Designing **E-paper Displays** for **IoT Applications**

PERVASIVE DISPLAYS

Executive summary

The needs of the IoT span a vast range 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 is an ideal display technology for many devices in the IoT. It can also enable novel IoT applications. Alongside its ability to achieve unheard-of battery life for devices with displays, e-paper has a variety of configuration options that enable it to flourish in a range of IoT areas.

E-paper can have rugged characteristics to suit industrial applications. E-paper 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, e-paper’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-color versions are available to attract extra attention for sales or special events.

Besides regular, full-screen refresh mode, e-paper can be configured for partial updates. Partial refreshes are quicker than full-screen ones, enabling animations and fast image response times. For example, partial 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. E-paper works particularly well with near-field communication (NFC), because it can run purely off RF energy scavenged from the NFC reader, thereby enabling batteryless designs.

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

Display requirements of the Internet of Things

Just as the personal computer and smartphone each 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 by its emphasis not on hardware superiority, but on interconnected data. 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 provide 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.

But 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 a lot of value.

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

E-paper: the ideal IoT display technology

E-paper, 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 (pixels), e-paper displays are filled with negatively charged black and positively charged white ink particles. By applying appropriate charges across the top and bottom of each capsule, you can create high-resolution images.

E-paper 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 e-paper displays can be thinner and lighter than LCDs. These low-power, low-processing requirements, and thin, light characteristics make e-paper the perfect display technology for the IoT.

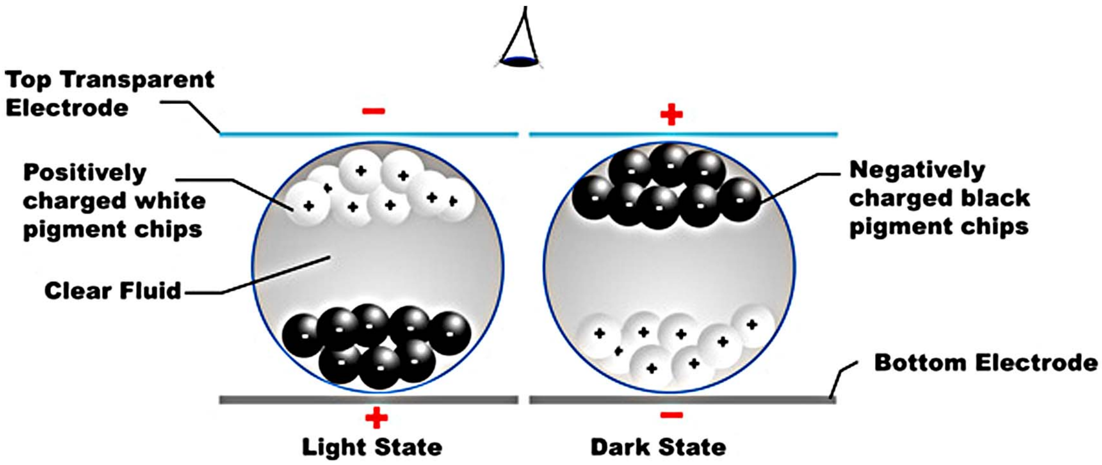


Fig 1. E-paper displays consist of thousands of capsules filled with charged black and white ink particles.

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, e-paper enables IoT use cases, such as electronic shelf labels, human-readable RFID tags, or NFC-updatable ID badges.

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. E-paper 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 years. E-paper’s low power consumption also enables it to be used with energy harvesting, for batteryless "no power" devices.

A key reason for e-paper'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, e-paper can enable displays that can operate significantly longer than TFT LCDs on a similar battery. E-paper 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 e-paper 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.

	Screen Update Operation		Power consumed per day w/6 updates (mAh)	Power consumed per year (mAh)
	Consumption (mA)	Duration (s)		
2-inch EPD module (V231, eTC/G2)	2.33	2.32	0.01	3.29
2-inch TFT LCD module	30	0.02	720	262,800

Fig 2. E-paper's power consumption is several orders of magnitude less than TFT LCDs.

Consider a 2-inch e-paper module and a TFT LCD of corresponding size, where the contents of the display need to be constantly visible, and updated six times a day. An optimized e-paper display would use just 3.29 mAh per year, while the 2-inch TFT LCD would use 262,800 mAh. Over the course of five years, the LCD would have consumed the power of around 6000 CR2032 coin cells, while the e-paper display would have barely used up 10% of a single coin cell's capacity.

Because e-paper displays 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 e-paper display 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 e-paper display is also strongly influenced by the type of module used and waveform optimization.

The physical characteristics of e-paper 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.

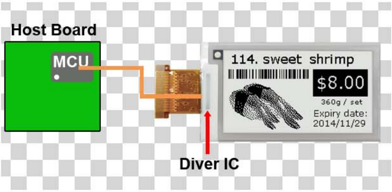
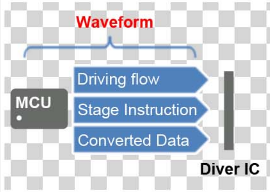
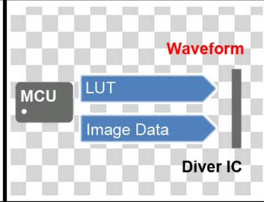
	eTC	iTC
Full name	external Timing Controller	internal Timing Controller
		
Driving waveform	Controlled by MCU	Embedded in driver IC
Customization/design flexibility	Higher	Lower
Design-in effort	Normal	Easier

Fig 3. iTC modules are easier to integrate, but eTC modules can achieve lower power consumption and greater control over display characteristics.

The easiest way to get started with e-paper is with internal Timing Controller (iTC) modules. These modules have waveforms stored on the Chip-On-Glass (COG) driver, which make them easier to program and integrate. The host system sends image data and temperature to the e-paper module, and the driver IC will generate the waveforms to drive the e-paper display properly. Typical current consumption during a screen-update operation for a 2.15-inch iTC display is 10 mA.

Modules using external Timing Controller (eTC) architecture can achieve even better power consumption performance. With this architecture, the waveforms driving the e-paper module are generated by the host MCU. These modules require less current to operate, and the host MCU has greater control over the optical performance, display characteristics and power usage of the e-paper display. For instance, a display could be optimized for a faster refresh rate at the cost of higher power consumption, or optimized for low power consumption while updating more slowly. Typical current consumption for a screen update operation on a 2-inch eTC e-paper module can vary from 8 mA to as low as 2.33 mA, depending on configuration.

While eTC can achieve significant power savings compared to iTC modules, both technologies' power consumption can be orders of magnitude lower than TFT LCDs or OLED displays.

Because of its low power consumption, e-paper 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.

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.

E-paper’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. E-paper also offers wide-temperature-range operation, as well as error-detection technologies to provide robust long-term operation in harsh industrial environments.

Wide-temperature operation
Alongside display modules designed for use from 0 °C to 50 °C, Pervasive Displays offers wide-temperature-range e-paper modules. These are designed for consistent optical performance in ambient temperatures from -20 °C to +50 °C.

Because they’re suitable for use in freezing conditions, wide-temperature models enable e-paper to be used for cold-chain data loggers, retail freezer displays or automotive applications.

Error-detection technologies
To support operation in harsh industrial environments, e-paper modules feature breakage detection and power on failure detection. If the screen breaks or fails to power-on correctly, an error code is initiated, which can be displayed locally through an LED or transmitted wirelessly to a remote application.

Display characteristics

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.

Bistable
Because most IoT devices just need to display simple sensor data or device information, e-paper enables them to do this efficiently, even with limited battery and processing resources.

Instead of needing to be constantly refreshed like a TFT LCD, an e-paper display retains an image, such as a temperature or pressure value, on its screen without power. This minimizes power consumption, and means a simple, low-power MCU can easily drive a high-resolution e-paper display. A battery-driven e-paper thermostat, for instance, can show a temperature value on its display constantly, where on an LCD, doing so would have severe implications for battery life.

Viewing angles and visibility
Designers of laptops, TVs and monitors can expect 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, e-paper 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°.

Refresh rate
While e-paper displays are bistable, they take a significant amount of time to update — typically one-to-two 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.

Fig 4. This 2.7-inch eTC e-paper module with capacitive touch overlay, demonstrates a responsive user interface for a thermostat, implemented using partial updates.

By using partial updates — where only part of the display is updated at a time — image refreshes can occur more rapidly, enabling designers to implement animations or user interfaces. With partial updates, image refresh rates can be decreased to as little as 100 ms, depending on the area and type of image being shown. In addition, partial updates eliminate the "flash" or “blink” effect seen with full-screen updates.

Wireless integration

With its low-power, bistable characteristics, e-paper is a natural fit for battery-powered wireless devices that would be unable to power traditional LCDs. The bistable nature of e-paper screen 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 e-paper display from the cloud, creating novel applications. Electronic shelf labels 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 e-paper displays can change the information displayed, based on location-awareness.

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

Fig 5. E-paper complements RFID by making the data stored on the tag human-readable.

The extremely low power requirements and bistable nature of e-paper means that displays work particularly well with NFC technology. NFC devices with e-paper displays 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.

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.

TI AdapTag Wireless Development Kit

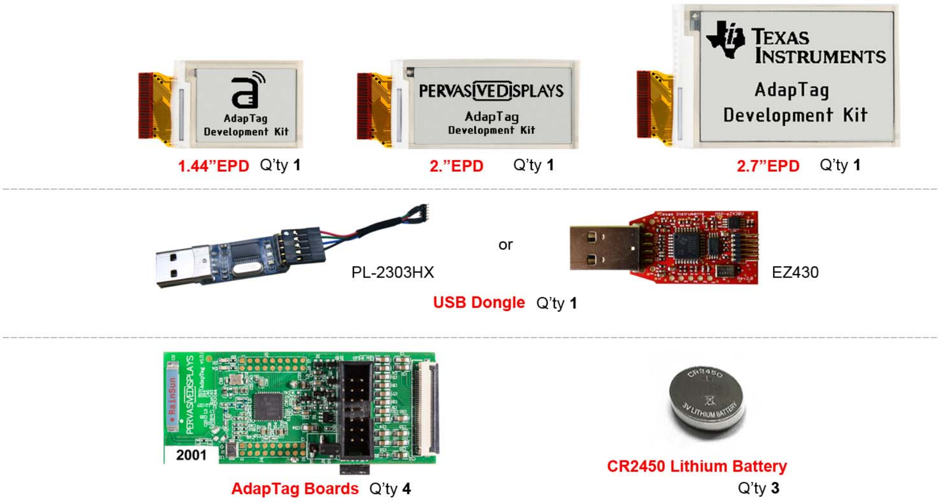


Fig 6. AdapTag Development Kit contents.

Developed in conjunction with Texas Instruments, the AdapTag Development Kit is an easy way to get started with e-paper, because no programming is needed. Consisting of a USB-to-UART dongle, four AdapTag Boards and e-paper displays in three sizes from 1.44-inch to 2.7-inch, the kit is easy to assemble and demonstrates a sub-GHz wireless e-paper network.

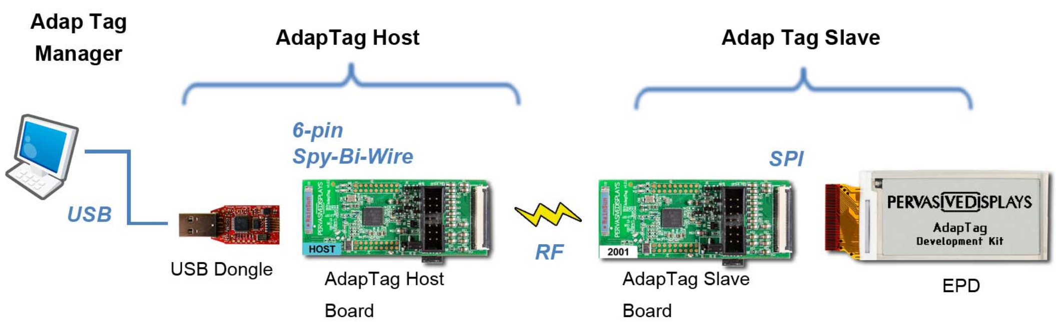


Fig 7. System block diagram for an AdapTag wireless e-paper display network.

One of the AdapTag boards is a host board. Connected to a PC using the USB dongle, it functions as the access point for the sub-GHz RF network. The other AdapTag boards function as slave devices. Connected to e-paper displays and coin cell batteries, they can be updated wirelessly from the host board.

To use the system, the user installs the AdapTag Manager software on a Windows PC, connects the AdapTag host board and can use the software's graphical interface to remotely update the e-paper displays on the AdapTag slave boards. Besides wireless updates, an e-paper display can also be attached to the AdapTag host board, enabling it to be updated over USB.

While the system is designed to work out-of-the-box, the AdapTag Manager software, AdapTag board firmware and hardware design are all open source, and function as demo.

TI SimpleLink™ Wi-Fi CC3200 wireless MCU-based EPD Reference design

Fig 8. TI's CC3200-based EPD reference design can be updated over local wireless networks or through the cloud, using MTTQ.

Texas Instruments has also made a reference design for a Low-Power Wi-Fi Enabled Electronic Paper Display available. Based on the SimpleLink CC3200 wireless MCU, the design uses a TI CC3200 Launchpad, along with an EPD Boosterpack to enable an e-paper display to be updated over a Wi-Fi network. Once the design is programmed and connected to an access point, users can update the display over a local Wi-Fi network through an HTTP page running on the Launchpad, or remotely over the Internet, using an MTTQ client.

EXT2 Extension Board

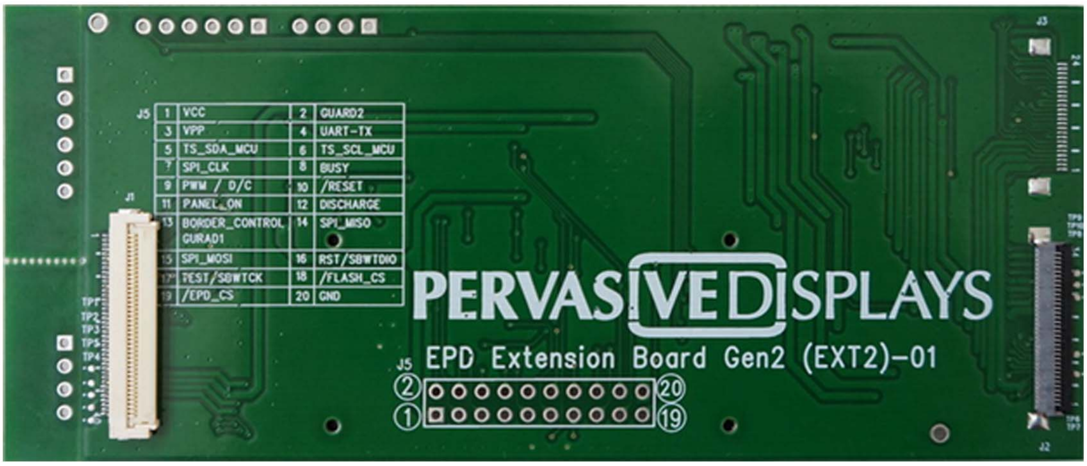


Fig 9. Top view of an EPD Extension Kit Gen2 board.

For a more flexible approach, the EXT2 extension board is designed to drive both iTC- and eTC-based EPD displays below 4.2 inches in size. Besides the EPD driving circuit, there is an onboard temperature sensor and 8 MB flash memory. Light guide and touch panel connectors make it easy to integrate a backlight or capacitive touch. Designed to mate perfectly with TI Launchpads, a bridging cable also enables it to connect with custom hardware.

Supporting development with either TI Code Composer Studio or Energia IDE, the EXT2 also has a custom GUI utility available, which enables users to easily test e-paper designs without having to write any code.