions of layered screens or display volumes that don't stack multiple LCDs but combine them with things like layered Pepper's Ghost, multiple projections on scrims, transparent acrylic, or LED cubes.

Around 2016, Looking Glass Factory developed Volume which was poised to be an affordable multiplane display. It achieved its effect by means of a projector and about 12 layers of angled material that catches a small sliver of the projector's raster. They used a custom plugin for Unity that allows you to drop a 3D scene into their renderer and have it slice it up appropriately for their volumetric display. Eventually the Volume was discontinued for their higher quality Looking Glass Portrait that uses a specialized light field approach.

Volumetric LED

There are also many pieces or products out there that use a 3D volume of individually addressable LEDs to create a layered volume with more viewing angles but a lower visual fidelity.

LEDPulse's Dragon displays are a productized version of this approach.

{% embed url="https://www.youtube.com/watch?v=X2l46-WhHj0" %}
LEDPulse Dragon {% endembed %}

LEDPulse Dragon O Display system with volumetric LED's
LEDPulse Dragon O Display system with volumetric LED's

Other DIY Approaches

Sofia Aranov's Refraction

{% embed url="https://vimeo.com/131984694" %} Sofia Aranov's Refraction
{% endembed %}

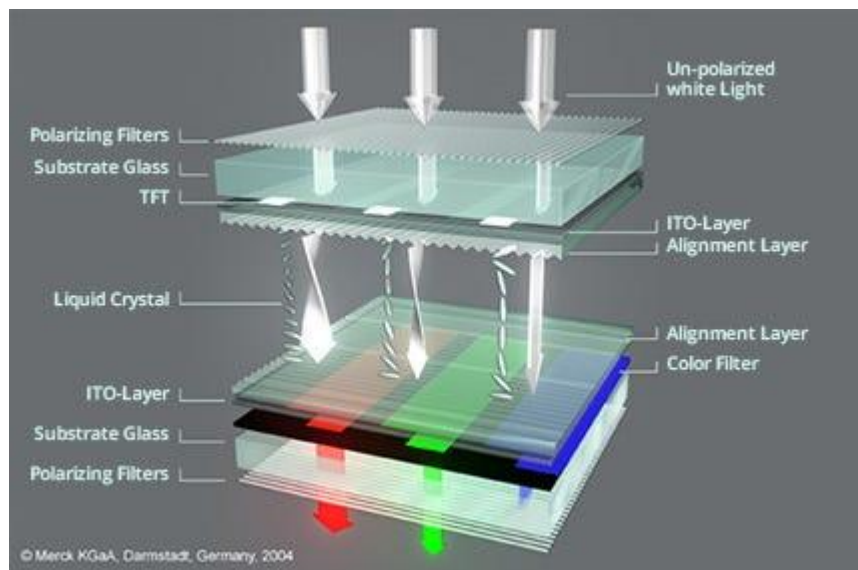
Blair Neal's Crayolascope

{% embed url="https://vimeo.com/44497765" %} Blair Neal's Crayolascope
{% endembed %} # Modified Polarizers

{% embed url="https://www.youtube.com/watch?v=9MbwVHUXE-c" %}
Karina Smigla-Bobinski's SIMULACRA — Link {% endembed %}

Besides being turned transparent, LCD's have another trick up their sleeve involving light polarization. By removing one of the polarization layers, the screen will look white to a viewer until they look through another polarizer. Below, I'll attempt to describe how this works.

A full explanation of the science behind wave polarization is a little bit outside of the scope of this book, but there is more information in the appendix. This video is a pretty solid explanation of polarized light and its usage with cameras. I encourage you to look into it because there are a lot of other great effects that can be employed via polarization. My explanation will be simplified in order to stay concise.



LCD Structure — Imace Source

You may remember from Physics class that light sometimes behaves as a particle, and sometimes as a wave. This light wave has a frequency, an amplitude and a rotation or polarization. As stated before, an LCD works by employing a backlight, a pair of linear polarizers, and a liquid crystal layer. When all of the light particles come off the backlight, they do not have a uniform polarization — they are just going all over the place. As they pass through the back polarizer, specialized molecules embedded in thin columns absorb any light that doesn't have a particular polarization. The polarized light then passes through the liquid crystal layer. When the liquid crystal

receives current, its molecular structure changes and it provides a transparent tunnel that can be variably twisted. The twist in the liquid crystal gives us a way to electronically modulate the rotation of the light wave.

As the light exits the liquid crystal and arrives at the front polarizer — this is where the magic happens. The front polarizer is the exact same material as the back polarizer, but its physical orientation is perpendicular to the back polarizer. This offset orientation effectively blocks or absorbs light of a particular polarization. If the light passes through the liquid crystal without being twisted, you will get a black pixel. If the liquid crystal twists the light 90° so that it passes through the front polarizer — you will get a white pixel. With the red/green/blue color filters on each pixel, the video signal is able to tune the wave orientation passing through each color to produce the millions of colors we see on an average display. Again — this is a very simplified explanation that glosses over a lot of important details related to different LCD technology.

So with all of the above in mind — if we remove the front polarizer, what happens? Now there is nothing to absorb the light that passed through the front polarizer and the viewer will just see white light. However, if you put a polarizer back in front of the screen, everything will appear normal again. This polarizer doesn't need to be right on top of the screen either. The polarizer can be in glasses that the view puts on or it can be placed meters away from the screen.

There are a lot of interesting possibilities available for these screens, but actually getting one to try is another matter. See my notes in the appendix on how you might make one yourself from an existing LCD. Fuse Technical Group is one vendor that offers these displays as a rentable or purchasable product and they are branded as WhiteSpace displays.



Flavien Théry's La Porte — [Link](#)

This technology is great for an unusual reveal to the viewer since it just looks like a white screen otherwise. The polarizing film can be placed at any distance from the screen and still allow the screen content to be visible, as long as the film is between the viewer and the modified LCD. You'll notice that depending on the way that the film is rotated relative to the screen, you can get things like inverted or warped colors since you are blocking different orientations of light. Also, due to the properties of polarized light, the content can be seen via the reflection off of other objects, or if you stick the polarization film on top of a mirror.

The artist Flavien Théry has some amazing pieces that employ modified LCD's and polarization film. In his piece La Porte he has a small door shaped object made of reflective material on top of a modified screen and the content is only viewable through the reflection on the door.

{% embed url="https://vimeo.com/76204664?embedded=true&owner=6895638&source=video_title" %} Flavien Théry's Contraires — A somewhat mind-bending use of modified LCD's and polarizers {% embed %}

The artist [Ryo Kishi](#) also has several projects that also explore create applications of polarizing film. His [dis:play\(bias\)](#) piece uses geometric elements covered in polarizing material to reveal the images. [Breathing Frame](#) uses small pinwheels fashioned from the material to display the content on screen.

Ryo Kishi's [dis:play\(bias\)](#) 2018
Ryo Kishi's [dis:play\(bias\)](#) 2018

```
{% embed url="https://vimeo.com/250105504?
embedded=true&owner=11960166&source=video_title" %} Ryo Kishi's
Breathing Frame {% embed %}
```

Polarization and Projected light

Unrelated to LCD monitors, light polarization is also a technique that can be used with [projectors](#) as well. Many 3D movies in cinemas have different systems to pass the light through a polarizer (either dual projectors with separate polarizers, or a spinning polarizer in sync with the framerate). To preserve the polarization of the light, many of these setups also require a specialized silver screen material or paint. The view is usually given either passive (each eye has a polarizer in a different orientation) or active glasses (which shutter each eye in sync with the projector) to ensure that each eye sees the image that is intended for it. I haven't found a good shareable example of polarized projectors being used in an unusual or artistic way, but there are definitely some possibilities out there.

Polarization without a digital display

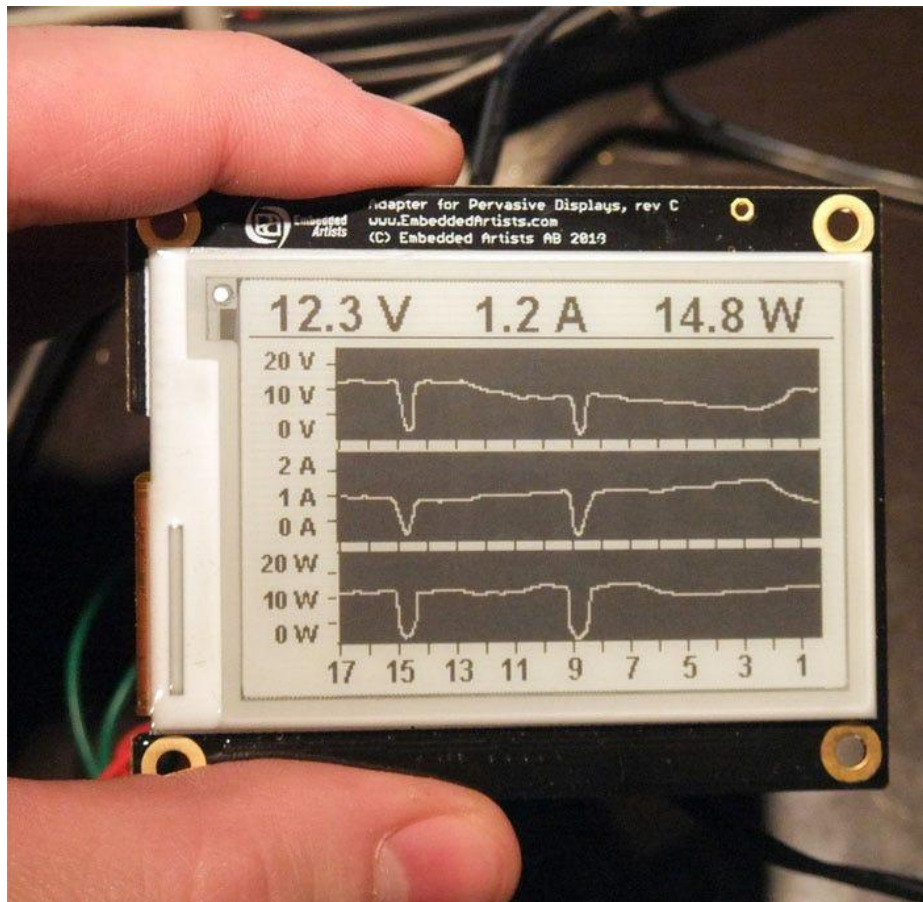
There are also artists that have explored the use of polarizing filters and material that either forgo the use of a digital display and just use a backlight, or they just use natural light. While these are not necessarily a display technology, they felt related enough to mention here. The principle is the same in that when a polarizer is viewed through another polarizer, their rotation relative to each other will determine the amount of light that is passed through. If you layer something like thin cellophane on top of a polarizer, you can also distort the lightwaves and shift the color. If one polarizer is physically rotated, you can also generate rudimentary animations or motion on the other surface.

Examples:

- [Austine Studios Polage](#)
- [Blair Neal's polarizer experiments](#)

Blair Neal's static polarizer experiments (Left: no polarizer, Right: viewed through a polarizer) # Electronic Paper/E-Ink

Electronic Paper Displays



Electronic Ink Display Example — Source

Electronic Ink or Electronic Paper displays are still a relatively new technology and are mostly found in electronic readers. They have some unique visual qualities that set them apart from any other display in this list.

There are a few different kinds of technologies that are considered E-ink displays, but the common one is a monochromatic electrophoretic display. These work by suspending charged particles in a fluid. A top and bottom layer with embedded electrodes sandwiches this fluid layer, and when the charge changes on a layer, the ink particles are pushed to the top, or pulled to the bottom. When the black ink particles are on top, they absorb light and appear black, and when they are pulled to the bottom layer, that pixel appears white because it is reflecting more light.

This display mechanism means that they do not transmit their own light (except in a few consumer models where a backlight has been added for night reading). Since they are only visible via light from the environment, this means that bright environments aren't nearly as much of a negative — and that makes them one of the only displays in this list that are viewable in direct sunlight. These displays are also incredibly low energy since they only use energy when changing the screen contents — without power, the screen would potentially hold its image indefinitely.

However, because of the way the technology works, the refresh rate of the screen is very low which makes it unsuitable for a lot of motion graphics. When the screen refreshes, there are also some ghosting artifacts that appear on parts as the ink particles reposition. Some screens will momentarily make all pixels black in an effort to normalize everything and prevent artifacts. Some screens can indeed refresh faster, at the expense of contrast and clarity artifacts. For more on the refresh rates of e-paper displays, check out [this resource](#). They are also typically able to only display monochrome images or a certain level of grayscale — displaying color with these is still an application that is in development but much closer to a consumer reality. Other methods of creating e-paper displays with graphene are also being [researched](#), with the added bonus that they have the potential to be flexible as well.

```
{% embed url="https://www.youtube.com/watch?v=OQSS4Bu5gZE" %}  
https://www.youtube.com/watch?v=OQSS4Bu5gZE {% endembed %}
```

Making use of E-ink displays in artworks is unfortunately impeded by the fact that purchasing a standalone screen of a significant size is very difficult. A lot of e-paper screens are also made fairly small — usually less than 12in, so even if you could [modify](#) an existing e-reader display, it wouldn't be very large. The consumer demand for these is primarily in e-readers so there is little incentive for the manufacturers to make screens that can be addressed as a normal video monitor with an HDMI input for example. Only recently have companies started producing and [selling](#) consumer models or development kits that connect via USB, but only in limited quantities. There are several e-ink development boards that can be addressed with a micro controller, but they are about the size of an index card or smaller.

[Visionect](#) is working on development kits for 32" e-ink screens that could potentially be tiled together to create a much larger display, but their price is still quite high compared to traditional displays. Some companies are also working on developing larger e-ink based "pixels" that can be tiled together to make incredibly large architectural elements that can change or be combined with projection mapping.

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{% embed url="https://vimeo.com/180645555?  
embedded=true&owner=994292&source=video_title" %}
```

Architectural E-Ink Prism

Below are some examples that use some of [E-Ink's Prism](#) material for large scale architectural installations.

```
{% embed url="https://www.youtube.com/watch?v=WdyH7u758kA" %}  
Architectural Coral {% endembed %}
```

```
{% embed url="https://www.youtube.com/watch?v=bfRsmoNDGvg" %}  
Various examples from E-Ink {% endembed %}
```

```
{% embed url="https://www.youtube.com/watch?v=kZzxmGjN6Gg" %} Sped  
up video of a flower using colored E-Ink {% endembed %}
```

Dazzle from Ueberall international that actually uses panels on the outside of a building

E°flow interactive sculpture from SEGD

e°Flow sculpture from SEGD using E-Ink
e°Flow sculpture from SEGD using E-Ink

```
{% embed url="https://vimeo.com/172943345?
embedded=true&owner=13001484&source=video_title" %}
```

Flexible Displays

- Flexible OLED
- Flexible LED panels

Flexible OLED

```
{% embed url="https://www.youtube.com/watch?v=P0wL65A3lYo" %}
```

Flexible displays have been appearing in tech news for years, but very few have reached consumers due to their niche uses and currently high cost of production. In the original version of this writeup in 2016, flexible screens were around in some form, but they were mostly concept units displayed at events liked CES. In 2022, flexible screens are still a niche area and come at a price premium, but they are much more accessible for consumers than they were.

OLED is the technology of choice for fleible displays because it can be manufactured on very thin layers on a plastic substrate. OLED's also emit their own light, so there is no need for an additional backlight, allowing for the thinnest possible display. The screens can be bent or rolled a considerable amount, and only one full edge needs to be connected to the electronics that drive the display. There is also a greater potential for these displays to be manufactured in unusual shapes other than rectangles.

While making flexible LCD's isn't impossible, there is a limit to the amount of bend that can be achieved and the cost implications make them a less than ideal choice.

One of the intriguing uses of a flexible display is that it can potentially be utilized as a user interface element. The flex of the screen could be sensed by software and used as a gesture in addition to swipe and tap gestures.

Actual sources for flexible displays that can be used for artistic or commercial purposes still requires some research.

LG is a common manufacturer of flexible displays - they do offer a "roll up TV" that is featured in a video below. They also offer a few different "open frame" options for displays that can be bent around the vertical or horizontal axes with a limited radius, depending on whether you get the portrait or

landscape model. These displays come with a pricetag of about \$20000-25000 (retail, but you can get better partner pricing via integrators) for a 55" display. When installing a display, you need a curve calibrator—some larger AV integrators may already have this device. These displays also require a detached, rigid control box, which is connected via a ribbon cable. In theory, the ribbon cable could be extended, but you should assume that the control box is somewhat visible from the sides. LG had a 77" version in 2017 that was also 40% transparent, but it looks like it never fully made it to market.

Samsung has released a number of smaller scale flexible OLED products as well. They currently advertise their FlexOLED as having a very small 1.4R bend radius that allows them to bend the display almost completely flat. They recently announced their new Flex G and S devices that explore different ways of bending a smartphone to transition from a phone to a tablet. A couple years ago they also released the commercially available Galaxy Z Fold3 and Flip3 that offered a sort of flipphone experience. The first test iterations of the Flip and Fold had a number of manufacturing and usage issues that led to a recall.

{% embed url="https://www.youtube.com/watch?v=GxIYOh6L1q4" %}

Royole offers the RoKit for about \$959 as an open source development kit for working with their Cicada Wing small scale flexible displays. They also have their own Android Smartphone, the Flexpai.

Royole's Rokit:

{% embed url="https://www.youtube.com/watch?v=WxgVYCxShvA" %}

{% embed url="https://www.youtube.com/watch?v=BKBk1MFoLyc" %}

LG Signature OLED R rollable TV:

{% embed url="https://www.youtube.com/watch?v=D1pa3UX89GA" %}
Rollable OLED {% endembed %}

Flexible LED

Flexible LED is a very different thing from OLED. There are large scale flexible LED displays for architectural purposes (like wrapping a column) and there are microLED displays that function similarly to OLED.

{% embed url="https://www.youtube.com/watch?v=6r1WsqIXQK4" %}
amFlex LED {% endembed %}

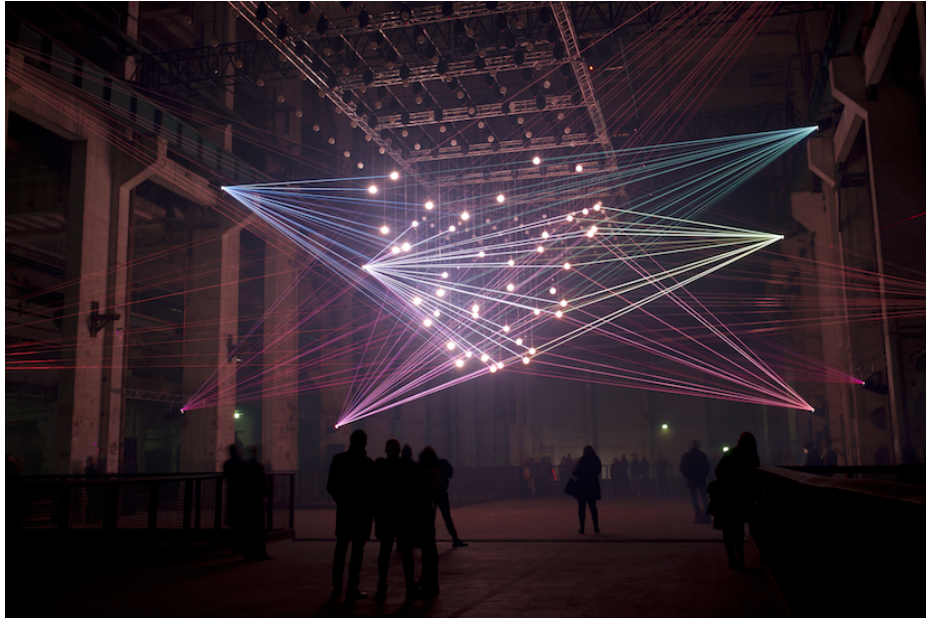
microLED stretchable prototype below:

{% embed url="https://www.youtube.com/watch?v=jmrRxafeQ_0" %} #
Lasers and Laser Projectors

- Laser Projectors
- Laser Projectors and Video Projection
- Laser Projectors and film techniques

- [Laser Diodes and other approaches](#)
- [Lasers and photosensitive surfaces](#)

Laser Projectors



Robert Henke's Deep Web — Source

[Laser projectors](#) have some really unique visual characteristics that make them ideal for the right content and application. Most of them work by shining a combination of different colored lasers (red, green and blue) onto a motorized mirror that moves incredibly fast. They have been around for a while, but due to several factors they aren't used very regularly in art pieces and performances. Here is a thirty minute [video](#) from the International Laser Display Association ([ILDA](#)) showing a range of different visuals that can be achieved with lasers. They are are understandably confused with other [laser video projectors](#) that usually use a more [traditional display and lasers as a light source](#).

The primary hindrance in working with lasers is that they are quite dangerous. While staring straight into a 10,000 lumen projector may feel uncomfortable, it is not nearly as likely to blind you. A laser light beam is so concentrated that it can cause serious damage by literally boiling the cells in your eyes until they burst and scar. Even a 1 milliwatt laser can cause permanent damage to your eyes if you stare at it, but 5mw and above is where your eye's natural reflex to blink won't even protect you — see more details on laser safety [here](#) and [here](#). Consumer laser pointers are comparably low powered and will be 1mw to 5mw. Laser projectors on the other hand are going to be 485mW, 1W, 2W or more. Brightness essentially correlates with wattage with these. High wattage beams can be fire hazards or burn the skin if used irresponsibly. It is recommended or required that you use specialized eye protection when working with these lasers because a stray reflection for only a few milliseconds can cause damage. Different states and countries have varying restrictions on the use of lasers in [live events](#) and most places require a licensed operator or a variance. The restrictions are typically on which direction the lasers shine, and how far

above or away from the audience they should be shining. Some laser projector vendors provide the necessary usage variance when purchasing them.

The danger factor is unfortunate because lasers have a very unique aesthetic. The sharpness of their beam gives them a vector quality that is almost impossible to represent with the pixel density available in today's projectors and displays. The scanning motion of the mirror makes the drawn lines sort of infinitely continuous instead of being comprised of discrete elements. The Vectrex of the 1980's had a similar aesthetic.



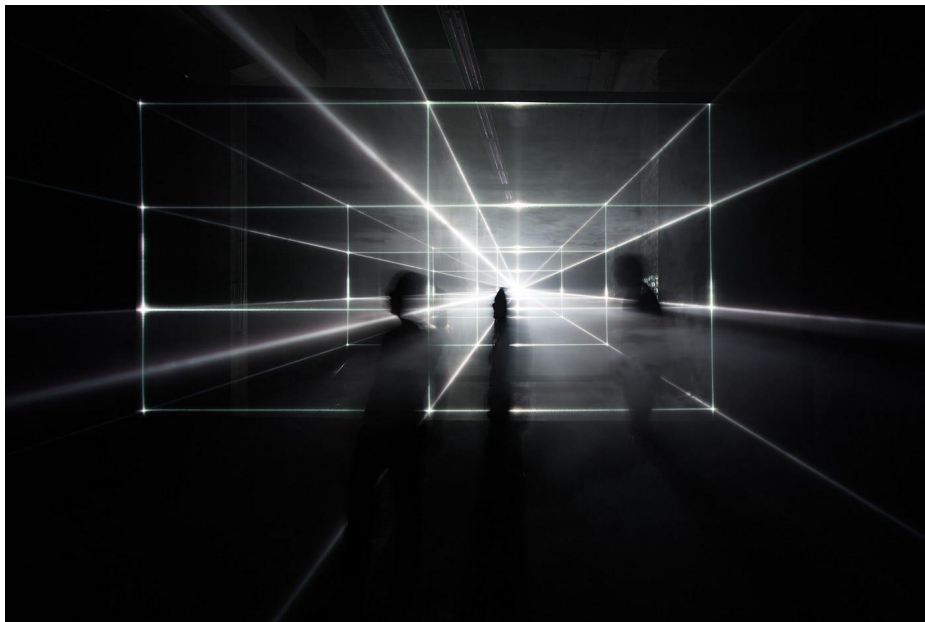
Example of an image drawn with a laser projector — Source

This mechanical method of drawing has its limitations in that the mirror can only move so fast and draw so much in a given “frame.” If a laser projector tries to draw an image that is too complex, the image can appear to flicker because it can't actually draw all of the points needed in a single frame, so its “framerate” drops. This flicker effect is painfully obvious when laser projectors are filmed, which makes them an unlikely choice for something you plan to document. Most laser projectors have specifications on how many points per second (pps) they can draw — some of the low end ones can do 20,000pps or 20kpps, and higher end ones can do double that or more. 20,000 points sounds like a lot, but 20,000 per second means you only get something like 330 individual points *per frame* if you're trying to draw at 60fps. This means you have to be smart about your content and economical about where your image complexity is.

Additionally, since the laser doesn't scan left to right, top to bottom like the electron beam in a CRT television, it means you can't just order your points all over the place, send them to the projector, and expect it to work out. Ideally, the beam should move as little as possible to its next point so that the motor isn't trying to draw one extreme side and then another — the time it takes to move the mirror that far can have a serious impact on its draw speed. This also means that you'll really only ever see shape outlines on these kinds of projectors, because filling in a shape would take far too many mirror motions and your eye wouldn't see it as continuous anymore. The motion of the mirror also limits the “throw ratio” of the projected image. The width of the projected image is typically much smaller than a lot of video

projectors that you may be used to — this means you need to be much further back from a surface if you want a larger image. The good news is, compared to video projectors, you're losing a lot less light when you increase the scale of your image. The specs on a laser projector don't always clearly tell you the expected width, so you will have to put on your math goggles to figure out the size at a given distance.

The other thing to consider about laser projectors is their contrast and their color reproduction ability. Regular projectors still have issues with their black levels because they are still shining light even when the scene is black, and this lowers their overall dynamic range. Laser projectors don't have this problem because they only project light where it needs to be, so their lines really pop. However, you're less likely to have access to a laser projector that can cover a wide color gamut — some cheaper projectors will only give you about 7 colors by mixing red, green and blue lasers. High quality projectors can do a wider range of color mixing. Dimming the beam can also be tricky unless you are using a high quality projector with a good blanking control.



Vanishing Point by United Visual Artists — Source

TUNDRA is a studio that has done several laser-based artworks. Their piece *The Day We Left Field* uses several projectors to sweep across a hanging field of plans that results in a very volumetric feel.

{% embed url="https://vimeo.com/374171958?embedded=true&owner=22060879&source=vimeo_logo" %} TUNDRA - The Day We Left Field {% endembed %}

Laser Projectors with Video

{% embed url="https://vimeo.com/652535281" %} Orbis by 1024 Architecture {% endembed %}

Laser projectors have a very specific aesthetic because of their individual lines and lack of ability to fill in content. There are a few artists and projects that are exploring what happens when you combine either multiple laser projectors or a laser projector and a video projector together to create high contrast content. In the video projector + laser projector camp, you can get the crisp bright lines of lasers and the fill and dynamics of a full video image. To achieve this you need software or content that aligns the light of the two projectors, essentially mapping them together.

{% embed url="https://vimeo.com/432565366" %} Lasermapping from Intus
{% endembed %}

There have been attempts at using laser projectors to create more "filled"/ rasterized content as well. One project below from Alberto Novello uses 4 laser projectors and special software to essentially create a raster image and overcome the limitations of how much of an image a single projector can draw.

{% embed url="https://vimeo.com/590262443" %} Alberto Novello's 4 Laser Raster Test
{% endembed %}

Other artists exploring the laser + video projector aesthetic:

- [Karl Skene](#)
- [1024Architecture](#)
- [aka_chang](#)

Laser Projector filming techniques

There are also some tricks that can be pulled off with laser projectors when combined with specialized filming techniques. [Precision Lasers](#) is a company that has pioneered and perfected this technique of synchronizing the animation of a laser with the shutter speed of a camera. The results of proper sync are beams of light that appear to be frozen in mid air. Their work for *Childish Gambino* for SNL is a classic example of the kinds of effects that are possible with this approach. The same visual does not come through to the naked eye in the same way due to the need for tight alignment, but it is still a fascinating application for filmed projects.

{% embed url="https://vimeo.com/279396312" %} Precision Lasers with Childish Gambino on SNL. {
{% endembed %}

{% embed url="https://www.youtube.com/watch?list=PLbOq6ny6l6_ng5Rau-6hV2Q1J75V_rWr1&v=ZTLKNizke2o" %}
Another Laser banding example {
{% endembed %}

Laser Diodes and other uses of Lasers

Matthew Schreiber's Focal Point
Matthew Schreiber's Focal Point

Some projects don't use Laser Projectors but rather use individual laser diodes in different sculptural ways, such as in Matthew Schrieber's Focal Point shown above. While these fall more firmly in the "light art" part of the display spectrum, I feel they are worth mentioning because they often involve an animation element.

This approach requires a bit of custom work to identify the right diode and then create a way to control or position them in just the right way. Laser Diodes also typically just stay in one color, hence the very red or green aesthetic shown in most examples. Diodes are a specialized lighting element and must be handled with care. Aside from the safety concerns of getting a diode that is too powerful, they also typically have some limitations on their "duty cycle" or how long they are designed to run continuously over a 24 hour period. If they run continuously for too long, they risk burning out or losing some of their overall power. Pieces must take this into account and have a way to power themselves down every few hours to make sure that their lifespan is preserved. Additionally, because of their nature of illumination, laser diode sculptures and display pieces often require the use of fog machines or hazers to fill the space with particles that allow people to see the beams themselves.

Other artists that work with lasers in this way are Shohei Fujimoto. Their piece *Intangible Forms* uses hundreds of individual diodes mounted on motorized elements that allow them to sweep and create shapes that float in the air (somewhat similar in spirit to volumetric projection).

Shohei Fujimoto - *Intangible Forms*
Shohei Fujimoto - *Intangible Forms*

{% embed url="https://www.youtube.com/watch?v=2E9zliYHq6g" %} Shohei Fujimoto's *Intangible Forms* {% endembed %}

{% embed url="https://vimeo.com/195369371" %} TUNDRA's *Outlines* {% endembed %}

See also:

- <https://rlfbckr.io/work/mirage/>

Lasers and photosensitive surfaces

Its also worth mentioning that lasers projecting onto photosensitive surfaces (aka glow-in-the-dark paper) can be used for a specialized visualization technique.

{% embed url="https://vimeo.com/386771736" %} Albert Novello's *Laser Projection on photosensitive surfaces* {% endembed %}

{% embed url="https://www.youtube.com/watch?index=6&list=PLa3fOs1KYGMOy-QVs_p-GXe5U35jK_rQh&v=Mt_4mfuwTAU" %} Daito Manabe and Motoi Ishibashi's experiments {% endembed %}

To add:

- Lasers and Projection mapping
- Pangolin Beam Brush <https://pangolin.com/blogs/news/beam-brush-paint-with-laser-light> # Lightfield Displays
- Looking Glass Displays
- Light Field Labs Solidlight
- Leia Displays
- Fovi3D
- Multi-lens experiments

This page showcases a collection of displays that use some other advanced optical techniques (such as lenticular, multilens arrays and other complex marketing terms) to create a sense of depth for a viewer. These displays often market themselves as holograms and holographic displays, but a more accurate term is a lightfield display.

{% embed url="https://www.youtube.com/watch?v=PgiyoweaPb4" %}

Looking Glass Factory Displays

Looking Glass Factory

Looking Glass Factory has been a pioneer in lightfield displays for years and has made a number of innovative products in this category. Their differentiator is that a lot of their products are geared towards an average consumer rather than only an expensive commercial market.

In very basic, but somewhat unaccurate terms, the display itself uses a very high resolution/high pixel density display and a specialized lenticular film that directs the light into a few dozen different viewing angles. A specialized imaging pipeline takes a 3D scene, slices it up into all of these different views, and puts each one on a thin slice on the display. As that light passes through the lenticular film, it gets refracted into the different angles and allows each of your eyes to see a different view. The effect itself is very convincing and really feels like a floating image is right in front of the display.

Their latest product, the Looking Glass Portrait is a 7.9" lightfield display with a 78° viewing cone and it goes for \$399. It's great for small experiments and things like viewing personal portraits. While it does allow for multiple viewers at the same time, its somewhat small size and narrow viewing cone needs careful consideration if it is to be used for an installation project.

{% embed url="https://www.youtube.com/watch?v=4pJxdNRA1CM" %}

Looking Glass Factory does offer 2 other more commercially oriented versions for large scale displays, but the price point is a large leap. They have a 4K Gen 2 display for around \$3000 that is about 15.6" diagonally. Their 8K Gen2 Display is \$20000 and about 32" on the diagonal. As the

displays get larger, they need to pack even more pixels into the display to create the same volumetric visual effect. This creates more and more overhead for rendering as well, but it will be interesting to see where this kind of technology goes as resolution density continues to evolve.

Below is an overview of Looking Glass's previous product that utilized somewhat similar technology but had a large slab of acrylic on top of the display that felt like a volume that contained the image. The newer version feels like an image you can touch.

{% embed url="https://www.youtube.com/watch?v=htFotQi_-jY" %}

Light Field Labs Solidlight Display

{% embed url="https://vimeo.com/622893790" %} <https://www.lightfieldlab.com/press-release-oct-2021> {% embed %}

Light Field Labs announced their Solidlight display in 2021. A commercial product or a demo that isn't hidden behind other material, has not yet appeared, but they do claim the ability to tile multiple units together so that very large displays can be created. The display they will offer will be approximately 28" as a single unit. Similar to other displays on this list, they also have a custom software rendering pipeline called WaveTracer so that 3D scenes can be ported and rendered on their display.

Here is the [closest to a more complete description](#) of how the technology works:

Light Field Lab's basic technology, branded SolidLight, is a 28in panel that is able to output 2.5 billion pixels, or more than 10 billion pixels per square metre.

"It is doing this at full P3 colour space in a way that has not been possible until now," he says. "Just one of these panels by itself is already the highest resolution display that has ever been designed."

Each panel packs a proprietary FPGA, GPUs, wall and display controllers. In front of that is the key innovation of a 'nano particle polymer surface energy relay'. "This gives us the opportunity to form a singular continuous wavefront composed of cones of light," he explains.

The wavefront contains amplitude based on patterns and frequencies that is being modulated by a phase guide that sits on top of the polymer surface.

"The phase guide control plane is what allows us to converge the amplitude into a focal region," he says. "In order for anything to exist as a true wavefront you need extremely high density sampling to generate billions and billions of photons."

Since it is modular and bezel-less, these panels can be combined to form video walls of any size with configurations exceeding hundreds of billions of pixels.

To put 2.5 Billion pixels in context: a standard 4K display is 3840x2160 which comes out to 8,294,400 pixels, and an 8K display is 33,177,600 pixels. So packing 2.5 billion pixels into a 28" panel (if that is truly what they are doing) is an incredibly dense display.

Leia Lightfield Display

Leia Lightfield Tablet Display

{% embed url="https://youtu.be/J2rGNRhNkTA" %} Leia Lumepad {% endembed %}

Leia Lightfield Displays are another commercially available product in the form of an android tablet that promises a lightfield experience. They use a specialized diffractive backlight technology that essentially delivers different viewing angles to each eye to create a sense of depth. More on the scientific approach in the video below.

Also more writing on the technology itself [here](#).

Here is a [whitepaper on the technology as well](#).

Leia may be working on an updated display from their tablet as well - a sample video of it is featured [here](#).

{% embed url="https://www.youtube.com/watch?v=-l9namlza4U" %} Leia 3D Display operating principles {% endembed %}

Fovi3D

Fovi3D is another unreleased experimental technology using microLED displays and a lot of other custom electronics to create a sense of depth.

FoVI3D's ActiveHogel™ is a frameless, tileable, spatial light modulator designed to accommodate large format light-field displays (LFD).

{% embed url="https://www.youtube.com/watch?v=J-lmjtbFa0w" %}

Multi Lens Display

I'm not sure if this truly fits in the light field category, but it feels close enough in operating principle. This experiment from around 2010 by [Hideki Kakeya](#) utilizes a display that shows multiple angles of some 3D content and an array of microlenses to provide multiple glasses-free angles of that content. [More information here](#).

{% embed url="https://youtu.be/xLWf2P6d8cg" %}

A similar [experiment from NVIDIA](#) is below:

{% embed url="https://www.youtube.com/watch?v=NdTycenXID8" %}

Related to the multi-lens experiments above, take a look at the [Misapplied Science's Parallel Reality LED display](#) that uses similar principles. # Head Mounted Displays

Head mounted displays



Hugo Gernsback's Television Goggles — 1963

Head-mounted displays (HMDs) could have their own article by themselves, but they are worth briefly mentioning here. These displays have been around in some form since at least the 1960s. These can be divided into two types depending on whether they are used for virtual reality, augmented, or mixed reality.

HMDs for virtual reality are typically a standard display (primarily OLED these days) and optics that are strapped to a user's face. Current consumer examples would be the various Oculus Rift Headsets (ie Oculus Quest 2), HTC Reverb, Playstation VR, and Valve Index.

In these displays, software renders a separate image for each eye, and sensors in the headset (or external tracking cameras) allow the software to adjust the rendered camera position to give an illusion of moving your head in a virtual space. The brain is extremely sensitive to latency between your head movements and what it expects your eyes to see. If the latency or delay between those two is too high, the sense of immersion is lost and some users can experience motion sickness. To counteract this, the tracking devices and displays are engineered to keep this latency as low as possible. To counteract the latency issue, the refresh rate of the display is usually higher than most 60hz monitors, which means that your content must be able to run faster than 60fps as well.



Toshiba's 2006 Full Dome HMD — Source

HMDs for augmented and mixed reality have a lot of different display methods depending on the manufacturer and the end goal. Eventually, the difference between augmented reality and virtual reality displays may only be a switch or fader that dims out the “real world” as the generated graphics are given more emphasis. The old Google Glass used a prism/projector technique. Microsoft HoloLens and HoloLens 2 uses an unusual method of edge lit holography or a waveguide element. The Magic Leap One uses a special layered technique of a similar method of a projector with a waveguide. Headsets like the Varjo XR-3 are a commercial grade mixed reality headset with a lot of technology packed in like eye tracking, more involved camera passthrough setups and more.

In addition to sensors like accelerometers and gyroscopes used to track head position, some of these displays use cameras to augment their visuals. By using computer vision techniques, devices like the HoloLens are able to track physical objects in front of the user and augment them accordingly. By

combining all of these tracking systems, these displays are able to make elements appear “holographic” since they can render different angles as the user walks around.

Upcoming advances for VR and AR are in areas like creating varifocal displays that allow for more realistic depth cues rather than today's fixed focus displays that feel “flatter” to a user.

Other Links:

- [TV Helmet # Overview](#)

In this section, we'll cover various light manipulation techniques. In my definition, techniques are a slightly different area than a specific “technology”, but it is ultimately a semantic difference. There are some projects mentioned in the previous section that could be considered a technique as well.

Typically in the techniques I mention below, you are using something like a standard display but in a non-standard way. You may be using a display and augmenting it with a plastic or cloth material, you may be using a fog machine to create a projection surface instead of a flat wall. # Pepper's Ghost

[Pepper's Ghost Diagram — Source](#)

[Pepper's Ghost Diagram — Source](#)

Pepper's Ghost is a classic illusion — it has been around for over a century and is still making headlines. 99% of the time, when you see a headline with the word “hologram” it is talking about Pepper's ghost.

Historically, the effect comes out of Phantasmagoria, a fascinating tradition of theater illusions that were developed in the 18th and 19th centuries that frightened audiences with never before seen images of spirits and floating otherworldly beings. The Magic Lantern is another one of these early theater effects and it is one of the earliest forms of the projector. The name Pepper's Ghost comes from John Henry Pepper who popularized the effect in the mid-1800's with his friend Henry Dircks (who arguably developed it before Pepper). However, the illusion was first described in the 1600's by an Italian scholar named Giambattista della Porta in his book Natural Magic:

Wherefore to describe the matter, let there be a chamber wherein no other light comes, unless by the door or window where the spectator looks in. Let the whole window or part of it be of glass, as we use to do to keep out the cold. But let one part be polished, that there may be a looking glass on both sides, whence the spectator must look in. For the rest do nothing. Let pictures be set over against this window, marble statues, and suchlike. For what is without will seem to be within, and what is behind the spectators back, he will think to be in the middle of the house, as far from the glass inward, as they stand from it outwardly, and so clearly and certainly, that he will think he sees nothing but truth. But lest the skill should be known, let the part be made so where the ornament is, that the spectator may not see it,

as above his head, that a pavement may come between above his head. And if an ingenious man do this, it is impossible that he should suppose that he is deceived.

Pepper's ghost is very easy to implement. The simplest version involves a transparent reflecting surface (a sheet of glass, plastic, or a half silvered mirror), and an image source (a monitor, projection screen, or a lit source). There are two versions of this effect that are commonly used — the classic one from the 19th century typically involves two separate physical spaces and specialized lighting. The modern version of Pepper's ghost involves a digital screen (monitor, or projected image) and a half silvered mirror or specialized film designed to be invisible to the viewer. This version is also used for teleprompters where the camera lens is positioned behind the mirror facing the speaker. Both are essentially the same in principal.

Artist Joshua Ellingson is exploring different ways of utilizing Pepper's Ghost with traditional displays to create a sort of hybrid experience.

{% embed url="https://vimeo.com/554964350?embedded=true&owner=2009307&source=video_title" %}

Glass mirrors are the most accessible way to achieve this effect (it can even be done with reflective plastic and a smart phone), but at a certain point it becomes difficult to scale the glass to be large enough. For stage productions, there is specialized plastic film that can be employed to reflect much larger surfaces. Musion is the primary company that comes up while searching, and another is Arena 3D. It is worth noting that Musion claims a patent on a version of this 100+ year old technology and has hit "imitations" with lawsuits in the past. It is also easy to source your own film from 3M or other sources in Asia — another version of the film is manufactured by DuPont.

Image of reflective foil setup for stage production — Source

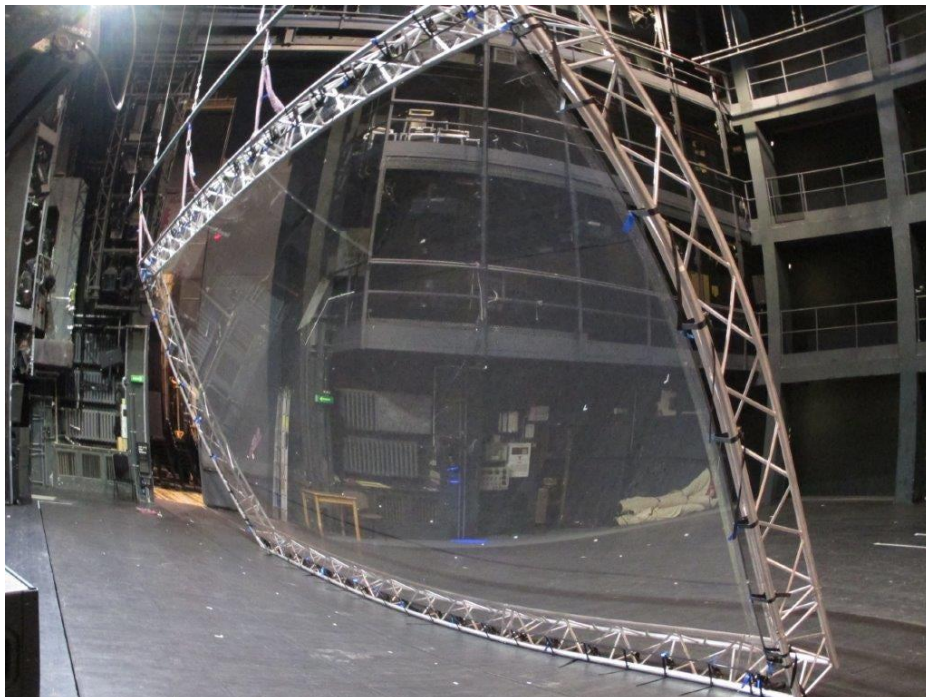


Image of reflective foil setup for stage production — Source

Carefully controlled lighting is essential for this effect to look its best. The source of the image must be bright in comparison to the surroundings behind the transparent surface. The observer should also be in a very dark space so their own reflection doesn't show up in the mirror. It is also helpful to have something slightly visible behind the transparent surface so that your floating image has something to float overtop of and give the viewer the parallax depth cue. The effect can be striking if combined with props behind the mirror — like a person sitting on a chair or animations that swirl around an object. However, there are limitations to this depth effect.



Pepper's Ghost Pyramid — Source

Peppers ghost is still very much a 2D effect and does not present an image in three dimensions. It is just a mirror reflecting another flat plane. Parallax between the reflected image and the background is what gives our eyes the illusion of the content floating in mid air. A false sense of 3D can be achieved depending on your source and how the reflecting surfaces are arranged. There are some implementations of the effect that put 4 mirrors in a pyramid shape under a monitor (some have marketed themselves as holograms — sparking controversy). By having the monitor display a different image for each mirror, the observer gets more of a 3D view as they walk around — even if it is just 4 discrete viewing angles. Head or eye tracking would have to be employed to make the effect a little more convincing, but then it would only work for one observer at a time. As it usually functions, the effect may look best from one vantage point, especially if you are trying to align it with an object behind the surface. This misalignment can be minimized by having your observer be further back so when they move their head, the parallax isn't as great as if they are right in front of the screen.

Projection on Static Transparent Material

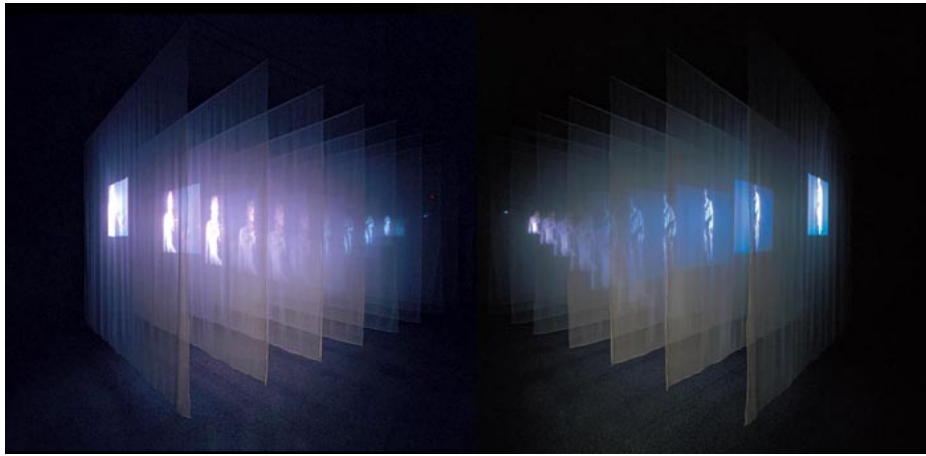


Image of Bill Viola's The Veiling — Source

Projecting on semi-transparent materials is essentially a variation on the Pepper's ghost illusion. It is also an effect that has been used in theater for a long time. In contrast to Pepper's ghost, this technique uses a transparent material to catch (not just reflect) the light from a projector. The viewer can still see through the material, but the projected light is scattered and appears to be transmitted from the material. Viewers can still see through the material allowing for a depth effect from parallax, but the illusion is still flat and two dimensional.

The implementation of this technique is one of the cheapest and most accessible on this list. You will need a semi transparent material and some means of projecting an image. The material you use depends on the scale or size of the end result and the type of effect you are going for. You also must consider whether you want to use front or rear projection. Rear projection (with the viewer facing the projector lens) will produce a noticeably brighter hotspot depending on the material used and where the projector is, and front projection means the image will spill behind the surface a little bit which may result in some doubling.

{% embed url="https://www.youtube.com/watch?v=T5-QBirTU-M" %}
Nonotak's Daydream is an example of this technique {% embed %}

As far as materials to use, on a small installation you may be able to get away with just a piece of fabric like tulle or netting — things like bridal veil material. White fabric will catch and transmit light the best, but sometimes black can still work and give you a similar effect with the fabric appearing more "invisible."

If you are trying to have an image appear on a storefront window or piece of glass, you will need a specially engineered film that is nice and transparent but still collects a lot of light from your projector. The proper film for glass can be very expensive for large pieces, so keep that in mind. One source has it at almost \$1200 for a piece that is 2.2m by 1.2m. Here are some possible vendors for this kind of film: [\[One\]](#) [\[Two\]](#). You can get away with cheaper

materials, of course, but the effect may be very different. Cheaper or DIY material may be either more opaque (yielding a brighter image but less transparency) or too transparent (yielding a faint image). Projecting on glass will certainly show something if there is significant dust on it, but the effect will be very dim.



Lucinda Child's piece "Dance" featuring scrim projection

To achieve much larger images for theater or stage, fabric is the most economical choice for a scrim. You can get very large seamless swaths of fabric for the purposes of stage projection. Some fabric will have larger holes in its netting which will make it more transparent but will also cause your projected image to be less bright as well, in addition to dropping the sharpness and fidelity of the image. Here is a great [resource](#) for more info on stage scrim projection materials, including silvered fabric. You can also layer these materials to get several planes since the light is passing through. The cone of light from the projector will cause the image to be larger or smaller on each depth layer depending on whether you are projecting from the front or the back. You can also only go so far with layering before your light runs out or just gets out of focus.

Similar to the requirements for Pepper's Ghost, this technique requires very controlled lighting. You will need to balance the ambient light that is hitting your fabric so you can preserve the illusion of a floating image — otherwise

it can just look like a standard projection screen that you can see through. Contrast is key here. It also helps to have the space behind the image not be completely dark to give the image more dimension. If the viewer can see behind the image then they get the layered effect and the sense of parallax that helps it appear more 3D even if it is still just 2D.

Content that works best on any of the semi-transparent materials tends to be imagery that does not fill the entire projected rectangle. The optimal approach is to have your content sit on a field of black, so that that it appears to have no bounds. A vignette or feathering on the edges can also help if you have elements that enter and exit from the sides, otherwise the viewer will see harsh edges. Semi transparent material also causes the projections to have a slight glow to them — the light beams get slightly diffused when passing through the material which tends to soften the sharpness of the image a little bit.

This technique below uses thousands of hanging bits of material to create a sort of volumetric form that is hit with multiple projectors:

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{% embed url="https://vimeo.com/105428635" %}
```

Volumetric Projection

Volumetric Projection

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{% embed url="https://vimeo.com/129862202?embedded=true&owner=712022&source=video_title" %}
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Volumetric projection is a technique that is a much more technical application of projecting into a thin sheet of fog. Instead of having light come from a single point, it uses multiple light sources or specialized optics. By combining these sources with the additive quality of projected light, this technique is able to create dimensional images with multiple viewing angles. There are a few scientific papers out there on similar processes, and we'll discuss laser plasma displays later on that share some characteristics.

Light Barrier by Kimchi and Chips is likely the first piece to use this technique. With *Light Barrier*, the artists project images onto an array of parabolic mirrors. Using custom software that analyzes where the pixel's light ends up after hitting the curved mirrors, they can approximate the path of light from each projected pixel. When this is done for the entire array of mirrors, they can calculate where in 3D space each pixel path intersects another after hitting the mirrors. The projection area above the mirrors is filled with haze from a fog machine — the medium for these intersecting light beams. If more beams illuminate a particular location in 3D space, then that spot will appear brighter. By hitting several of these overlapping spots together, the combined focal point becomes brighter, and images can be formed in the haze. There are other ways to achieve similar variations on the effect that involve multiple projector sources, but this gets logistically complex and expensive very quickly.

This technique currently has its limitations. Making recognizable images requires a calculation engine and custom software, meaning you can't just drop in any content and have it show up in 3D. The workflows for generating content based on depth maps are improving, but there is also going to be an upper limit to how fine the details can be. It may take several dozen converging pixels to make a recognizable voxel — so once we have higher resolution projectors we might be able to put together even more complex visuals. Full color projection with this technique is also a challenge because the overlapping colors add together and change the colors for different viewing angles. White is also going to show up the best for an effect that is already going to be slightly faint compared to other projection methods. Nonetheless, it is an exciting area of discovery and still has a lot of potential to explore.

Kimchi and Chips have expanded on this idea with other projects. *Another Moon* uses an array of high powered laser projectors (powered from solar energy collected during the day) to create a large scale floating sphere in the sky at night.

Kimchi and Chips - Another Moon (2021)
Kimchi and Chips - Another Moon (2021)

Realted to the above, in Halo they have also explored the idea of using specialized mirror arrays to focus sunlight into a cloud of fog to generate a floating sphere.

Kimchi and Chips - Halo (2018)
Kimchi and Chips - Halo (2018)

There are also variations on this idea that don't involve fog or specialized optics. A simple way is to use layers of fabric — the image will be the same on each layer but will get larger or smaller on each pass. There is also the method employed by the Lumarca where a grid of thin strings are stretched to make a large volume. Each string in the volume can then be precisely mapped by a few columns of pixels from the projector. When the location of each column is then mapped to a known 3D space, it becomes easy to render simple graphics on the array of strings that appear to have volume. The strings transmit the light a bit, so it is easy to see from all sides. This method also has some density and fidelity limitations but is also easy to scale.

{% embed url="https://www.youtube.com/watch?v=dPaLT80qY3M" %}

There are also abstract applications of projection that could be considered volumetric, like Liminal Scope II by the studio Hovver. This uses a pair of projectors in a fabricated circular structure filled with fog and mirrors. This approach allows them to create a sort of volumetric circular volume of light in an enclosed space.

Liminal Scope II by Hovver
Liminal Scope II by Hovver

{% embed url="https://vimeo.com/260129299?embedded=true&owner=53255680&source=video_title" %} Liminal Scope II by Hovver {% embed %}

The technique below for WOW's *Light of Birth* project from 2015 is somewhat of the inverse of the Kimchi and Chips method. Instead of one projector and an array of mirrors, this project uses an array of over 2 dozen projectors to achieve a similar technique.

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{% embed url="https://vimeo.com/148280386?
embedded=true&owner=2849000&source=video_title" %} # Projection on
Water or Fog
```

For this technique, instead of a static material like cloth, you can use water, haze or another atomized fluid to catch light and provide a semi-transparent screen.

Water Screens

```
{% embed url="https://vimeo.com/49029399?
embedded=true&owner=570396&source=video_title" %} https://vimeo.com/49029399?embedded=true&source=video\_title&owner=570396 {%
endembed %}
```

There are two types of water based projection surfaces — either the water is moving upwards or falling downwards. For an upward blast, these rely on a high powered water jet and a special attachment that spreads the water into a large flat half circle screen of water and mist. The size of the screen is limited by physics and the power of the water pump — most companies can generate screens that are in the range of 20–30m wide and about 6–10m high. This mist is then usually hit with rear projection by a high powered projector. This results in a semi transparent screen that can be hidden or revealed at the flip of a switch in the middle of a body of water.

Falling water screens are much more manageable to install indoors. These have a mechanism that just pushes water through spaced out nozzles on the top piece and collects and recycles the water in a basin on the bottom. Some systems are even able to selectively open and close the top nozzles to allow water to fall in different ways.

The effect of water screens is very unique due to the haze of smaller water mist particles causing a halo and giving the 2D image more volume. There is also a textural quality to the water and mist that you should plan on, as it can add some glow and reduce sharpness a bit. Rear projection works best on these screens, so there will be a persistent hotspot behind the content, but this may not impact too much depending on your setup. Front projection is possible, but you run the risk of doubling the image onto other surfaces behind the semi-transparent screen.

Fog Screens/Laminar Flow

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{% embed url="https://vimeo.com/121979573?
embedded=true&owner=1790761&source=video_title" %} https://vimeo.com/121979573?embedded=true&source=video\_title&owner=1790761 {%
endembed %}
```

These screens rely on a steady controlled flow of haze or water mist to create a thin layer of semitransparent fog that can be rear projected. A series of valves directs the mist into a narrow sheet, and the projected light is refracted off the particles. The haze can be water or oil based.

This technique works best indoors because of minimal air currents and the light contrast needed for the best illusion. Due to physics, this technique is limited by the screen size that can be created. A lot of commercially available screens can only get to something like a 2m by 1.5m size. The width can be extended with multiple mist units, but the height is the primary hindrance since the mist gets less dense after a certain distance from the valves and fans. Also, since this screen is so transparent, the viewer will get a strong hotspot from the projector and the content will shoot right through onto adjacent surfaces. Commercially available units are available, but aren't cheap — some are almost \$20,000 or more. DIY options also exist, but require a lot of materials. Getting the haze production right in a DIY setup is probably going to be the biggest challenge since most fog machines tend to accumulate in an enclosed space rather than dissipate.

There are several artists exploring applications with fog screens as well. Joanie Lemercier's Brume project explores a number of different visual and interactive applications of using a plane of fog as a projection surface.

{% embed url="https://vimeo.com/478103130?embedded=true&owner=16634945&source=video_title" %} Joanie Lemercier's *Brume* project {% endembed %}

{% embed url="https://youtu.be/XXsfO_jlv4" %} Mistform Adaptive shape screen {% endembed %}

{% embed url="https://youtu.be/mwsOSaVNXks" %}

Projection on water droplets

This is a specialized example using high speed projection and a special way of making drops appear to "levitate" or move in slow motion. This effect is achieved by carefully synchronizing the movement/dropping of water with a light source and create different phase relationships between the two movements.

{% embed url="https://www.youtube.com/watch?v=BRLx4IMetu4" %} "drop" by annolab {% endembed %}

See also:

- Leia Display - Fog Screen product

Leia Display X300 - Fog Screen for projection
Leia Display X300 - Fog Screen for projection

Projecting on clouds from a plane # Diffusion and Distortion Techniques

- Artistic Approaches
- Fiber Optics

- Ulexite/TV Stone
- Computational Caustics
- LED through wood veneer
- Others

Artistic Approaches

This is a challenging category to compartmentalize, but there is a lot of great work to consider here. Sometimes you don't need a cutting edge display or experimental hardware to do something new. By placing different optical materials in front of a monitor, projection or LED video wall you can create something that doesn't feel like a standard display at all. Of course it can be a little more challenging to show sharp coherent images with a technique like this, but sometimes a piece is much more about playing with texture and motion more than legibility.



Mary Franck's piece "Diffuse Objects"

There are many examples of this kind of work. Mary Franck's pieces *Diffuse Objects* and *Gilded and Unreal* are a great starting point. These pieces combine a standard LCD screen with custom formed materials. The content show on the screen interacts with the materials in a way that gives the light and imagery more physicality and dimension than it would on a flat screen.

Another piece in this area is Lucy Hardcastle's *Qualia*. This is a touch sensitive version of a 3D object that has light passing through it. I'm only speculating on how this works, but from the video it looks like it is projection (note DLP projection rainbow bands) from underneath into a 3d form that has been frosted. I suspect the touch sensitivity is done using IR light and a camera in a similar way to rear projection touch tables.

Fiber Optics and Acrylic

If you're not into diffusion and blur, you can be a more precise with your light redirection techniques by using fiber optic materials. Yeseul Song's *Glow Box* is a fabricated object that uses fiber optics and a projector to produce low resolution images that have been bent through the fiber optic cables.

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{% embed url="https://vimeo.com/231647907?
embedded=true&owner=2439164&source=video_title" %} https://vimeo.com/231647907?embedded=true&source=video\_title&owner=2439164 {%
endembed %}
```

Working with fiber optics can be expanded into longer or larger forms as well. MIT Mobile Experience Lab made something called *The Cloud* in 2008 that was a large cloud shaped structure that had hundreds of fiber optic strands coming off of it like hairs. Each strand could be individually illuminated and from the video it seems there is an interaction method to let people touch strands and have them respond. Very basic imagery and text could be rendered across the fiber optic strands with what I hope wasn't an individual LED per strand, but in 2008 that may have been the only option for a shape that unusual.

This technique below uses clear acrylic/3D printed material on top of a standard display to create a sort of volumetric effect using really basic materials.

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{% embed url="https://vimeo.com/185815036" %}
```

Ulexite/TV Rock

If strands and pixels aren't your thing, there is also a material called *Ulexite* that is essentially a natural fiber optic rock. Also called "TV Rock" this material has a crystal structure that appears to project the image of whatever is on the bottom of it to the top surface. I've only seen small pieces of it, but if you had a larger polished piece, you could do some unusual surface mapping effects that would look very different compared to just glass or densely packed fiber optic strands.

{% embed url="https://www.youtube.com/watch?v=isPBecyaZYg" %} Ulexite demo video {% endembed %}

Computational Caustics

In another related direction to Ulexite, some researchers are investigating a technique that uses specially formed plastics that geometrically model caustics so that the final material can display a coherent image when light is focused through them in just the right way. [Here is some research](#) on this topic.

{% embed url="https://www.youtube.com/watch?v=R00lvqcl9jU" %}

The company [Rayform](#) is offering the creation of these coherent caustics as a service for different applications using a patented process. They allow for the creation of physical things that allow for image creation using either reflection (light bouncing off a material) or refraction (light passing through). The resulting physical elements basically look like wavy plastic or glass, but the magic appears when you shine a light through them. They even have a [jewelry line](#) for getting custom reflection messages printed.

Rayform essentially takes a few things into consideration - the position of the source of light (point source is best, but sunlight can work), the size of the refraction surface, and the distance to the "projection surface" where the image shows up. When they take all of these into account, their specialized algorithm can generate a 3D model that can then be used to create a mold for making multiple copies of your intended piece.

{% embed url="https://www.youtube.com/watch?v=lqrsptUdxHs" %} Rayform Overview {% endembed %}

Rayform's Folded Heart
Rayform's Folded Heart

Rayform Examples:

- [Sun Cube](#)
- [Folded Heart](#)

Low resolution Diffusion

Finally, there are techniques that are just doing a low resolution diffusion or reflection of light like pixel displays. There are tons of examples of this Jason Eppink's [Pixelator](#) is a piece that co-ops public advertising monitors in NYC and distorts them into more pleasant abstract designs using diffusion and foamcore frames. [Jim Campbell's](#) work has been a great example of this kind of low resolution image making for a while as well.

Wood Veneer and LED

Some companies have explored doing diffusion through very thin wood panels, such as this project from [DetailLED](#) that puts LEDs behind a wood veneer. Something to keep in mind with this approach is the color shifting due to the natural wood, and the loss of light/additional heat - as well as the specialized fabrication to install the very thin wood veneer.

[DetailLED using LED with wood veneer](#)

[DetailLED using LED with wood veneer](#)

{% embed url="https://vimeo.com/7983664" %} plyLight {% endembed %}

Others

[Red Paper Heart's Expression Wall](#)

{% embed url="https://vimeo.com/252741449" %}

- [Studio Roosegaard - Beyond Lenticular # Overview](#)

This section is for topics related to displays that are more in the space of art projects, curiosities or lab experiments. They may not be practical for implementation in your own project, but they are worth exploring for stretching your idea of what a "display" could be. # Switchable Glass

While this technology is a little further out from traditional display technology, switchable glass feels appropriate to cover in some form here. There are some artworks below that do use switchglass as more of an abstracted display rather than just one large panel. Additionally, it can be combined with traditional display technologies to create something a little more unique.

When it comes to switchable glass, there are several different technologies.

- [PDLC](#)
- [SPD](#)
- [Electrochromic](#)
- [LCD](#)

PDLC

PDLC is Polymer-dispersed liquid crystal. When an electrical current is applied, it basically goes from clear to diffuse and opaque. The reaction and change occurs very quickly and can be used to create unusual effects. It also uses a low amount of energy compared to traditional displays. When electrical current is not applied, the film is opaque, but when it is applied it becomes transparent. This effect is also "dimmmable" in the sense that varying levels of current can ramp the opacity up or down.

Artist Simon Heijdens has one of the better known examples of using PDLC in in their project [Shade](#) that uses hundreds of triangles and nearly invisible electrical leads to create different visual effects with sunlight.

{% embed url="https://vimeo.com/106669679" %} Simon Heijden's *Shade* {% endembed %}

While there are a number of resources for PDLC Smart Glass in normal installations and configurations, they are mostly concerned with static applications on windows/conference rooms/etc. For specialized applications, like fragmented elements or larger architectural elements, you may need to collaborate with a company like [Gauzy](#).

SPD

SPD stands for Suspended Particle Device.

SPD is similar to PDLC in mechanism, but more of an opacity/tint change than diffusion. It primarily stays in one color that is sort of a purple blue, so it has limited uses. It can transition fairly quickly but not as fast as PDLC or LCD.

Image from Gauzy
Image from Gauzy

{% embed url="https://www.youtube.com/watch?t=3s&v=vvMfKS6iduk" %} Gauzy's SPD reference {% endembed %}

SPD is a specialized product, but you can find it from vendors such as [Gauzy](#).

Electrochromic Glass

This also operates under similar principles as the others. It is primarily a change in tint, as in SPD, but not in diffusion/opacity, as in PDLC. The clarity through the glass is largely untouched but it can cut a lot of the incoming light. The transition for this method works much more slowly, so it shouldn't be used for displays that require very fast image making. It is also just a transition between two colored states. One commercial use for Electrochromic glass is in airplane windows to replace shades

[Sage Glass](#) is one manufacturer of Electrochromic Glass.

LCD

LCD is a bit of a different class here and has been discussed briefly in the [transparent](#) section, but it uses large LCD panels as individual pixels to turn different grayscale colors. The switching of the LCD opacity can happen rapidly just as in normal LCD monitors.

It has been used for projects such as Sosolimited and Hypersonic's [Patterned by Nature](#)

{% embed url="https://vimeo.com/41009719" %} Patterned by Nature {% endembed %}

Jason Bruges's studio also makes heavy use of specialized LCD panels, like in the piece [Digital Fountain](#).

Jason Bruges Studio Digital Fountain
Jason Bruges Studio Digital Fountain

Finding a source for making custom LCD's in this way is a bit of a challenge since they are such a niche product. One source may be [Pacer](#). Another is [White Wing Logic](#) based in the UK who has created or advised on a number of the projects for Jason Bruges's studio. # Drone Displays

[Work in progress]

Wikipedia for [Drone art](#)

Drones are a relatively recent entry to the display technology field. For these projects, fleets of hundreds of drones are programmed to essentially fly up and create a very large scale volumetric display in the sky for a limited amount of time. All of this requires a lot of advanced technology in avionics, sensors, positioning technology, 3d modeling, and wireless communication. Due to the battery limitations on drones, these kinds of things are really only suited for temporary displays that last less than half an hour, but they still provide a very stunning effect that can be visible almost 2km away.

The most commonly mentioned provider is [Intel's division that handles drone displays](#). It's worth mentioning that on their site (as of 2022) they offer 200 drones for a base of \$99,000 or 500 "Premium" drones for \$299,000. For super large displays like the world record below (with 3281 UAV's), these require thousands of drones to create enough points of light to make a dense image. There are also significant logistical elements to working with these displays, like planning for local aviation laws, securing a space large enough to launch/land from, and planning around weather and other physical constraints.

[SkyMagic](#) and [Celestial](#) are other vendor options that offer this kind of technology for events.

{% embed url="https://www.youtube.com/watch?v=-c3ywdTpX8I" %}

A very early example of coordinated drones being used as part of a light show is this 2012 piece from Marshmallow Laser Feast called [Meet Your Creator](#):

{% embed url="https://vimeo.com/105175961?embedded=true&owner=403780&source=vimeo_logo" %}

description: Paint that can light up and change color when a current is applied to it.

Electrochromic Paint

Electrochromic Paint is a specialized paint that lights up in a color similar to glow-in-the-dark paint when an electrical current is applied. One of the main providers of the electric paint is Lumilor.

There are some restrictions about the amount of surface area (not much larger than 280 square inches for a single lightup sector) that can be lit up with this kind of paint, but for the right application it can be a great fit. Additionally, it doesn't have an infinite lifespan, or its brightness tends to fade over time, so it's not particularly suited for permanent installations.

{% embed url="https://www.youtube.com/watch?v=Y_OIK2IBqXE" %}

{% embed url="https://www.lumilor.com" %}

{% embed url="https://www.americanscientist.org/article/switching-colors-with-electricity" %}

{% embed url="https://rdotdisplays.com/articles/nissan" %} # Scanning Fiber Optics

{% embed url="https://www.youtube.com/watch?v=c9ZapsZvapM" %}

There are a few different approaches to this technology, but one form of it uses a small element of fiber optics, a light source, and an electromechanical method of quickly vibrating the fiber optic point of light in front of a lens array so that persistence of vision can create a small scale image in front of someone's eye for the purposes of augmented reality.

See [aresearch paper on this topic](#).

[Another paper](#)

{% embed url="https://opg.optica.org/oe/fulltext.cfm?id=382063&uri=oe-26-5-5576" %}

{% embed url="https://www.science.org/doi/10.1126/sciadv.abe4458" %}

- # Acoustic Levitation Display

{% embed url="https://youtu.be/Tm8JRIJ1q50" %}

Also referred to as an Acoustophoretic Volumetric Display

This area of research uses ultrasonic soundwaves and the principle of standing waves to “levitate” thin and light particles of material and (in some cases) move them at a high enough speed to make coherent images and shapes. The applications of this technology are somewhat limited to small scale particles and small display areas, but it is worth seeing this as another unusual area of display research.

{% embed url="https://www.youtube.com/watch?v=jOnxr9Ez_Kc" %}

There are a number of labs and researchers exploring this technique There is a DIY approach called a Sonic Surface.

There is JOLED from the University of Sussex

{% embed url="https://www.youtube.com/watch?v=U-wAGqZ_Qcg" %}

Another example from the University of Tokyo that levitates small bits of foam with different shapes:

{% embed url="https://www.youtube.com/watch?v=odJxJRAxdFU" %}

For the above: Yoichi Ochiai / 落合陽一(The University of Tokyo / 東京大学)
Takayuki Hoshi / 星貴之(Nagoya Institute of Technology / 名古屋工業大学)
Jun Rekimoto / 曆本純一 (The University of Tokyo / Sony CSL) White paper:
<https://arxiv.org/abs/1312.4006>

There are even small DIY kits that allow for home experimentation with standing waves on a micro scale.

More links:

- <https://hackaday.com/tag/acoustic-levitation/>

· Plasma Combustion

Plasma Combustion

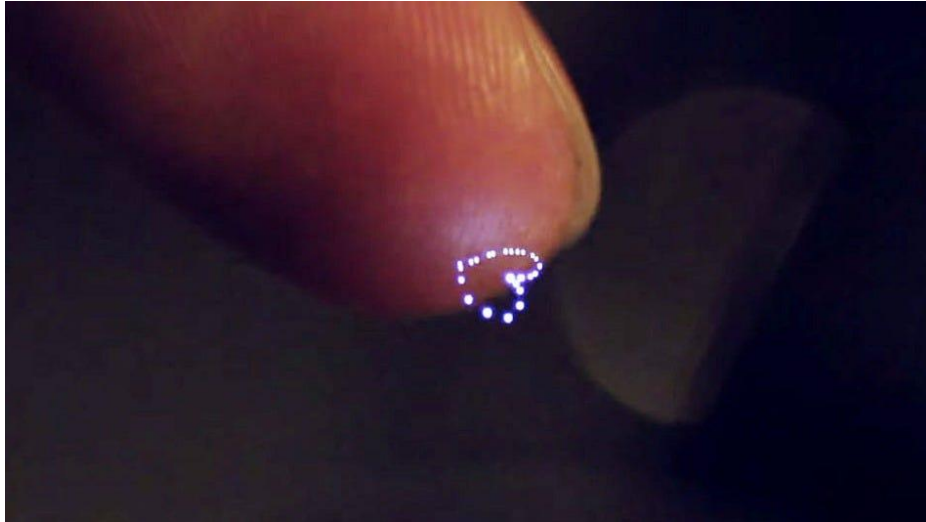


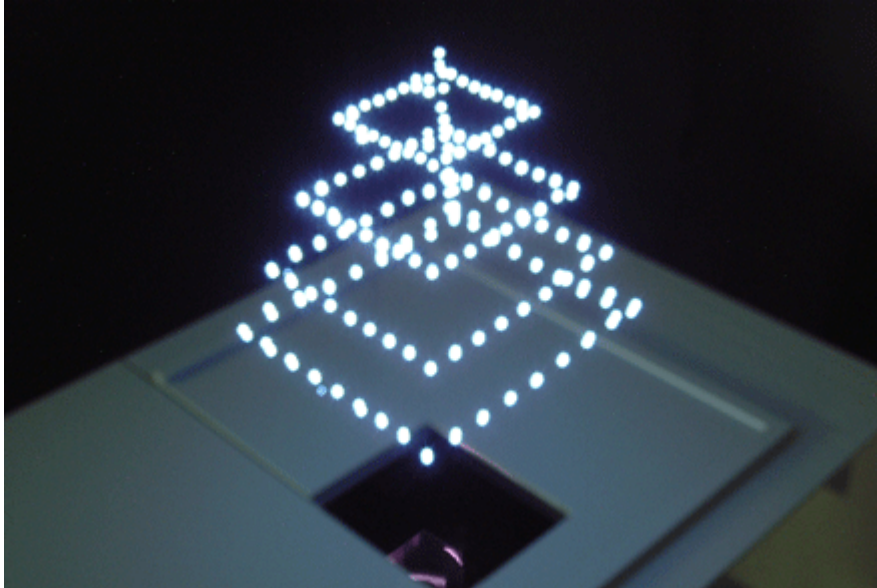
Image from paper Fairy Lights in Femtoseconds — Source

This kind of display acts in a similar way to Volumetric Projection, but it is considerably more dangerous and expensive. There are only one or two companies working on this display type right now, and one is [Aerial Burton](#). There is limited information on how this display actually works, so take my layman's explanation with a grain of salt. This display technique works by focusing high powered lasers onto a point in space. When the energy at that point gets hot enough, the air molecules get ionized and release some photons. Aside from ionized plasma, fluorescence is one, and [cavitation](#) is another when involving a fluid medium. Here is a demonstration [video](#) of the Aerial Burton display:

{% embed url="https://www.youtube.com/watch?v=GNoOiXkXmYQ" %}

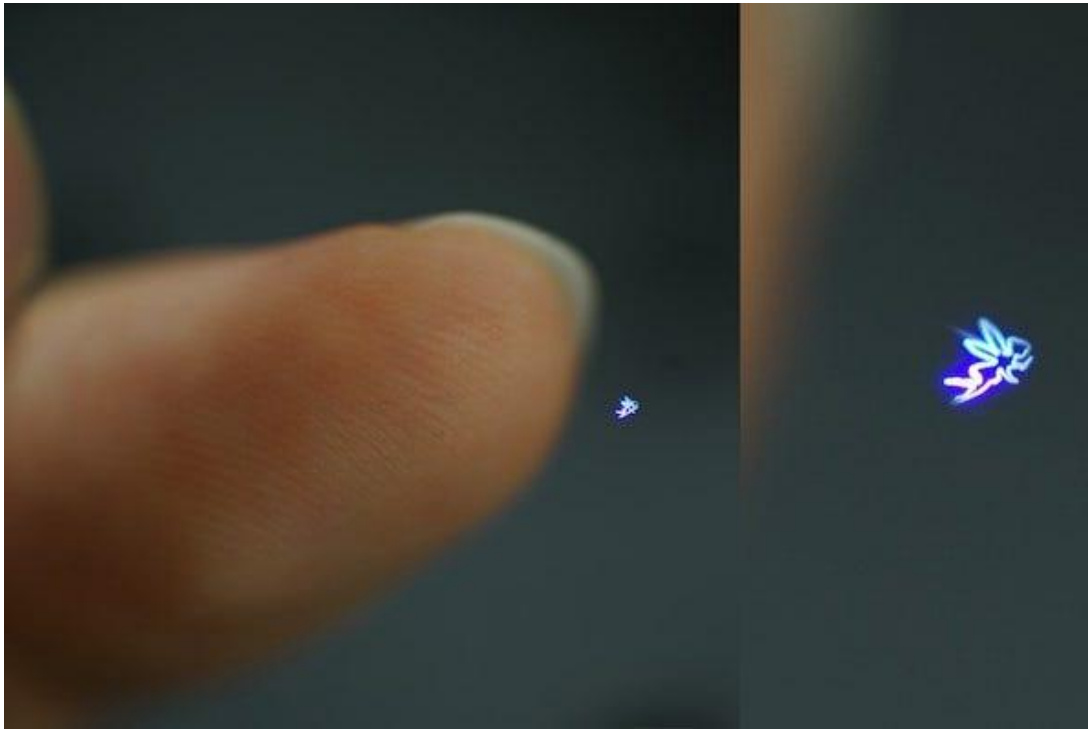
Two forms of Aerial Burton's displays — one with a fluid based medium and one based entirely in air — [Source](#)





This display unfortunately has many drawbacks that are similar to those of a laser projector. They still work by moving a mirror very quickly, so there is a limited number of points that they can draw at a given time. There is also an added crackling noise component because of the tiny explosions needed to make the visuals. These tiny explosions can also emit an ozone gas that can be potentially harmful if used in an enclosed space.

Another set of researchers in Japan have been working on a much smaller implementation of this same technique that they are calling the Fairy Lights display system. The primary difference is that this version is touchable. By firing the lasers much faster than the Aerial Burton method, the images are smaller and not as bright, but much safer. The tangible element can be used as an additional cue for interaction with the display. They still have similar drawbacks related to visual fidelity (number of dots per second) and added popping noise (their paper says about 22dB of noise is added when using the display). Here is a video featuring some of the interactions and visuals that can be produced.



High Refresh Rate Displays

This page needs a bit more structure, but is meant to cover some sources on high refresh rate displays and their applications. There is a lot of creative potential in a high refresh rate display that is still largely untapped. Most displays run at 60hz/frames per second which comes out to about 16.8ms per visible frame. Very fast, but not exactly a speed limit - real life doesn't have a frame rate and your eyes and brain don't exactly process in discrete frames either - 60hz just feels "comfortable" to most and was the minimum of what was technically achievable years ago.

Most manufacturers are pursuing effects in the spatial/resolution dimension (8K, 16K, 3D, etc), but as monitors get 240hz and beyond, there are new untapped areas of visual exploration and information delivery that can be explored. Additionally, as resolution gets higher and higher, a higher framerate will also become critical for improved visual fidelity and realness as it becomes harder and harder to tell the difference between 16K and beyond in close-up viewing scenarios. In smartphones and tablets we're starting to see a lot more 120hz displays than just the standard 60hz, and a lot of this is for a smoother animation experience. Outside of standard LCD and OLED, LED video walls do have the capability to change at very fast speeds in the 500hz range, but their driver electronics are usually designed to interface with standard 60hz output devices.

Most of the conversation around high refresh rates is dominated by gaming displays and applications to gaming, so it can be hard to find interesting updates that are outside of that space. There are a lot of advantages to high refresh rates for smoothness of animation, but there is also the potential for nearly invisible information transmission to another digital device (think of it as QR code that can hold more information than just a URL).

The Voxon VX1 volumetric display uses a specialized graphical pipeline to project images at nearly 4000 frames per second onto a mechanical surface that moves up and down. As the surface moves, the persistence of vision effect allows people to see those “slices” as more of a light volume.

There are some discussions out there of what a 1000hz/frames per second display could do for visual fidelity and reaction time as well. There are a lot of technical hurdles to overcome to get to something even close to that kind of display that would also be commercially viable, but I suspect we'll see something like it in the next decade.

Some refresh rate comparisons on a 390hz display:

{% embed url="https://www.youtube.com/watch?v=GrVWF91zCGU" %} Acer Nitro 390hz display {% endembed %}

Other Experiments

- Light Leaks
- Wedge Display
- Lickable Display
- Electrowetting Display
- Deconstructed LCD
- Colloidal Bubble Display
- Parallel Reality Display
- Phases Mirror Display
- Robotics and Displays

Light Leaks

Using standard projectors, an array of mirror balls, a lot of math, and a map of the space, Kyle McDonald and Jonas Jongejan created this piece to create spatialized visuals.

{% embed url="https://vimeo.com/66167082" %}

Wedge Display

The CamFPD Wedge Display- No updates or news since 2004. Seems to be a similar principle to waveguide displays used for AR headsets by “projecting” light on a flat plane.

CamFPD Wedge
CamFPD Wedge

Lickable Display

A researcher has combined a traditional display with an aerosol dispenser to spray a screen with different flavors that can be licked by a user to be able to taste what is on screen. The project is called Taste the TV by researcher Homei Miyashita

Homei Miyashita's Lickable Display
Homei Miyashita's Lickable Display

Liquavista Electrowetting Displays

These displays promised an alternative to E-Ink but with a faster refresh rate but never made it to market. [You can read more about them here.](#)

Deconstructed LCD

{% embed url="https://vimeo.com/248809615" %} [Cere Davis's Liquid Loom](#)
{% endembed %}

Colloidal Bubble Display

This experiment involves using a special colloidal solution and an ultrasonic speaker that can be used to "tune" the transparency and reflectiveness of a bubble when light is projected on it.

{% embed url="https://youtu.be/tvxJs_4m0ZE" %}

Parallel Reality Display

The company [Misapplied Sciences](#) has developed a concept of a Parallel Reality Display that promises the ability to display different pixels to different viewers (in very simplified terms).

These pixels can simultaneously project up to millions of light rays of different colors and brightness. Each ray can then be software-directed to a specific person.

Below is a demonstration of what 12 different viewpoints could look like to different viewers from a single display.

{% embed url="https://www.youtube.com/watch?v=ptXTSuMkuvA" %}
Misapplied Sciences Parallel Reality Display {% endembed %}

Phases by AV&C

This piece really strays between lighting element and display for me, but I think it's worth mentioning. It uses an array of mirrors and lights to create controlled reflections around the space - [Phases by Vincent Houze and AV&C](#)

{% embed url="https://vimeo.com/207143053" %} Phases by Vincent Houze and AV&C {% endembed %}

Robotics and Displays

There are a few examples out there of displays on robot arms and moving displays. I'd say these are a little different from the mechanical displays in the other section since this is about moving whole units of a display versus moving individual pixel elements.

{% embed url="https://vimeo.com/644631363?embedded=true&owner=21846195&source=video_title" %} Dotdotdash for Adidas and Prada {% endembed %}

And while the below project from Bot and Dolly is really a projection mapping example, it really needs to be mentioned in this category.

{% embed url="https://vimeo.com/75361102" %} Box by Bot and Dolly {% endembed %}

Overview

This section is meant for covering more vintage applications of displays. While most of these are no longer in use, that essentially makes them alternative displays as well at this point. Considering past display technologies still offer some valuable insights into what the future could hold as well. Also - there was some wild and crazy stuff that people used to get up to... # Cathode Ray Tube

(Work in progress)

CRT

[Wikipedia](#) for CRT

I don't think I could explain CRT stuff much better than the wikipedia page, so you're better off looking there, but here are some videos worth watching.

{% embed url="https://www.youtube.com/watch?v=v7Fd-ymxkKk" %}

The notable stuff for using CRT's in new installations is that they are finicky, not super bright (don't use them outside), and can sometimes have issues with filming well.

There are still providers out there for buying [CRT's for things like museum installations](#). See [Dotronix](#) for more info on buying "new" CRT's.

{% embed url="https://www.youtube.com/watch?t=4s&v=ijAaLxiYiWM" %} Nam June Paik's Wobbulator {% endembed %}

Vectex Displays

These are essentially a different flavor of a CRT display, but they should be mentioned in the same breath. See some videos featuring these below:

{% embed url="https://www.youtube.com/watch?v=o73UrUAL0sk" %}

{% embed url="https://www.youtube.com/watch?v=9wkEL3RcW8s" %}

- Other Links
 - [Autostereoscopic display from 1995](#) using high speed CRT's and an LCD grating
 - [Gaslit title sequence with CRT](#)
 - Also mention: Vectrex/Oscilloscopes

Eggcrate and other Numeric Displays

- Eggcrate
- Nixie tubes
- Others

Eggcrate

Eggcrate Display

Eggcrate Display

{% embed url="https://en.wikipedia.org/wiki/Text_display" %}

An **eggcrate display** is one older method of displaying an alphanumeric character. It consists of a matrix of incandescent light bulbs. A foam rubber mask with an array of holes surrounding the bulbs is attached to the display, causing it to resemble an egg crate.

Some eggcrate displays use a complete 5×7 matrix for each digit, permitting the display of nearly all alphanumeric characters. Other types display only numeric characters and optionally a dollar sign. This type of eggcrate display is popularly used for sports scoreboards.

Eggcrate displays have been used on many game shows to display contestants' scores and/or for countdown clocks because other types of displays, such as LED seven-segment displays, were prone to being washed out by bright studio lights. Though they continued to see extensive use well into the late 1990s, many shows began adopting LCDs in the 2000s. They have also been used as variable-message signs on highways, although they were later superseded by flip-disc, fiber optic, and eventually LED displays.

Nixie Tubes

- [Link](#)

{% embed url="https://www.youtube.com/watch?v=gERE4st1H0o" %}

{% embed url="https://www.youtube.com/watch?v=wxL4ElboiuA" %}

Others

- [Link to Friendlywire compendium](#)
- [Industrial Alchemy midcentury numeric displays](#)

Pyrotechnics and Other Curiosities

- Pyrotechnics
- Eidophor Projector

Pyrotechnics

Pyrotechnics could easily be considered as a precursor to modern digital display technology for large scale displays. [See my deep dive here](#)

A “living firework” with a bunch of lit up pixels as a precursor to LED’s

A “living firework” with a bunch of lit up pixels as a precursor to LED’s

A large pyrotechnic display showing faces lit up in light.

A large pyrotechnic display showing faces lit up in light.

Eidophor Projector

[Wikipedia page](#)

Eidophors used an optical system somewhat similar to a conventional [movie projector](#), but substituted a slowly rotating mirrored disk or dish for the film. The disk was covered with a thin film of transparent high-viscosity oil, and through the use of a scanned [electron](#) beam, electrostatic charges could be deposited onto the oil, causing its surface to deform. Light was shone on the disc by a striped mirror consisting of strips of reflective material alternating with transparent non-reflective areas. Areas of the oil unaffected by the electron beam would allow the light to be reflected directly back to the mirror and towards the light source, whereas light passing through deformed areas would be displaced and would pass through the adjacent transparent areas and onwards through the projection system. As the disk rotated, a [doctor blade](#) discharged and smoothed the ripples in the oil, readying it for re-use on another television frame.^[10]The

Eidophor was a large and cumbersome device and not commonly used until there was a need for good-quality large-screen projection. This opportunity arose as part of the NASA space program, where the technology was deployed in mission control.

How an Eidophor Projector works
How an Eidophor Projector works

{% embed url="https://youtu.be/3-BvMcqEc98" %} # Closing Notes

The topics covered are just a few of the possible options for display types and techniques of working with light. Once you find a research paper on one, there are a million other paths in the references of that paper. I hope this gave you a good idea of the range of amazing technologies out there — from the DIY \$5 option to the theoretical and fanciful. There are other effects we didn't explore in detail like stereoscopic displays for home 3D movie viewing, lenticular effects and many more. There are also a lot of technologies that never took off, either for reasons of cost, complexity, or ownership. Things like CamFPD's wedge display, or Electrowetting displays (similar to e-ink) were ones that had great commercial potential only 10 years ago, but never ended up taking off for one reason or the other. Some techniques are quite old and were never acquired as intellectual property and will eventually be available in the public domain. There are whole conventions devoted to advancements in display technology, but much of it never reaches the general public or the artistic community. Lots of great options, ripe for use or modification. The more we experiment and use these technologies, the sooner we'll get to advance the ones on the fringe. If interest in these alternative displays increases, they will become more normalized and costs will come down, opening the door for even more experimentation.

We'll be seeing a lot more display developments in the next few decades, so keep your eyes open and see which ones might be a good fit for your artistic vision.



#

Misleading Terms

This section will cover some brief notes on frequently misleading terms used to market various displays. Here are a few:

- Hologram
- Autostereoscopic Displays/3D TV's
- LED TV's
- 3D LED Displays and Forced Perspective

Holograms

{% embed url="https://vimeo.com/73974644?embedded=true&owner=562128&source=video_title" %}

It should be mentioned that none of the displays mentioned in other sections are in line with the definition of a [hologram](#). A hologram is closer to a photographic medium as it captures an imprint of the light waves that bounce off an object. Most of the media headlines these days with the word “hologram” are typically talking about simple optical tricks or AR. Holograms have taken on a cultural meaning that differs from the scientific definition, similar to the cultural rebranding of “synesthesia” or “literally.” This [article](#) by Oliver Reylos has a concise summary of what is considered holographic and what isn’t. In his words:

When viewing close-by objects, there are six major depth cues that help us perceive three dimensions:

- *Perspective foreshortening: farther away objects appear smaller*
- *Occlusion: nearer objects hide farther objects*
- *Binocular parallax / stereopsis: left and right eyes see different views of the same objects*
- *Monocular (motion) parallax: objects shift depending on how far away they are when head is moved*
- *Convergence: eyes cross when focusing on close objects*
- *Accommodation: eyes’ lenses change focus depending on objects’ distances*

Almost all of the displays or techniques in this article have some holographic properties like parallax or multiple viewing angles, but are primarily in a class of their own. Would you call an oil painting a sculpture?

Autostereoscopic Displays/3D TV’s

3D TV’s are primarily a marketing term for something that is more accurately called an autostereoscopic display. These TV’s aren’t pushed as much in 2022 because they never really caught on for most of the public, primarily because they overpromised the 3D effect.

[More on various types of 3D Televisions.](#)

LED TV’s

This term has been mixed up for a while and is more accurately known as an LED-Backlit TV.

LED’s as a light source were an important development for backlit LCD’s many years ago and allowed the creation of thinner and more energy efficient LCD displays of the traditional CCFL (Cold Cathode Fluorescent Light) light source. Unfortunately the marketing term causes them to be mixed up with [LED video displays](#) which use a very different approach for creating light. There are more and more displays and TV’s that are starting to use things like [microLED](#) technology that will eventually make this even more confusing, but for now you can usually assume that an LED TV or monitor is usually only referring to the backlight.

[More on LED Backlit TV’s](#)

3D LED Displays and Forced Perspective

There have been more and more of these kinds of videos popping up on social media in the last few years. While this isn't necessarily a misleading term, the way they are presented in a video setting is misleading to how they are perceived in real life.

Light Field Labs has a breakdown where they explain this phenomenon fairly well:

There has been a great deal of hype in recent years around the use of various optical illusions such as forced perspective or anamorphosis that make content on large format displays appear three dimensional—in particular using installations that wrap around the building like that at 20 Times Square. The advantage of the wrap-around design is that content can be used to create the impression that the screen is a large cube that has been cut out of the building. Action can then take place on this “stage” area that appears to extend back into the structure. If the stage area is smaller than the screen, objects can be made to appear as though they are moving out of the display.

In the first example below, the far end of the digital display is darkened so it looks like part of the building. When the hand passes into this part of the screen it looks as if there is building frontage behind it, tricking the viewer into thinking it must have reached out beyond the dimensions of the display. The illusion is spectacular when viewed from the right angle, but breaks down when the viewer moves to a different vantage point.

{% embed url="https://www.youtube.com/watch?v=9ILDUmofK18" %}

And here is a video that kind of debunks what these displays look like when moving around them in an actual city setting:

{% embed url="https://www.youtube.com/watch?v=BFKCRS4PpCk" %} #
Notes about Touch Screens

Since touchscreen technology is adjacent to specialized displays, I figured it would be good to have a brief section here that covered a few different touch screen technologies.

Types:

- PCAP/Projected Capacitance
- Infrared
- Resistive
- Surface Acoustic Waves
- Surface Capacitive
- LIDAR
- Object/Marker recognition on screens # Virtual Production and XR

This section is meant to provide some links and resources on things like virtual production and Extended Reality (XR). There are many resources that cover this topic in considerable detail, so this will be very brief.

This area of study is a large synergy across different disciplines like content production, filming, LED displays, motion tracking, and lighting. It felt necessary to acknowledge it as part of the continuum of digital displays.

In a weird way, you could consider XR as a specialized display on its own because of how it utilizes sensor technology and game engines to render a believable environment to the perspective of the camera. In the same way that an AR/VR headset renders a certain perspective to the viewer's eyes, this is just that same concept but unwrapped into a sort of externally facing thing. I think that certain kinds of displays will eventually incorporate more and more sensors that are just considered fixed elements of the display.

In very brief terms, many setups for XR utilize a rendering engine like Unreal or Notch to render a scene in real time. The scene is rendered on high resolution LED tiles where actors and other props are used to set the scene. A tracking system (like a Vive Tracker) is attached to the camera and it allows the real-world camera to essentially duplicate the virtual camera position in the rendered 3D scene. There is a lot of details I'm not covering here like the importance of scene lighting, the frame sync/genlock between the LED scene and the camera, and the alignment of the camera intrinsics to the virtual camera so that movement feels natural and smooth for the background of the scene.

Some other resources:

- [The difference between XR and Virtual Production](#)

Low budget XR overview:

{% embed url="https://www.youtube.com/watch?v=DQT0Qy856mA" %}

{% embed url="https://www.youtube.com/watch?v=9BtyhCyTJt0" %}

{% embed url="https://www.youtube.com/watch?v=HDb6EGipO-Y" %} #
LCD Polarizer Removal

DIY Notes to Remove the Polarizer from your Monitor



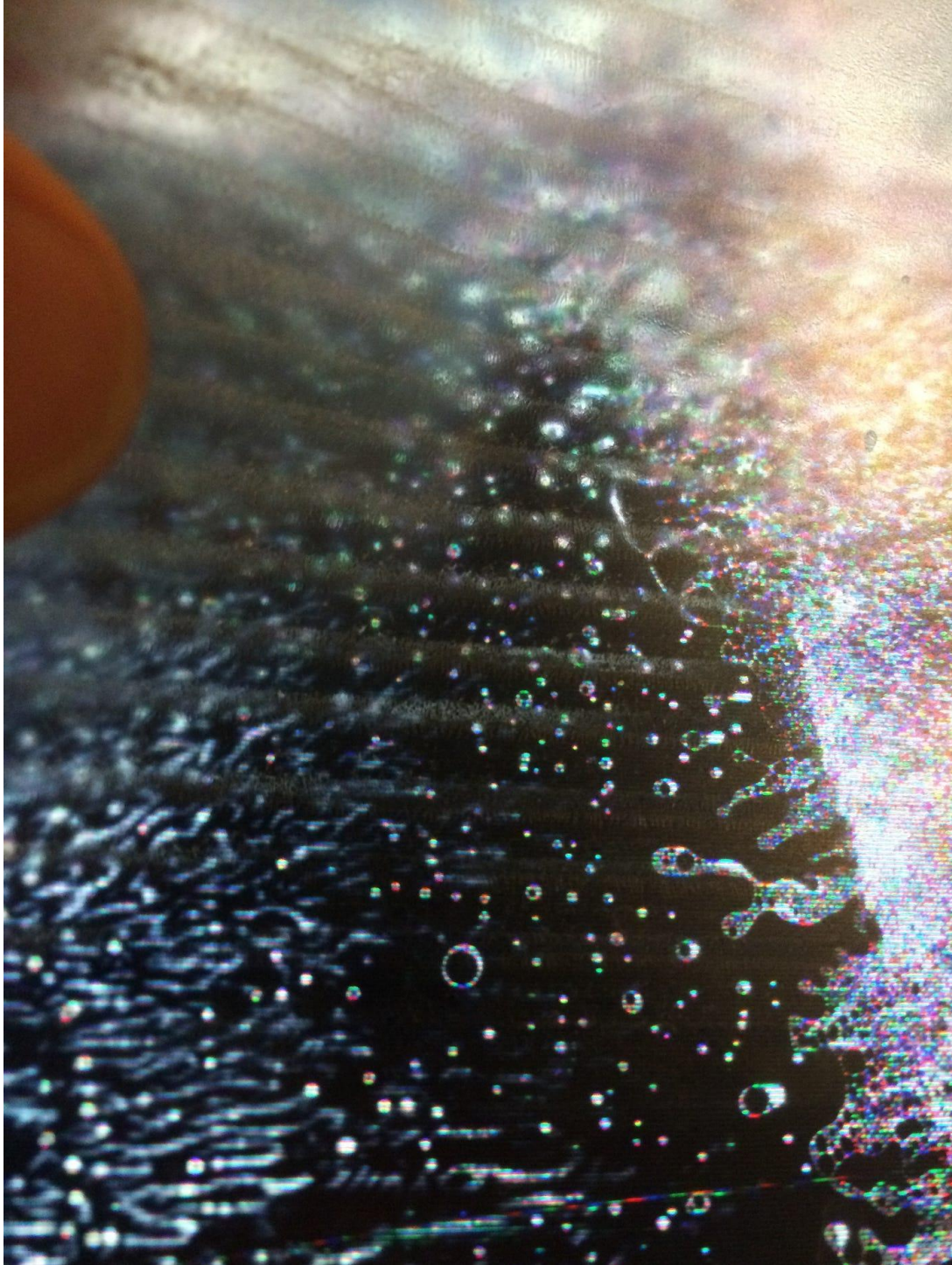
Image of attempting to slowly scrape the film off of a monitor with a razor blade

Since these screens aren't typically manufactured like this, you will have to open the screen up and remove the polarization layer off yourself. Similar to my notes on making your own transparent screen, this involves opening up the screen and potentially breaking your monitor casing, electrocuting yourself, or cracking the delicate LCD. I broke 2 screens before I got this right, and every manufacturer applies their polarization film differently. Sometimes you can peel it right off, and sometimes it will be applied with adhesive and require a few hours with a razor blade and some acetone to dissolve the adhesive. The film tends to have a "grain" to it, so if you start on a corner and that corner of the film snaps off, try the opposite corner. Pull very very slowly — one wrong move, and you'll crack the glass holding the liquid crystal in place. The film itself is also very sharp — paper cut style — I sliced my hands up more than once. Patience is the name of the game.

Once you have the film off the screen, you may be saying "Hey! What gives — this film is all blurry!" The explanation is that manufacturers combine the polarization layer with a diffusion layer to improve viewing angles, but this makes the film difficult to use if it is not sitting directly on top of the screen. However, there are tons of online vendors for sheets of linear polarization film that do not have diffusion. If you're not in the DIY spirit or need to get this done on a massive scale, there are screen vendors listed in the

references section that do have the ability to remove polarization film from very large displays and are closer to the supply chain than a consumer could get.

Image of my failed attempt at removing the polarizer — moved too quickly and cracked the glass



DIY Transparent Screens

Notes on DIY Transparent screens

You can modify an existing LCD monitor to be transparent by opening up the monitor and removing the backlight yourself. Insert boilerplate copy about how you should not attempt this without understanding that you may completely break your screen or cause personal injury/electrocution and the author assumes no responsibility — please be cautious and safe.

Speaking from personal experience, this is a difficult modification to perform on monitors from the factory, quite simply because they are not designed to be used this way. I have done this to 4 or 5 different LCD screens and there is a tremendous amount of variability in how different manufacturers assemble their screens, so there is not a consistent guide that would work for each screen. You may be able to open the screen up, but that may require breaking the internal plastic tabs that hold it together — ensuring that you can't quite put it together again. You must also go very slowly to ensure you aren't going to crack the screen or rip or damage the delicate electronics inside.

Once you have it opened up, the backlight and LCD screen are often sandwiched together with a metal frame that must be carefully wedged off. One of the long edges of the LCD panel is going to have a very fragile thin plastic flex cable that traverses the whole side. This flex cable essentially controls each column of pixels individually, so if any part of it gets damaged, you may lose that part of the screen or the screen entirely. Removing this element and its PCB from the rest of the case and the backlight is probably the hardest part of the whole process. Additionally, some screens have an additional diffusion film that is bonded to their polarizer for the purpose of improving viewing angles — unfortunately, this layer makes content behind the screens get completely blurred out.

They used to sell things like transparent LCD's before they could make affordable high definition LCD panels that can fit in today's projectors. They were sold as bulky glass panels that could be connected to a computer and placed on top of an overhead projector.

Also worth noting a total DIY method making LCD's:

{% embed url="https://www.youtube.com/watch?v=d4QFNWBSZYg" %}