PERVASIVE DISPLAYS

Designing IoT Applications with E-Paper Displays

Doc. No. PDW002 Rev. **02** (Nov 2025)

Executive summary

The needs of the Internet of Things (IoT) encompasses a wide variety of devices and operating environments.

Often, the only thing uniting them is the need for low power consumption and wireless communication.

With its ultra-low power consumption and bistable display characteristics, both of which are well-suited to wireless updates, e-paper display (EPD) is an ideal display technology for many IoT devices. It can also enable novel IoT applications. Alongside its ability to achieve unheard-of battery life for devices with displays, EPD has a variety of configuration options that enable it to flourish in a range of IoT areas.

EPD can be made rugged characteristics to suit industrial applications. EPD modules are available in wide temperature ranges and are thin and light, making them easy to integrate into devices. They can also come with error-detection technologies to ensure robust operation. Moreover, EPD's

superior viewing angles and reflective nature make it easily readable in many conditions, including bright light.

E-paper's display characteristics enable it to excel in retail environments. As a bistable display technology, it works well for shelf labels and signage, while multi-colour versions are available to attract extra attention for sales or special events.

Besides regular, full-screen refresh mode, EPD can be configured for fast (partial) updates. Fast refreshes are quicker than full-screen ones, enabling animations and fast image response times. For example, fast refreshes could be used to show quickly changing values in a metering application, or button-press animations for a touchscreen interface.

Wireless features are essential for the IoT. Thanks to its bistable nature, e-paper's powering needs synchronize perfectly with modern wireless protocols, such as Bluetooth Low Energy and ZigBee, and enable devices to maximize time spent in sleep mode. EPD works particularly well with near-field communication (NFC), because it can run purely off RF energy scavenged from the NFC reader, thereby enabling battery-less designs.

To help IoT device designers get started with EPDs, Pervasive Displays and its partners offer a range of development kits, evaluation boards and reference designs.

Copyright

龍亭新技股份有限公司 Pervasive Displays Inc.

4F, No. 28, Chuangye Rd., Tainan Science Park, Tainan City 74144, Taiwan (R.O.C.)

Tel: +886-6-279-5399

https://www.pervasivedisplays.com

Content

List of figures

List of tables

1. Display requirements of the Internet of Things

Just as the personal computer and the smartphone revolutionized the way we live and do business, the Internet of Things (IoT) promises to change our lives by connecting our physical world with the power of the cloud.

Brought about by the emergence of cloud applications, big data, cheap sensors, wireless sensors and microcontroller units (MCUs), the IoT differs from past technological revolutions in that it emphasises interconnected data rather than hardware superiority. The power of the IoT comes from providing real-time data from our physical world to the people and systems where it provides the most value.

Unlike the powerful PCs and smartphones that have driven recent technological shifts and provided rich multimedia experiences, the devices in the IoT are often lightweight, embedded systems, optimized to be small, low-cost, and with long battery life.

Focused on sensing or actuating their environment, low-power MCUs are a better fit for these new devices than complex multi-core processors, while high-definition liquid crystal displays (LCDs) are out of the question.

However, while rich touchscreen interfaces are unsuitable for IoT applications, the complete absence of any kind of display or human interface is undesirable. Whether it's a connected tag to keep track of items in a warehouse, a sensor/actuator in a factory, a water meter or a temperature and humidity sensor on a farm, making real-time state information visible directly on the device can add significant value.

The traditional way of adding feedback to simple embedded systems is through LEDs, but this approach is extremely limited, and requires user instructions if it's to communicate anything more complex than simple state values.

1.1. E-paper: the ideal IoT display technology

E-paper (EPD), a low-power display technology that mimics the look of traditional paper and ink, enables IoT devices to provide much richer information directly on the device, without the power or processing requirements of a traditional TFT LCD.

Made up of thousands of tiny capsules or cups (pixels), EPDs are filled with negatively charged black and positively charged white ink particles for the monochrome EPD. By applying appropriate charges across the top and bottom of each capsule, you can create high-resolution images.

EPD is bistable, meaning no power is required to maintain an image after it has been formed. It's also reflective; like traditional ink and paper, it uses reflected light to make its image visible, rather than relying on a backlight. The absence of a backlight also means EPDs can be thinner and lighter than LCDs. These low-power, low-processing requirements, and thin, light characteristics make EPD the perfect display technology for the IoT.

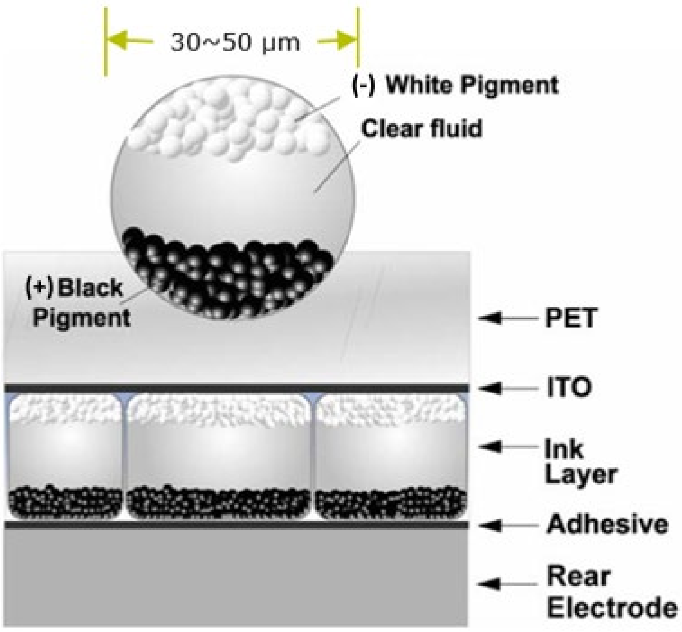

Figure 1 - E-paper displays consist of thousands of capsules filled with charged black and white ink particles. (Source: E Ink)

E-paper for the IoT enables immediate feedback of device information for user action. And using either push buttons or touch interfaces, it can enable more sophisticated user interfaces for device operation, configuration or maintenance if necessary. Finally, EPD enables IoT use cases, such as electronic shelf labels, human-readable RFID tags, or NFC-updatable ID badges.

1.2. Power consumption

For many IoT node devices, battery life is the most important design consideration.

Whether it's a metering application, smart tag or thermostat, these devices are battery-powered and often deployed where battery replacement is difficult or inconvenient. EPD provides an unbeatable power advantage, being a reflective, bistable display technology. Designed in conjunction with power-optimized wireless technologies such as Bluetooth Low Energy, battery-powered e-paper devices can last for months or even many years. EPD's low power consumption also enables it to be used with energy harvesting, for battery-less "no power" devices.

A key reason for EPD's low power use is that it's reflective, so unlike LCDs, doesn't require a backlight. With the display module often dominating power consumption in embedded systems, and the backlight dominating power consumption of the display module, EPD enables displays that can operate significantly longer than TFT LCDs on a similar battery. EPD can also be used in devices without the power budget for a traditional TFT LCD.

Besides the absence of a backlight, the bistable nature of EPD means the image on such a display is retained between screen updates without any power usage.

This is in stark contrast to TFT LCDs, which have to be constantly refreshed to maintain an image.

To measure the impact of the screen technology on power consumption, the same application was adapted and run on the same micro-controller

Raspberry Pi Pico connected first to a 2.4" TFT displays with 240 x 320 pixels and 24-bit colours and then to a 2.66" EPD monochrome display with 296 x 152 pixels.

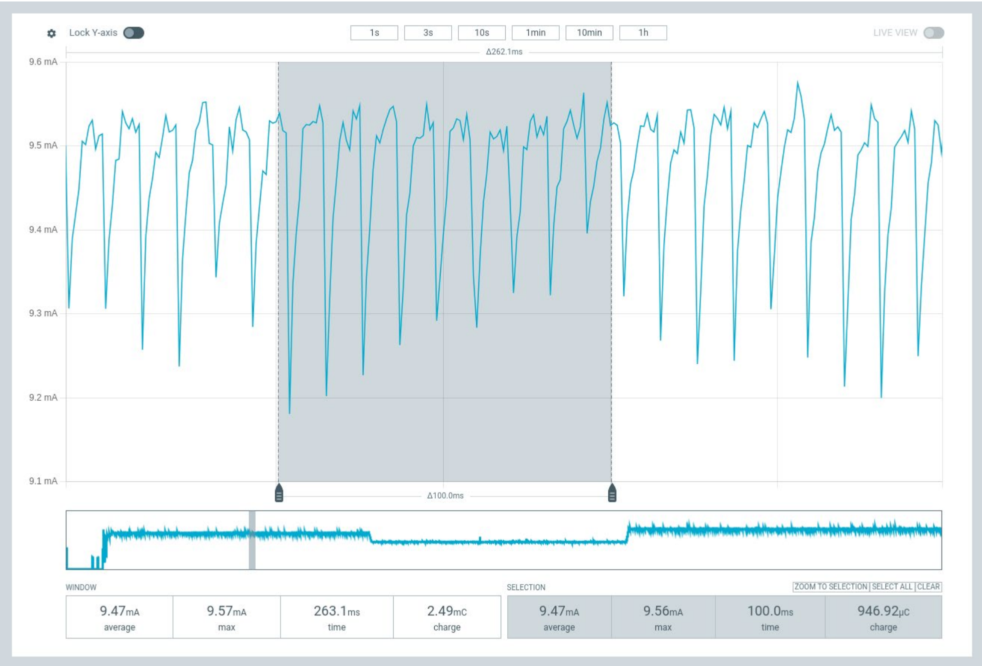

Figure 2 - TFT 2.4" LCD refresh

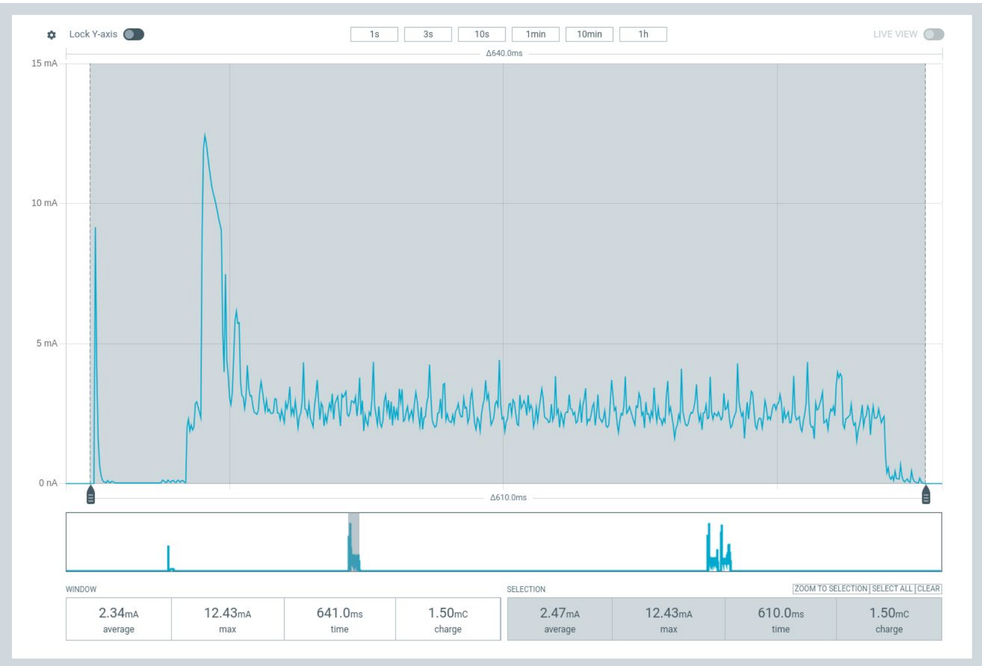

Figure 3 – EPD 2.66" BW fast refresh

The results give a clear idea of the difference between the TFT screen, where the backlight requires power continuously, and the EPD, where power is only needed to modify the image on the screen.

Screen	Refresh			Sleep		Day	Year
Technology	Current	Duration	Energy	Energy	Energy	Current	Duration
	mA	*s*	*mAh*	*mAh*	*mAs*	*mA*	*s*
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 - TFT and e-paper comparison with 6 updates per day

Consider a 2.66” EPD module and a 2.4” TFT LCD, where the contents of the display need to be constantly visible, and updated six times a day. An optimized EPD would use just 9.3 mAh per year, while the TFT LCD would use 83,019 mAh.

Over the course of five years, the TFT LCD would have consumed the power of around 138 CR2450 coin cells of 600 mAh capacity, while the EPD would have barely used up 1.6% of a single coin cell capacity.

Because EPDs only consume power during screen updates, the technology is particularly suited for applications where the screen doesn't need to update frequently. While a frequently updated EPD will still outperform a correspondingly sized TFT LCD because of the lack of backlight, the energy savings will be significantly reduced.

Besides screen update frequency, power consumption of the EPD is also strongly influenced by the type of module used and waveform optimization.

The physical characteristics of EPD mean it is possible for remnants of the previous image to appear in new frames, if the module is not driven properly. To eliminate this "ghosting" effect, a new frame should be displayed multiple times in a specific sequence, with a certain time-delay between each frame. This sequence is called a waveform. The waveform will vary depending on ambient temperature, as well as performance and power requirements.

Because of its low power consumption, EPD can also be powered using harvested energy, such as solar, thermal or RF energy. This enables "no power" designs such as NFC-powered luggage tags, solar-powered bus stop signage, or badges, with no battery life constraints.

2. Industrial environments

While smart home appliances and wearables get a lot of media coverage, the IoT's largest impact is in industrial applications. Manufacturing, oil & gas, agriculture and logistics are just some of the markets currently being impacted on a large scale by the convergence of wireless sensors, cloud connectivity and analytics.

EPD's low power consumption makes it possible to deploy battery-powered sensors in remote or difficult-to-access locations, and for these to operate for months or years on end. EPD also offers wide-temperature-range operation, as well as error-detection technologies to provide robust long-term operation in harsh industrial environments.

2.1. Wide-temperature operation

Alongside display modules designed for use from 0 °C to 50 °C, Pervasive Displays offers other films with extended temperature support.

The wide-temperature e-paper modules are designed for consistent optical performance in ambient temperatures from -20 °C to +60 °C with normal update and +0 °C to +50 °C with fast update.

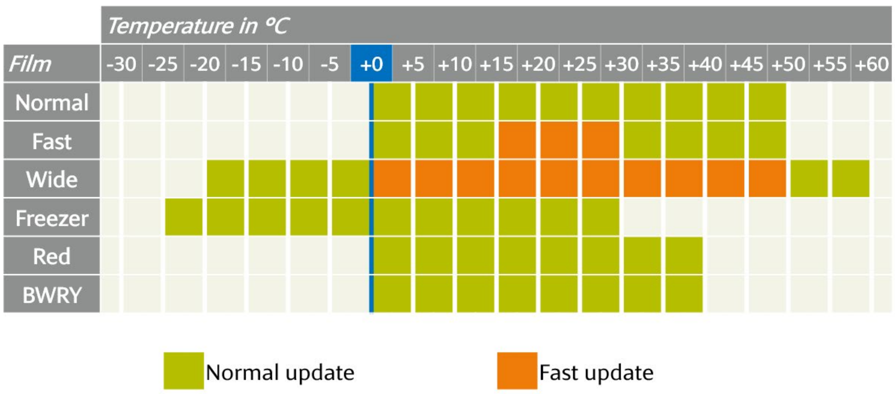

Figure 4 - Temperature ranges for different films

The Freezer e-paper modules support -25 °C to +30 °C with normal update.

Because they are suitable for use in freezing conditions, wide-temperature and Freezer models enable EPD to be used for cold-chain data loggers, retail freezer displays or automotive applications.

2.2. Rugged foil protection

Until now, there have been very few EPD options on the market that can withstand harsh operational conditions. This is because they are susceptible to deterioration due to exposure to UV and humidity, as well as ongoing wear and tear. This has limited the range of applications in which EPDs can be used. Pervasive can now supply our customers with a groundbreaking solution, opening up new possibilities.

The top surface of each EPD module can incorporate an optically bonded cover lens, which is made from either polymethyl-methacrylate (PMMA) or tempered glass, along with a UV filtering layer. The proprietary protective sheet also applies to the EPD construction makes modules ten times more resistant to humidity, as well as safeguarding them from scratches. The thermal properties exhibited by this protective sheet and the accompanying edge sealant (with minimal expansion and contraction) means that cracking due to heat variations will not occur. Consequently, the EPDs are not prone to moisture ingress which would otherwise shorten their working lifespan. A resin board is attached to the rear of the module, which alleviates the risk of deformation when the EPD experiences an external impact force.

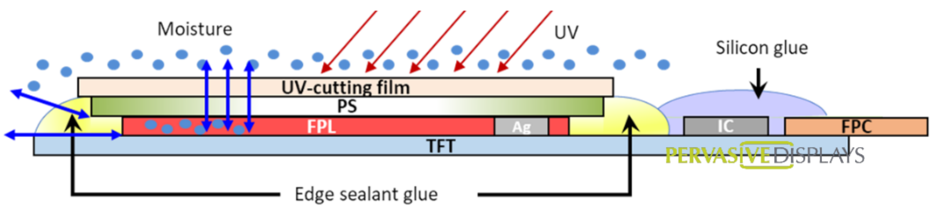

Figure 5 Cross-section of an EPD with UV-cut rugged protection.

3. Visual experience

Whereas consumer electronics are complex, user-centric devices designed for delivering multimedia video and rich graphical interfaces, IoT devices are simple and data-centric. IoT devices do not need to deliver high-definition video, but must display business data or user interfaces clearly, across various viewing angles and lighting conditions, often on resource-constrained systems.

3.1. Viewing angles and visibility

The designers of laptops, TVs and monitors can expect their customers to use these devices in relatively consistent lighting and visibility conditions. Viewing angles can be expected to be mostly straight-on, with the majority of usage indoors or in the shade.

IoT devices, on the other hand, are constrained by their environment. Meters, sensors, and other connected devices are often fixed in place, or in positions with less-than-ideal viewing angles and lighting conditions.

Mimicking the optical qualities of ink on paper, EPD addresses many of the visibility issues, thanks to its reflective nature. This provides strong contrast for high visibility, even in bright sunlight, and viewing angles close to 180°.

3.2. Refresh rate

While EPDs are bistable, they take a significant amount of time to update, typically two-to-three seconds with normal update for a monochrome EPD (the three-color above EPD takes ten to twenty seconds), because the display needs to be cycled to prevent image ghosting. This refresh speed is sufficient for static image displays, such as signage, or displaying infrequently changing data. But for user interfaces, animations, or frequently changing data, it may need to be faster.

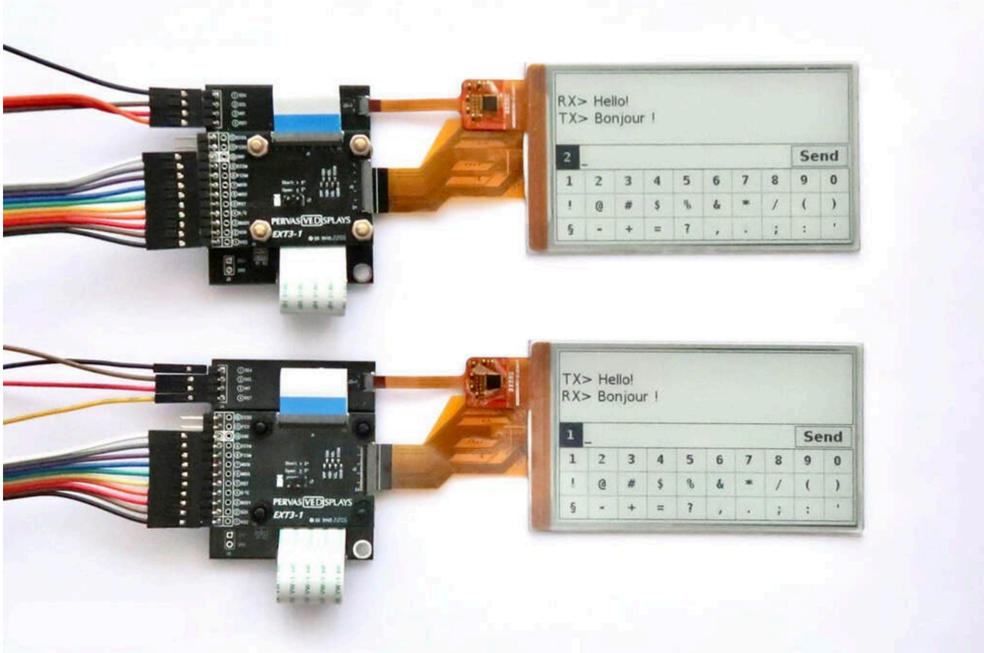

Figure 6 - This project combines two iTC 2.7" panels with touch to send and receive text messages

By using fast update, only the pixels that change from black to white or from white to black are updated. The image refreshes can occur more rapidly, enabling designers to implement animations or user interfaces. Fast update offers two benefits: image refresh rates can be decreased to as little as 600 ms (200 ms is possible but the ghosting phenomenon obviously); and image refresh is performed in a smooth way without the familiar blinking effect. Speed within the human response time and smooth transition make e-paper displays suitable for interactive human-machine interfaces.

4. Wireless integration

With its low-power, bistable characteristics, EPD is a natural fit for battery-powered wireless devices that would be unable to power traditional LCDs.

The bistable nature of EPD updates harmonizes perfectly with IoT-optimized wireless protocols, such as Bluetooth Low Energy, by enabling battery-powered devices to maximize time spent in sleep mode.

Wireless communication can also be used to update the EPD from the cloud, creating novel applications. Electronic shelf labels (ESL) in a retail store can be updated from a centralized location, making price management much more efficient and dynamic. Wirelessly connected e-paper signage around a building can similarly be updated easily and remotely, to reflect real-time room occupancy, for example.

Badges with EPDs can change the information displayed, based on location-awareness.

EPD also complements RF-based wireless technologies well. RFID tags, designed for easy, automated asset tracking, are made to be machine-readable.

EPD can be used in conjunction with RFID to create visible tags for asset tracking, logistics or manufacturing, with a human-readable window into the data stored on the device.

Figure 7 - E-paper complements RFID by making the data stored on the tag human-readable.

The extremely low power requirements and bistable nature of EPD means that displays work particularly well with NFC technology. NFC devices with EPDs can be designed to work with no internal power source, operating completely using the RF energy generated by a smartphone or other NFC-reading device. This enables applications such as lightweight, reusable visitor badges, luggage tags, payment cards and shipping labels to be powered purely off harvested RF energy.

5. Getting started

A range of IoT-focused development kits, evaluation boards and reference designs are available to simplify e-paper development and speed time-to-market.

5.1. EPDK-Matter

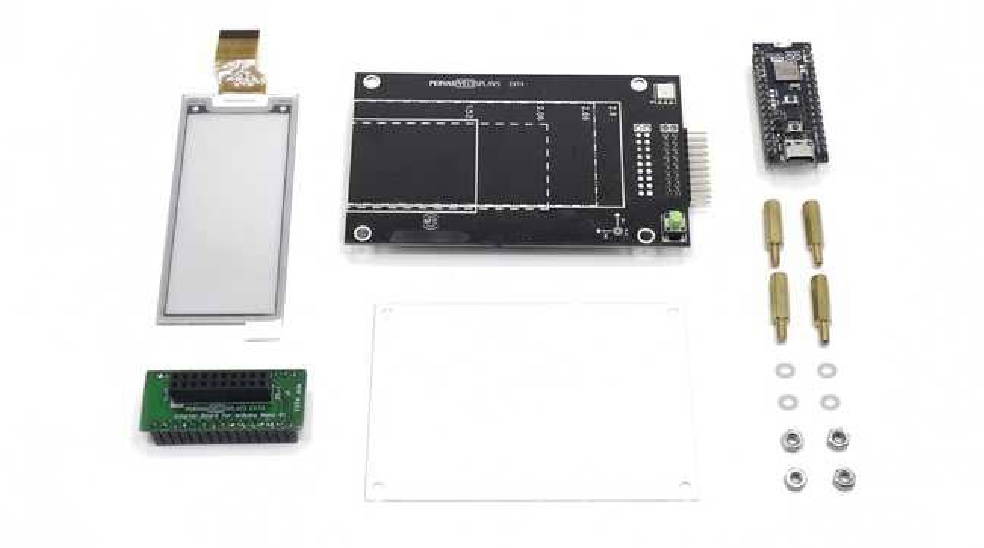

Figure 8 - The EPDK-Matter content

Developed in conjunction with Arduino and Silicon Labs, the EPDK-Matter Development Kit is the world's first kit to explore the Matter protocol. The self-contained kit includes an EXT4 Expansion Board, a state-of-the-art 2.90" EPD screen and an adapter board for an easy connectivity, all three designed and manufactured by Pervasive Displays; and bundles with the Arduino Nano Matter board from Arduino based on the MGM240S module from Silicon Labs. The open-source libraries include Matter examples and leverage the Arduino SDK, together with extensive documentation.

The software relies on two open-source libraries running on the Arduino SDK. The Matter library, part of official Silicon Labs Arduino Core, brings the features of the Matter protocol. The Pervasive Displays Library Suite (or PDLS) provides a high-level interface to drive the e-paper screens, and includes multiple examples, of which two Matter devices: a remotely controlled RGB LED and a temperature and humidity sensor.

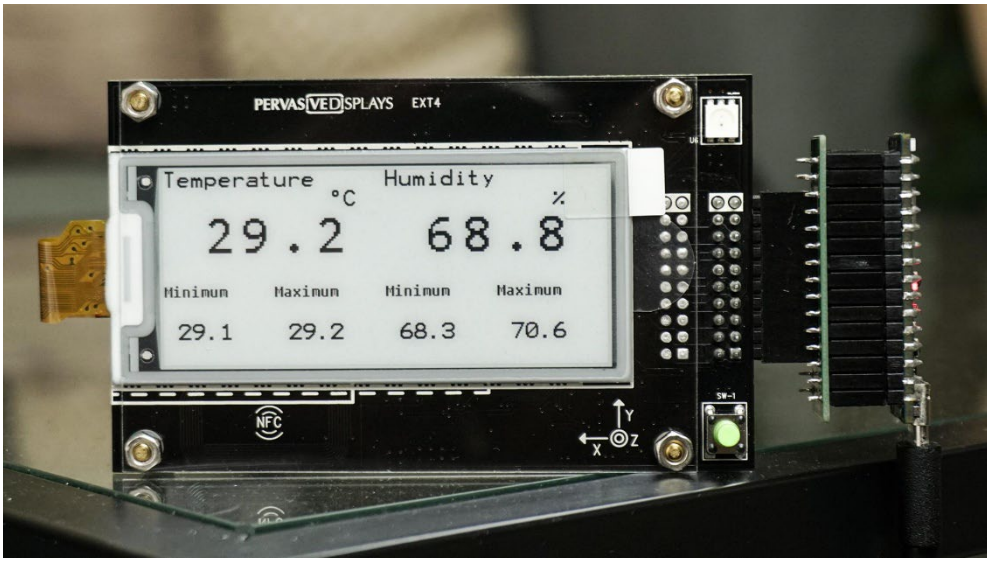

Figure 9 - The temperature and humidity sensor connected to Matter

The EPD plays a critical role for the user experience. The EPD shows the QR-code to join the Matter network on a fast, easy and secure way. It also displays the values of the sensors for immediate reading.

Figure 10 - The e-paper display plays a critical role for a fast and secure Matter commissioning

While the system is designed to work with the Arduino Nano Matter board, the adapter board is also compatible with the other boards of the extended Arduino Nano family, providing a fast and safe connection to the other boards of the Arduino Nano family.

Let's mention the Arduino Nano BLE and BLE Sense, powered by the Nordic Semi nFR52840 with support for Bluetooth LE, Bluetooth Mesh, NFC, Thread and Zigbee; the Arduino Nano ESP32, based on the u-blox NORA-W106 module built around the Espressif ESP32-S3 for WiFi and BLE connectivity; or the Arduino Nano RP2040 Connect, with the Raspberry Pi RP2040 MCU and the U-blox Nina W102 module for WiFi and BLE connectivity.

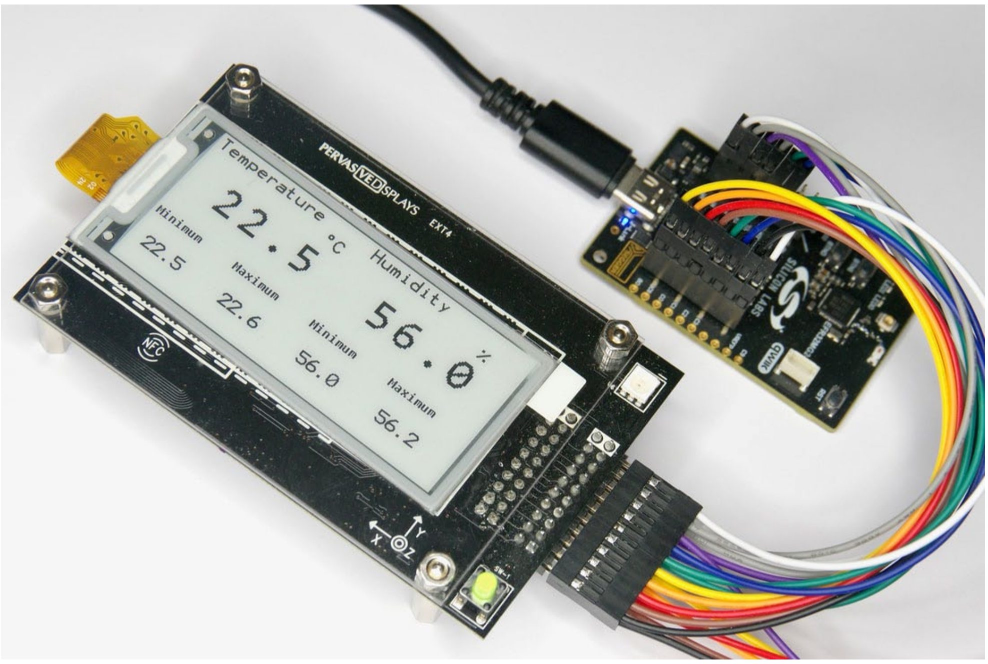

Figure 11 - The 20-way cable connects the EXT4 to any controller board

The 20-way cable allows to connect the EXT4 to virtually any microcontroller board or single board computer with an SPI port.

The E-Paper Display Kit for Matter goes beyond the Matter scenario and is ready for any IoT / IIoT application where remote display, data acquisition and low power are critical, such as smart retail, smart factory, inventory management, environmental control (meters, HMI), or home and building automation (HVAC, thermostat).

5.2. EXT4 Extension Board

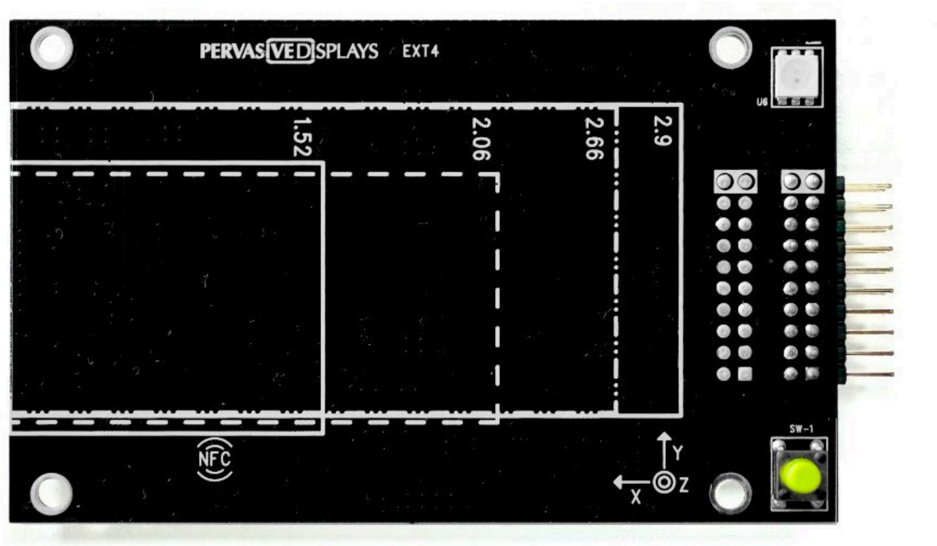

Figure 12 - Top view of Extension Board EXT4

For a more flexible approach, the EXT4 extension board is designed to drive iTC-based EPD displays below 2.9” in size, either monochrome black-and-white or colour black-white-red-yellow. The top face also exposes a button and an RGB LED.

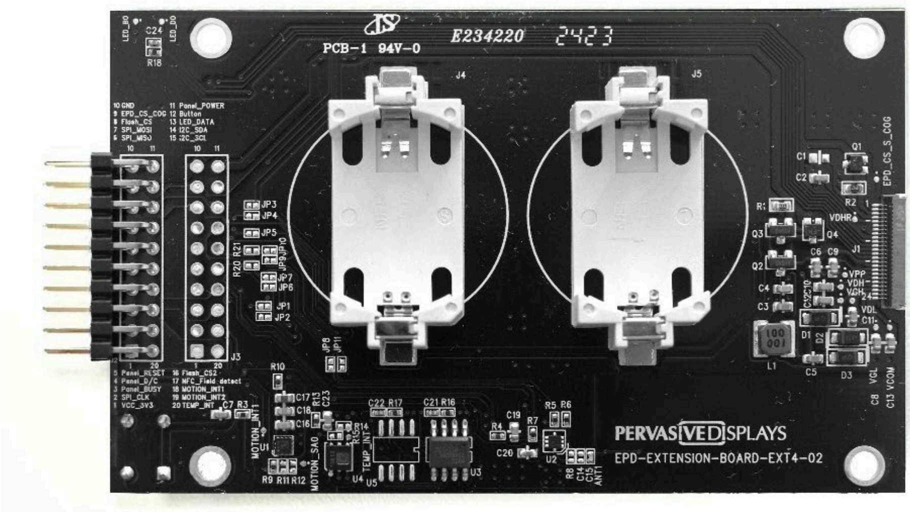

Figure 13 - Bottom view of Extension Board EXT4

Besides the EPD driving circuit, the board hosts an 8 MB flash memory and pads for another external SPI memory; a wide array of sensors, including an accelerometer, a thermometer and hydrometer; and a passive NFC antenna.

The bottom face also includes two holders for CR2450 coin-cell batteries.

The 20-way cable can connect to any board featuring SPI and I^2C. All the interrupts of the sensors are exposed.

The Pervasive Displays Library Suite provide examples targeting the Arduino SDK. It can easily be ported to any other SDK by adapting the peripherals library.

6. Appendix

6.1. 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	Look-Up Table
MCU	Microcontroller unit
NFC	Near-Field Communication
PDI, PDi	Pervasive Displays Incorporated
TFT	Thin-Film Transistor

6.2. Revision history

Version	Date	Page	Description
1	2020		Initial version
2	2025-11		Restructured the contents Updated the fold information Removed eTC and iTC explanation Updated to EPDK-Matter and EXT4

Pervasive Displays Inc. 4F, No. 28, Chuangye Rd.,Tainan Science Park, Tainan City (74144) Taiwan (R.O.C.) T: (+886)(6) 2795399