Understanding when **e-paper** is the right display technology for your design

PERVASIVE DISPLAYS

Introduction

E-paper displays (EPDs) sprang to the public’s attention through their use in e-readers, such as the Amazon Kindle series, Barnes & Noble’s NOOK devices, and Kobo’s various models. People around the world have enthusiastically embraced these EPD-equipped devices, attracted by the paper-like reading experience and long battery life, both of which compare extremely favorably to tablets and smartphones.

Figure 1: E-paper displays used as screens in various e-readers.

EPDs have also been used extensively as electronic shelf labels in retail, where their display flexibility and ease of legibility makes them superior to paper labels or liquid crystal segment displays.

With e-paper technology now mature, widely known and available at scale, increasing numbers of product manufacturers across other sectors are assessing whether it’s the right display technology for their application. This could be to replace an existing type of display, or to add a display to a device that previously did not have one.

Figure 2: Electronic shelf labels are easy to update,
can use color to highlight text and also display QR codes.

This white paper is designed to help designers and engineers decide whether e-paper is appropriate for their products, by explaining:

- How EPDs work.
- Key real-world benefits of EPDs.
- Pros and cons of alternative display technologies.
- Ideal EPD use cases.

How e-paper displays work

To determine whether an EPD is appropriate for an application, it's important to understand how these displays work. We'll focus primarily on black-and-white displays, which make up the majority of EPDs sold for industrial applications, although three-color EPDs, capable of displaying black, white and yellow, or black, white and red, are also available and are popular for electronic shelf labels whilst greyscale versions are used in e-readers.

Capsules and ink particles
The display is made up of a monolayer of liquid-filled capsules, each containing electrically charged black and white ink particles. The black particles carry a positive charge, and the white particles a negative charge.

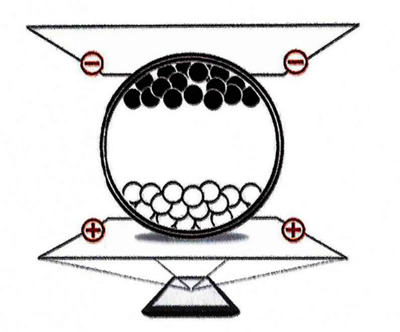

Figure 3: E Ink's two-pigment electronic ink system. Source: E Ink

The capsules are sandwiched between electrodes, which can apply different electric fields to the top and bottom of each capsule. By applying a positive electric field to the top electrode and a negative field to the bottom electrode, you bring the white particles into view and pull the black ones to the base of the capsule, out of sight. Reverse the electric fields to make the black particles visible and hide the white ones.

Three-color EPDs, such as those capable of displaying black, white and red, or black, white and yellow, are a little more complex, because the black, white and red/yellow particles must all carry different charges. For example, the black particles may carry a +15V charge, the white ones –15V, and the red/yellow ones +5V. Controlling which color appears on the display requires more sophisticated driving, with different electrical forces, timings and frequencies. As a result, these three-color EPDs require more energy to operate than black-and-white ones. We cover energy consumption in depth later.

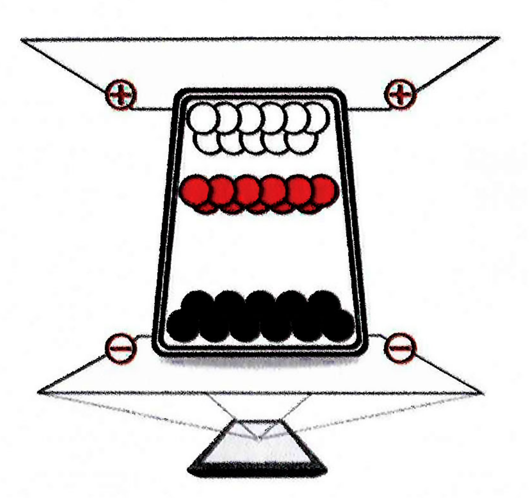

Figure 4: The spectra product line utilizes a 3-pigment ink system in a microcup structure. Source: E Ink

Bistable image: No energy required to maintain content on the display
Once you've applied the necessary electric fields across the display to draw the image you need, EPDs require no further energy to keep the content visible. The physical ink particles remain in position until you apply a different electric field, even in the absence of a power source.

Reflective display: Ease of readability and no backlight
Moreover, because the EPD image is made up of physical particles, the contents of the display become visible when ambient light is reflected off the light areas and absorbed by the dark areas. This is precisely the same way we can read printed ink on paper.

This has two key consequences. Firstly, it means EPDs don't require a backlight. And secondly, it enables EPDs to be read even in bright sunlight and harsh lighting – conditions where other display technologies can struggle for legibility, due to the fact that the ambient lighting is more powerful than the display's backlight.

Updating the contents of an EPD: Full and partial updates
There are two ways to change the content displayed on an EPD. The first is called a 'full update', and the second a 'partial update'.

A full update of a black-and-white EPD involves drawing an invert of the entire final image (i.e. all pixels that will ultimately be black are turned white, and vice versa), before inverting this again to create the image. This creates the 'blink' effect you may be familiar with from e-reader devices.

A partial update only changes the necessary pixels on the display from black to white, or white to black. There's no blink with a partial update. Moreover, they take around 25% of the time of a full update, and therefore use significantly less energy.

However, after making a couple of partial updates, the 'ghost' of earlier images and text can remain visible on the screen. A full update will eliminate this. For this reason, it's common to see e-paper displays perform updates according to a sequence such as partial-partial-partial-full partial-partial-partial-full.

Driving an e-paper display

Like any display, an EPD needs some form of controller. This will typically be embedded alongside the display element, which is the case with an internal timing controller (iTC), or it will be part of the PCBA, which is the case with an external timing controller (eTC). The latter will usually be implemented as firmware running on the main microprocessor or microcontroller.

Both eTCs and iTCs have their advantages. For products where it's essential to minimize the energy footprint of every component, it's likely engineers will already have selected an MCU that's designed and manufactured to deliver exceptional energy-efficiency. Using this same MCU to control the EPD extends these low-energy benefits to the driving of the display, thereby minimizing its impact on the overall power budget. As a consequence, using an eTC rather than an iTC will typically be three times more energy-efficient. This makes them particularly attractive for anyone designing equipment using energy harvesting, where every microamp counts.

That said, iTCs make the process of programming and integrating the display simpler than eTCs.

To make controlling the display easier for engineers and product designers, Pervasive Displays pre-programs its iTC-equipped EPDs, using one-time programming. This means the complexity of driving the display, including intricacies such as applying the right charges in the right places at the right times, is taken care of by the display controller.

Designers and engineers choosing EPDs with an iTC need to be aware that if they choose an EPD with a pre-programmed iTC, there are differences between the ways in which vendors carry out this pre-programming. Slight manufacturing variances between batches of the same display panel can mean different batches require slightly different driving waveforms to achieve the same results. Pervasive Displays tests each batch of screens coming off the production line, and optimizes the waveform we apply to the iTCs, to ensure the displays will perform consistently in use.

Conversely, if all the iTCs were to be pre-programmed with an identical waveform, there's a risk of inconsistent visual performance. The displayed image could look perfect on one batch, and faded on the next.

Moreover, operating in particularly hot or cold environments can require different waveforms compared to more temperate conditions. If a product is likely to see this type of use, we advise designers to speak to their display vendor about it – a good EPD maker will apply a fine-tuned waveform to the displays, to optimize them for use in the expected conditions.

Consistency of performance over time
Pervasive Displays has invested heavily in the manufacturing lines that produce our EPDs. The production process is highly automated, which minimizes the opportunity for the variations that can occur on production lines that rely on significant human input. This, coupled with the batch-specific waveforms we apply, mean the EPDs we produce offer exceptionally consistent performance over long periods of time.

Figure 5: Pervasive Displays' automated production line

Touchscreen-capable
Lastly, EPDs can be combined with touch-sensitive overlays, to create intuitive touchscreen user experiences. Pervasive Displays works with partners that can provide this touchscreen feature for customers.

Real-world benefits of e-paper displays

The various characteristics of EPDs, including those we've outlined above, combine to create a number of real-world benefits for product designers and engineers.

Low energy usage in applications with limited screen updates

Often the most compelling benefit of e-paper displays is how little energy they consume – when used in applications that only require sporadic screen updates. This is because of the fact that once something is displayed on an EPD, it requires no further energy to remain visible, unlike a TFT LCD, for example, which must continually refresh, even to maintain a static image.

The comparison table below illustrates the difference in daily and annual energy usage between a variety of similarly-sized EPDs and a TFT LCD. Note the particularly low energy consumption achievable when using an external timing controller, as well as the difference in annual energy consumption between a black-and-white EPD and a black, white and red EPD. It is important to bear in mind that the energy consumption of displays using eTCs may vary with MCU performance.

	Single screen refresh			**Energy needed for always-on display, with six content changes per day**		Energy consumed per year (mAh)
	Consumption (mA)	Duration (s)	Total energy consumed per refresh (mAs)	(mAs)	(mAh)	
2-inch black-and-white EPD with external timing controller (eTC) (V231, eTC/G2)	2.32	2.32	5.4056	32.4336	0.009	3.288
2.13-inch black-and-white EPD with internal timing controller (iTC)	8	2	16	96	0.0267	9.733
2.13-inch black-white-red EPD with internal timing controller (iTC)	8	18	144	864	0.24	87.6
2-inch TFT LCD module	30	0.02	0.6	2,592,000	720	262,800

EPDs consequently have very little impact on a product's overall power budget. Even devices with very small batteries, such as a CR2032 coin cell (with a capacity of around 225 mAh), can typically support a display in this type of use case, without significantly increasing the frequency with which the battery needs to be replaced.

Indeed, the amount of energy required to update an EPD is sufficiently low as to enable it to refresh the screen using solely harvested energy, such as from a nearby RFID reader. Typically, a coil transmits energy to enable the information briefly storing the energy it harvests – typically a supercapacitor. Since a supercapacitor costs more than a coin cell battery, designers will need to weigh up whether the advantages of energy harvesting, such as never having to change a battery, outweigh the higher unit costs. The other consideration is that because a black, white and red or black, white and yellow EPD requires more energy to update, it will need a larger supercapacitor, and to be within range of the RF energy source for longer than a black-and-white one.

Easy readability – by humans and machines
The second big advantage of EPDs is that their reflective nature makes them easy to read, even in harsh lighting conditions, such as bright sunlight. Non-reflective display technologies, such as TFT LCD, and to a lesser extent OLED, can struggle in these situations – how many times have you had to cup your hand over your smartphone to be able to read it on a summer's day?

In addition, EPDs' reflective nature also means data they display can be read by machines, including existing scanners used to read printed barcodes or QR codes.

Lastly, the EPD's ink particles scatter light uniformly in all directions, similar to printed ink on paper. As a result, EPDs offer exceptionally wide viewing angles – close to 180° in any direction – and a natural, paper-like reading experience.

High image quality
One of the attributes that's made EPDs so popular is the quality of image they can produce. With pixel densities typically between 100 and 210 dpi for industrial use and higher pixel density for e-readers, EPDs can display both sharp, attractive text in a variety of fonts, as well as detailed images.

This gives product designers the ability to display the information they need to in a way that's appropriate for their use case, without being constrained by the display hardware.

Suitability for use in harsh conditions
E-paper displays can be used in devices that will be exposed to harsh physical conditions. Industrial equipment is a good example.

Rugged options are available, where the EPD comes with a resin board attached to its glass substrate, making it 50% more impact-resistant than a conventional model.

There are also displays available capable of operating at temperatures as low as –25°C, others that can operate in heat of up to 50°C, as well as models capable of spanning a range from –20°C to 50°C.

Humidity is another important consideration for many engineers. EPDs are available that can operate in very low (down to 10%) and very high relative humidity (up to 90%) for certain periods.

The temperature and humidity ranges in which a display can operate are linked, while black-and-white displays are generally more versatile on both fronts than black, white and red and black, white and yellow ones.

For designers and engineers considering e-paper for use in extremes of humidity and/or temperature, we recommend they speak to their EPD vendor's field application engineering team to discuss their requirements and explore options. Better-quality materials in the EPD, greater redundancy around critical components, and more sophisticated manufacturing processes all contribute to a display that will be more resilient to harsh conditions in the long term. A good vendor will be honest and advise if e-paper is genuinely going to be suitable for the application.

Ease of use for designers and engineers

Application designers and engineers ideally want to be spending their time focusing on developing the high-value features of their product, rather than the intricacies of how individual components work. By choosing the right EPD, the process of adding and using a display can be straightforward.

As we touched on earlier, selecting an EPD with an internal timing controller (iTC) results in greater ease of programming and integration for the engineer.

Moreover, selecting a model where the iTC is pre-programmed with key functionality makes things easier still. This ensures, for example, that a designer can simply send an image in the correct format to the display, and the controller takes care of physically drawing it on the screen.

Proven technology

Lastly, e-paper is a proven and mature display technology, underlined by the enormous volumes of e-readers and shelf labels that have been sold over the last decade.

Currently, some six million EPD-equipped electronic shelf labels are manufactured every month. There is also a broad and well-developed technology ecosystem around e-paper.

Competing display technologies: The pros and cons compared to e-paper

E-paper won't be the only display technology a designer or engineer should consider when creating their product. It's important to assess the different options and select the right technology, based on the use case.

To help designers make this decision, we've outlined the main technologies that those who look at EPDs also typically consider, and their respective strengths and weaknesses.

LCD segment displays
Found in all sorts of applications, including pocket calculators, retail shelf labels, digital thermometers and more, this proven display technology has the benefit of being inexpensive and exceptionally energy-efficient.

The main drawback of segment displays is that their display capabilities are defined when they're manufactured. Typically, this will be numerals, created using the familiar seven-segment layout. Designers can add special symbols to their display before it's manufactured – such as a 'battery low' indicator. But once the display comes off the production line, the only flexibility a product designer has is to switch individual segments or symbols on and off. This means, of course, that there isn't the opportunity to display different barcodes or QR codes.

In addition, liquid crystal segment displays don't offer as wide a viewing angle as EPDs. And lastly, because this segment technology has been around for such a long time, products with these displays can look and feel antiquated, even if the rest of the product is state-of-the-art.

TFT LCD
Widely used in televisions, computer monitors, phones and other digital screens, TFT LCDs can display rich, colorful, dynamic images.

This quality of experience comes at a cost. Because these displays require a backlight, and must refresh continually, they require a large battery or mains power connection. Modern TFT-LCD-equipped smartphones require charging much more frequently than the early mobile phones of the 1990s and early 2000s. The vivid color displays are a big part of the reason why.

In addition, TFT LCDs can be difficult to read in bright ambient lighting conditions, notably sunlight. And they can also be unreadable by certain electronic scanners.

Figure 6: TFT-LCD displays are used for televisions. Source: CHIMEI

Other low-energy displays
Other options in the low-energy display space include cholesteric LCDs and LCD memory-in-pixel displays.

Like EPDs, cholesteric LCDs are bistable and reflective, so benefit from low energy consumption and readability in harsh lighting conditions. The main drawbacks of cholesteric LCDs center around the viewing experience. Firstly, the contrast and reflectivity of cholesteric displays are inferior to EPDs, and indeed the contrast drops much more quickly as you widen the angle at which you're viewing a cholesteric display. As a result, while this type of display may have a very high contrast ratio when you're looking at it front-on, it becomes increasingly difficult to read the further to either side you move, even when it has a scattering layer.

Secondly, cholesteric LCDs typically have a color hue to the panel. A lot of work has been done to create a neutral white on these displays, but that results in the darker colors not looking neutral. Similarly, a display tuned to give a neutral black will often display whites with a yellow or green hue.

The other technology designers may come across is LCD memory-in-pixel. This type of display is reflective, but not bi-stable, even though the in-pixel memory means the energy required to maintain a static image is lower than a conventional backlit TFT LCD. Since they first appeared on the market, memory-in-pixel LCDs have seen most traction in certain low-energy applications requiring frequent updates to the display, such as fitness watches and cycle computers – applications for which EPDs are perhaps less suited. In addition, the relatively small number of products using this technology means it doesn't have an ecosystem around it that's as large and mature as the one around EPDs.

When to use EPDs

Having looked at the pros and cons of the various alternative display technologies, we wanted to provide a short summary of the typical use cases for which EPDs are best-suited.

In summary, an EPD will be a good fit if several of the following apply:

- You need to provide easy-to-read information to a human or machine.
- You require more flexibility over what you can display than can be achieved with a liquid crystal segment display.
- The information you'll be displaying is relatively static – i.e. the data changes infrequently, or the person viewing it doesn't need it to be the very latest information.
- The display will be used outdoors in direct sunlight, or in other harsh lighting conditions.
- There is no mains power connection and the device must run off a battery or harvested energy.
- You require a thin display for your application.
- The screen must be lightweight.

Some ideal EPD use cases

Let's now look at a few real-world use cases to which EPDs are ideally suited.

Retail shelf labels: Replacing paper tags or liquid crystal segment displays
The labels that appear on shop shelves beneath different products to show their price and other information, are an ideal EPD use case, as evidenced by the technology's success in this space.

An EPD displays rich information, such as the product name, its price, price-per-weight, barcode or QR code. In addition, the display can include content such as 'SPECIAL OFFER', using either red or yellow, to draw people's attention to certain products. The barcode or QR code on the EPD label can be read using a store's existing equipment, whether that's a customer self-scanning device, employee stock-taking PDA or backroom scanner.

Figure 7: Electronic shelf labels are easy update and can use color to attract attention.

This product information changes very rarely – once or twice a day would be frequent in this space. This means an EPD-equipped shelf tag can run off a small battery for around five years at a time. And if the store already has RF-equipped devices, these can be used to update the display contents when needed.

All of this means retailers can switch to EPD-equipped tags without significant changes to their equipment or ways of working.

Logistics tags: Human- and machine-readable
The tags used to identify and route crates or containers of goods are a perfect use case for rugged EPDs. Their high resolution means they can show barcodes, QR codes and text. The reflective nature of the display ensures scanners that may already be used to read paper labels won't need replacing, and their content can easily be read by humans outdoors or in harshly lit warehouses.

Equally, in a setup that uses RFID tracking tags, adding an EPD makes key information available to anyone, including those who don’t have an RFID scanner.

The contents of the display remain relatively static, so the tag can run for years off one or more coin cell batteries.

Figure 8: E-paper displays can be scanned with a reader and are ideal for logistics applications

Remote IoT sensors: Adding a display where there was none

Everything from factories, homes and offices to entire cities are being linked up using sensors, enabling remote monitoring and smart control. Many of these sensor devices are placed in relatively remote locations, where there isn’t necessarily a mains power connection. Plus, they’re required to operate for years at a time between battery changes.

While the sensors are sending data to a cloud-based monitoring platform for viewing via a smartphone or tablet, there are many situations where also having a display on the sensor device is beneficial. Imagine an engineer sent to diagnose a possible issue with a device in an awkward position. Once they reach the sensor, pulling out their smartphone to get its latest reading may not be safe or practical. A display on the device instantly gives the engineer information such as its status, the latest reading, error codes or other details – for example a temperature reading on cold chain goods to ensure their compliance.

E-paper is the perfect display technology for these remote sensors, which spend much of their time in standby mode to conserve energy. Engineers could add a display-update task to run when the device wakes up to take and transmit a reading. This would flash up the data and the time it was recorded. Once it’s there, the device can go back into standby, with the information remaining visible for anyone to read, even if the battery runs out of charge.

In-home safety equipment: Improving battery-powered alarms
Many people have battery-powered smoke and carbon monoxide alarms in their homes. When the batteries in these devices get low, they typically emit short beeps to alert you to replace or recharge them. But what if no one is home when the device sounds these alerts, and its battery runs out before they return? Unless the person checks whether the 'operate' light is still flashing periodically or physically pushes the 'test' button, they have no idea their alarm is no longer working. Additionally, there's no easy way for the device to notify the homeowner or tenant if it develops a fault.

An EPD can help in a number of ways. Firstly, it can enable people to see the current battery level at a glance. Updates can be relatively infrequent until the battery gets low, at which point the frequency should increase. When the battery gets very low or completely empty, the display can bring up an eye-catching red warning symbol, to alert the owner or tenant that their alarm battery urgently needs changing or charging. And because the display is bistable, the warning remains visible, even when the battery is completely flat.

Equally, if the device develops a fault, it can proactively flash up a QR code that points someone to appropriate support resources.

Domestic weather monitoring stations

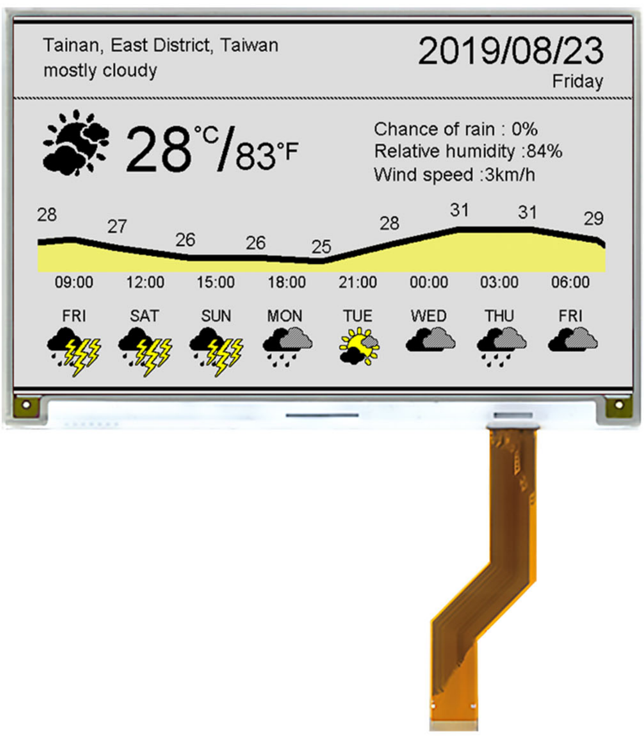

Figure 9: An EPD for a weather monitoring application.

Liquid crystal segment displays have their drawbacks in these devices, largely due to their inflexibility. A weather monitor vendor will typically need to design and manufacture a bespoke panel for each product they make, and once the display comes off the production line, there's very little scope to enhance the functionality of the overall product.

Conversely, EPDs give manufacturers enormous flexibility. Firstly, they can use the same EPD panel in multiple product tiers. Secondly, they can incorporate multi-language support, making it easier to sell their product in different countries. Thirdly, they can enhance the user experience, by enabling personalized views, or larger text and image sizes. Fourth, the flexibility of the EPD means manufacturers can also upgrade their products' capabilities over time, including those already in the field.

Conclusion

As evidenced by their extensive use in e-readers and retail shelf labels, EPDs are now a mature and well-established technology. They enable designers to add displays to devices that could previously not have supported one, or to significantly enhance the user experience of products currently using other display technologies.

Engineers considering EPDs for their products need to understand how these displays work, what their strengths are and the broad applications to which they are suited. This paper has set out the benefits of EPDs, and also compared them to alternative technologies that engineers will likely be considering. The key is to assess each option objectively, and work with the vendor’s field application engineering team, to make an informed decision.

If e-paper is the right technology for your product, there are development kits available from Pervasive Displays, as well as extensive design and implementation support from our in-house teams and regional partners. You can find more details on our website at www.pervasivedisplays.com

Figure 10: Pervasive Displays products