PERVASIVE DISPLAYS

A Guide to E-Paper Technology and Its Growing Range of Applications

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Executive summary

E-paper, made famous by the Amazon Kindle, is an electronic display technology which mimics the appearance of paper. Using the same inks as the traditional printing industry, e-paper displays (EPDs) have tiny capsules or cups filled with charged ink particles. When the proper charge is applied, highly detailed images can be created with the contrast ratio and readability as traditional printed material.

As a bistable display technology, e-paper can be extremely low power, enabling it to be used in devices without the power budget of a traditional LCD display. Once the text and images of an EPD have been rendered, no power is needed to maintain the display.

In fact, e-paper is so energy efficient that harvested energy can be used to make updates, enabling the use of RFID or NFC devices with battery-less EPDs.

E-paper's ability to add thin, light, highly-readable displays to low power or no power devices opens up a wide range of applications across the internet of things (loT) space, from logistics to discrete manufacturing, to retail. Examples of Battery-less, human-readable RFID tags for logistics and manufacturing, electronic shelf labels (ESL) that can be monitored and updated remotely, smart badges with integrated displays; these are just a fraction of the possibilities of e-paper applications from Pervasive Displays.

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Technology overview

Mimicking the readability of ink and paper, e-paper combines the active-matrix TFT technology used in LCD displays with a layer of electronic ink. The ink layer consists of millions of tiny microcapsules or microcups with electrically charged pigment particles suspended between a transparent top and bottom electrodes. As the appropriate charges are applied, highly detailed images are formed with the contrast and readability of traditional printed material.

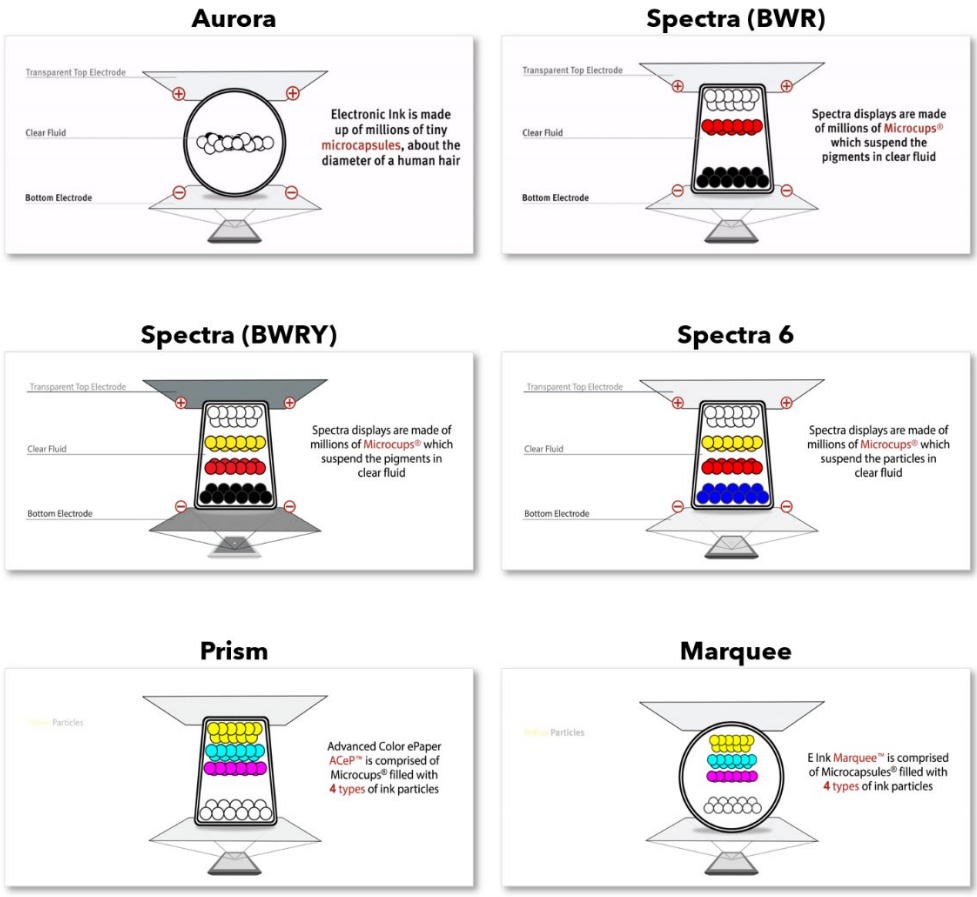

Figure 1 – E-paper rotates electrically-charged particles to display different white colours. (Source: E Ink)

E-paper displays are bistable. Each visual state of a capsule or cup can be held without power needing to be applied. This means e-paper displays

only consume power when updating the screen and retain images even when the power is off.

Unlike LCD displays that depend on backlighting, e-paper displays are also reflective and can be read in ambient light or even bright sunlight, just like traditional printed material. This eliminates the need for power consuming backlights in well-lit environments, and also helps reduce eye strain.

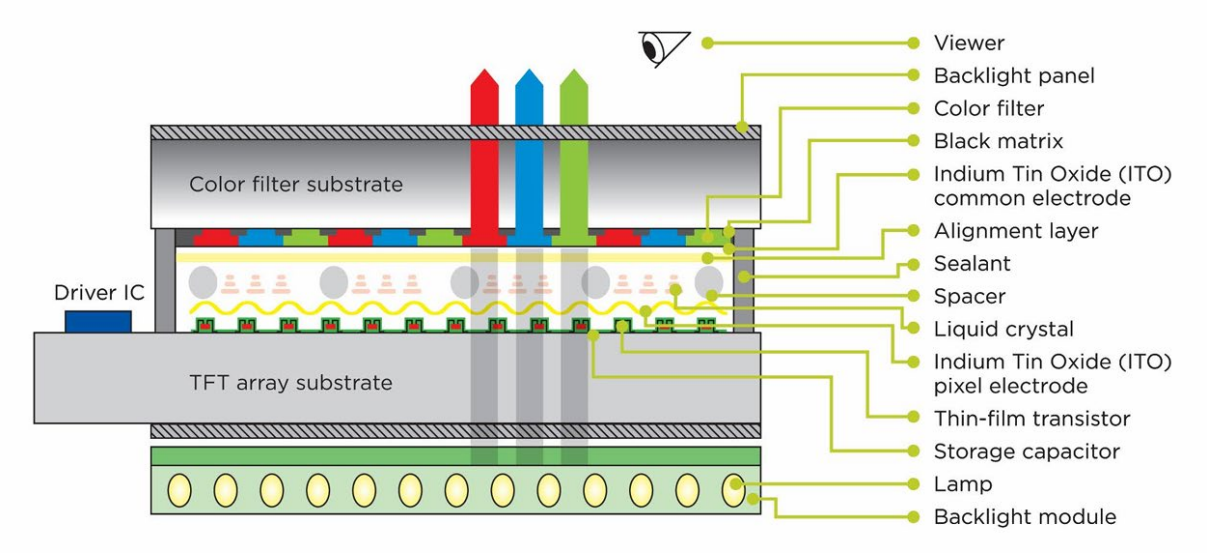

Figure 2 – Cross-section of a colour TFT LCD.
(Source: Pervasive Displays)

EPDs are assembled by adding a film of electronic ink, known as a Front Plane Laminate (FPL), on top of an active-matrix TFT backplane (or flexible plastic-based substrate) which is then covered with a protective sheet. The panel is driven by custom chip on glass ICs (COG, driver IC) and connected to an external MCU through a flexible printed circuit (FPC) cable. Depending on the e-paper module, timing control software can be located either on the driver IC itself, or run on an external microcontroller.

Due to the specific physical and electrical properties of electronic ink, the characteristics of the waveform generated by the timing control software is crucial to the visual performance, power consumption, and reliability

of e-paper displays. Displays driven by proper waveforms are power efficient, and can hold visually clear, high contrast images for indefinite periods of time, while poor quality (or not fine-tuned) waveforms deplete battery life quickly and can cause ghosting or other unwanted visual effects.

The timing control software can be integrated into the driver IC on the EPD itself, or located on an external MCU, each with its own benefits and trade-offs. EPD modules with internal timing controllers (ITC) are simpler to integrate and reduce design time, but those with external timing controllers (ETC) can minimize power consumption and processor speed requirements.

Benefits

E-paper's remarkably low power consumption, high readability, as well as its thin and light characteristics make it a perfect display option for devices without incurring the expense of a traditional LCD display.

1.1. Ultra-Low Power Consumption

Thanks to its bistable nature, e-paper is an extremely low power consumption display technology, allowing it to be used in devices without the power budget associated with a traditional LCD display, or to create devices with an incredibly long battery life.

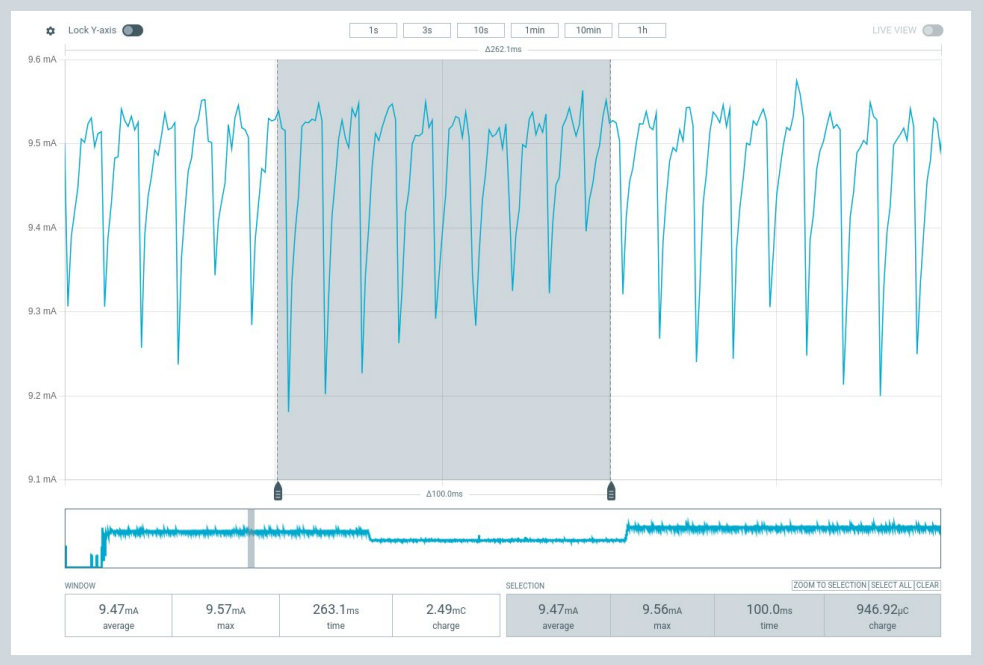

Figure 3 - TFT 2.4" LCD refresh

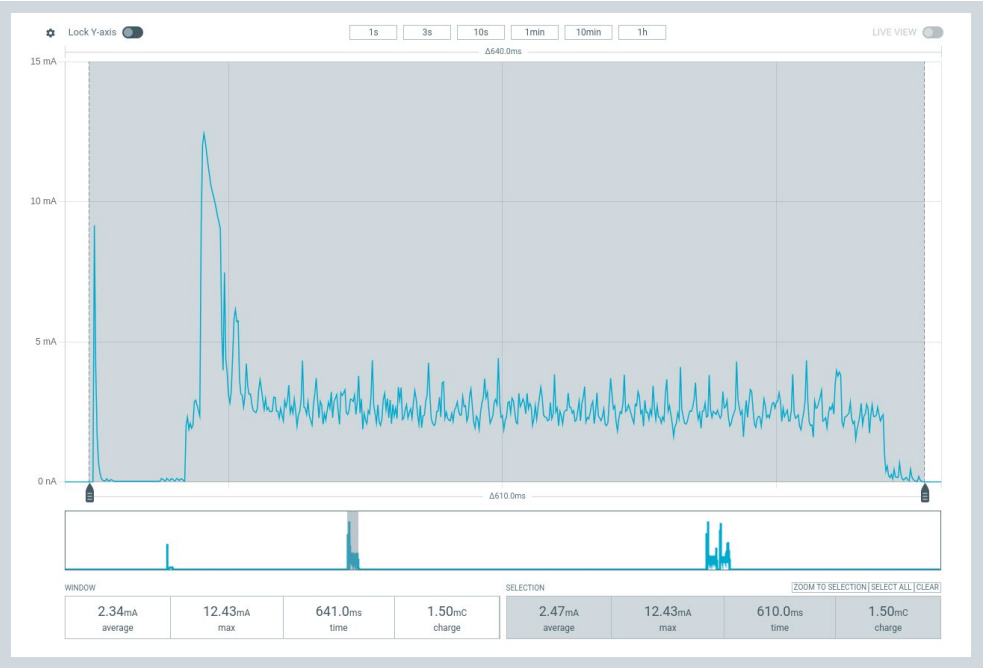

Figure 4 – EPD 2.66" BW fast refresh

The power consumption of an EPD is on a completely different level than that of an active-matrix LCD display. While LCD displays need to be refreshed at 60 Hz or more, consuming power each time even to display a static image, EPDs only need to be refreshed when the image is changed. This makes e-paper perfectly suited for applications with infrequent screen updates, such as metering, sensing, logistics tags, ID badges, signage etc.

Screen	Refresh				Sleep	Day	Year
Technology	Current	Duration	Energy	Energy	Energy	Energy	Energy
	mA	*s*	*mAs*	*mAs*	*mAs*	*mAh*	*mAh*
EPD 2.66" BW Fast update	2.459	0.610	1.500	0.001	92	0.026	9.3
TFT 2.4" with backlight	9.470	0.100	0.947	9.477	818,813	227	83,019

Table 1 - Comparison of screen technologies based on 6 updates per day

Contrary to TFT displays where backlighting is required and represents a major power consumer, e-paper can be read in ambient light without the need for a backlight, reducing power usage during sleep even further for many use cases.

On the example above, the TFT 2.4” would require 138 coin-cell batteries CR2450 of 600 mAh capacity, while the EPD 2.66” would consume 1.6% of the same battery over the same period.

1.2. NFC/RFID Energy-Harvesting Capability

The extremely low power consumption of EPD makes it suitable for using the energy harvested from NFC/RFID readers. The same RF field that energizes an NFC or RFID antenna to read data from a device carries enough power to update an EPD. This enables "no-power" EPD powered purely from RF energy, without the need for an internal battery.

1.3. High Readability – Even Outdoors

Using the same pigments as the printing industry, EPD's contrast, viewing angles and readability are similar to traditional ink and paper. Readability is superb in both ambient light and bright sunlight, making e-paper suitable for outdoor applications that would challenge LCD displays such as signage.

1.4. Thin and Lightweight

E-paper technology is thinner and lighter than LCDs. A 2.06” EPD module is 0.85 millimetre in thickness and weighs just 2.9g, while a corresponding TFT LCD display is roughly double the thickness and weight. Devices using e-paper can thus be made thinner and lighter, perfectly fitting the requirements of many loT applications.

1.5. Suitability for use in harsh conditions

EPD can be used in devices that will be exposed to harsh physical conditions. Industrial equipment, device and meter are good examples.

Rugged options are available, where the EPD comes with a resin board attached underneath the glass substrate or a tempered cover lens

attached on top of EPD, making it more impact-resistant than a conventional model.

There are also displays available capable of operating at temperatures as low as -25°C and extending up to +60°C for wider operating range, while the storage temperature range can be extended to +75°C. Humidity is another important consideration for many use cases. EPDs are available that can operate in very low (even 0%) and very high relative humidity (up to 90%) for certain periods.

Current and Future Applications

There is a growing shift in the marketplace from consumer devices with large power and processing budgets designed for multimedia, towards smaller, interconnected, power-constrained devices designed to sense, compute, and communicate business information. This is the Internet of Things, driven by industrial applications.

E-paper's ability to add thin, light, highly-readable displays to these extremely power constrained devices is opening up a wide range of new applications across the loT space, from logistics to discrete manufacturing, to retail.

1.6. Electronic Shelf Labels Enable Dynamic Pricing for Retailers

Electronic shelf labelling (ESL) is changing the retail space, reducing price management costs and making dynamic pricing possible.

Whereas traditional price tags require staff to constantly replace and update shelf labels as prices change, ESL labels are wirelessly connected, allowing for remote, central management of all the price labels at a single or even multiple retail locations.

ESL also allows for dynamic pricing, letting retailers adjust prices faster to respond to changing market conditions and inventory levels. For grocery stores, for instance, being able to turn over slow moving or perishable inventory through promotional pricing or increase prices in response to a sudden increase in produce costs is essential for profitability.

Retail shelf labels have high readability challenges as they must be readable by both humans and machines. Good contrast across various lighting conditions and wide viewing angles are key, as customers must be able to read prices at a glance, and barcode readers must be able to scan codes easily.

Battery life is another key requirement as, with hundreds of ESL devices commonly deployed at a single retail location, frequent recharging is out of the question.

Figure 5 – This Electronic Shelf Label powered by a Pervasive Display EPD has excellent readability and a 10-year above battery life (Source: Vusion Group)

For ESL, e-paper is the perfect technology, providing high contrast images easily readable by 2D and 3D barcode readers in a variety of lighting conditions, and consisting of a bistable display which only consumes power when updated

Figure 6 – Colour displays feature black white, red and yellow for high-impact messages (Source: Vusion Group)

For retail applications, the latest EPD modules feature four pigments: white, black, yellow and red ink, allowing for more dynamic shelf labelling

excellent for highlighting promotions. EPD modules from Pervasive Displays also feature health monitoring technologies which detects screen breakage or problems powering up the display, helping to make sure pricing labels across a retail location are working reliably

Retailers such as Walmart, Carrefour, Media Saturn and Edeka are already starting to use the current generation of e-paper based ESL devices which allow retailers to control prices dynamically and lower labour costs through centralized price management. But the potential of retail ESL devices is only just being explored, and future ESL devices are positioned to improve operational efficiencies and retail profits even further.

1.7. E-paper + RFID/NFC Provide Immediate Visibility Throughout the Supply Chain

Figure 7 – This batteryless smart tag combines NFC technology with an e-paper display (Source: PDi-Digital GmbH)

E-paper works phenomenally well as a complementary technology for RFID or NFC as it has the ability to visibly display information these RF-based technologies cannot.

A properly designed EPD has minimal impact on a RFID or NFC device's battery life and can even use harvested energy from the tag reader just like a passive NFC/RFID device. The combination of wireless asset tracking capabilities with the immediate visibility of e-paper has profound implications for a range of industries, including logistics, manufacturing and distribution, to medicine, and construction.

RFID and NFC tags, which are available in either battery powered or battery-less forms, are wireless devices that provide asset tracking and identification functionality similar to barcodes. Unlike barcodes, they can be accessed wirelessly and the data they store can be updated as well.

RFID/NFC technology offers significant advantages for many industries, particularly logistics and manufacturing. For example, assets entering or leaving a warehouse, being loaded onto a truck or onto a warehouse shelf or factory bin can all be automatically logged and tracked, and their internal status can also be updated as needed. The increased visibility and automation made possible by these technologies has huge benefits for the entire supply chain.

Despite the advantages of RFID/NFC, it isn't possible for RFID tags to fully replace paper labels and barcodes yet. This is because a paper label has both a scannable barcode and information which can be read with the naked eye. Unless they are part of a printed label, RFID tags can't be read with the naked eye and require a specialized scanner (or gateway) to access and update data, which makes paper labels an essential requirement for many applications.

The need for a specialized scanner when using RF technology has slowed its adoption and meant paper labels are still widely used in many industries such as logistics, which would otherwise benefit heavily from the increased automation and visibility made possible by the use of RF technology.

EPD solves the need for a specialized scanner perfectly, giving immediate, at a glance visibility into tag data. In addition, EPD's low power requirements would allow it to be energized by an RF field, like a regular RF tag in order to update the displayed information.

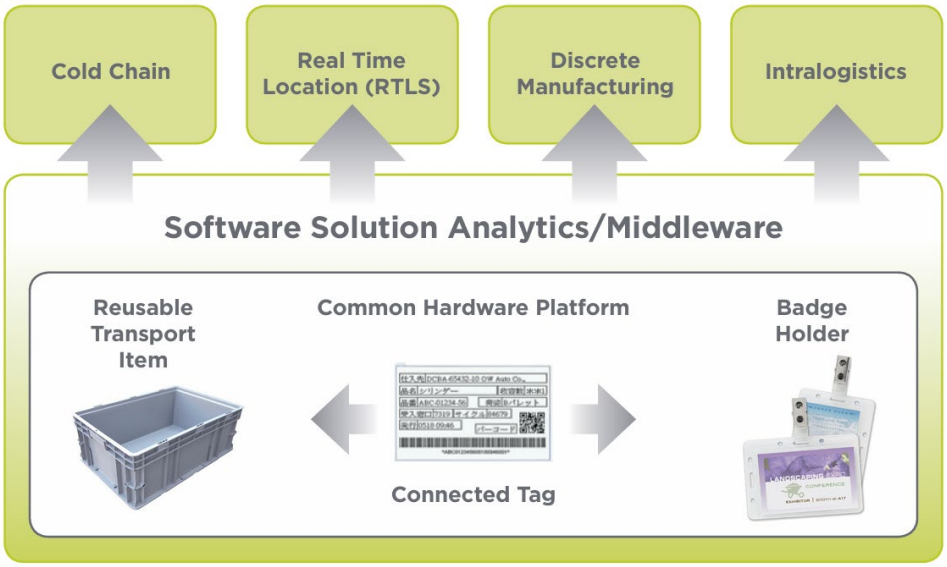

Figure 8 – Connected tags with e-paper and RFID or NFC have the potential to serve a variety of markets using a common hardware platform. (Source: Pervasive Displays)

EPD-enabled RFID/NFC tags allow the automation and asset tracking capabilities of this promising technology to be fully realized without sacrificing the human-readability of paper labels, providing value throughout the supply chain, from manufacturing and shipping to distribution.

1.8. Display for Power-Constrained IoT Devices

Beyond retail and logistics, the applications of EPD for the IoT are vast and limited only by our imagination.

Because of power constraints, many battery-powered IoT devices, such as utility meters, cold-chain temperature data loggers, environmental sensors, and blood glucose monitors forgo traditional displays and transmit data directly to the cloud, where it must be read through specialized apps on network connected devices.

EPD's ultra-low power consumption and ability to retain an image, even if the device is off, allows these low power devices to incorporate a display showing sensor data to operators. This is possible without the required equipment on hand and can work even when there are network

connectivity issues. In case of device failure, error messages or device information can also be displayed on the screen and retained without power even if the device is turned off.

1.9. Getting Started with E-Paper

The easiest way to get started with e-paper is with a development kit from Pervasive Displays.

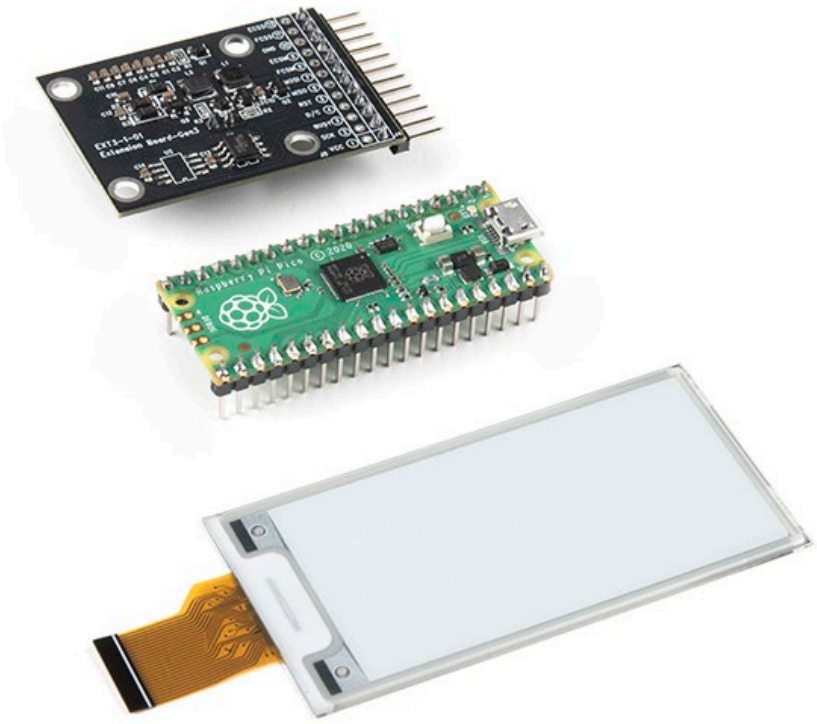

Figure 9 - The EPDK includes everything to start exploring the e-paper technology

The recommended kit is the EPD Pico Development Kit (or EPDK), which includes everything to start exploring the e-paper technology.

The all-in-one kit includes an EPD Extension Board Generation 3 (EXT3.1); a Raspberry Pi Pico RP2040 as host micro-controller; a 2.66" monochrome EPD with wide temperature and embedded fast update;

connection cables and two printed documents, a pins map and a quick start guide for step-by-step instructions.

The software available online includes driver code, examples and a comprehensive open-source library, with a full documentation.

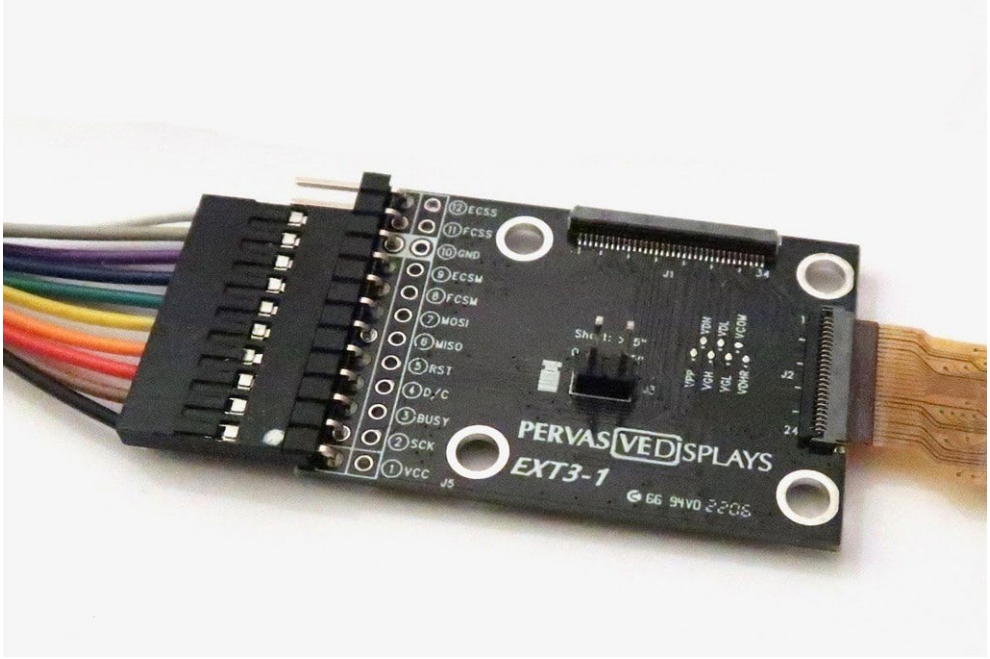

Figure 10 - The EXT3.1 extension board can be used separately

The components can be used separately and adapted to specific needs and use cases. The EPD Extension Board Generation 3 (EXT3.1) can drive any EPDs with an internal timing controller from the Pervasive Displays extensive range, with diagonals from 1" to 12", and monochrome or black-white-red-yellow variants. With the EXT3-Touch expansion board, the EXT3.1 extension board can also drive screens with touch, like the 3.70"-Touch panel and more. The same EXT3.1 board can be connected to other host micro-controller boards.

The EPDK kit is ideal to discover the e-paper technology, evaluate the many features and benefits it brings, and start a next project. High contrast, daylight readability, low power, make the e-paper technology a perfect choice for IoT (Internet of Things), edge computing and HMI (Human Machine Interface) applications.

Appendix

1.10. Glossary of acronyms

Acronym	Meaning
COG	Chip on Glass, Driver IC
EoL	End of life, product discontinued
EPD	Electrophoretic Display, e-Paper Display
eTC	External Timing controller
FPL	E ink material film, Front Panel Laminate
HMI	Human machine interface
HVAC	Heating, ventilation and air conditioning
iTC	Internal timing controller
ITO	Indium Tin Oxide
LUT	LookUp Table
MCU	Microcontroller unit
PDI, PDi	Pervasive Displays Incorporated
PDLS	Pervasive Displays Library Suite
TFT	Thin-Film Transistor

1.11. Revision history

Version	Date	Page	Description
1	2020		Initial release
2	2025-11		Restructured the contents Updated the old information Replaced the outdated images Updated to EPDK and EXT3.1

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