PERVASIVE DISPLAYS

Fast Update Application Guide

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Preface

EPD* features extremely low power, allowing it to be used in devices once the content has been rendered then no power is needed to maintain the display. The normal and standard refresh cycle for an EPD calls Global Update provides the best optical performance.

Global Update satisfies most of the use cases. However, the refresh time cannot meet the interactive scenario and the use case of a device for the Internet of Things. This application guide will introduce the Fast Update provides an overall introduction including technology, operating approach and limitation to help you understand how to realize it in your applications.

* **EPD**: Electrophoretic display, Electronic paper display or E-Paper display

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1. General description

1.1 Overview

This section will introduce the materials and drivers that have been used on the products of Pervasive Displays Inc (PDi). After generally understanding the most of knowledge, we will start introducing the driving difference between Global Update and Fast Update. Afterward we will explain how to implement the Fast Update in different driver solution. At the last section, you will learn about the pros and cons of this technology using e-Paper display (EPD) to be realized in your applications.

Prerequisites:

1) You have worked or tested our EPD modules and the screen has been refreshed successfully.
2) You have roughly understanding of the characteristics of EPD and already known that EPD cannot play animation effects because Fast Update is a special and non-standard driving approach for EPD.
3) You must follow our instructions to implement Fast Update from this document, and you are solely responsible for the result of any self-modification.

1.2 E ink imaging film (FPL)

E ink imaging film is also called FPL (Front Panel Laminate) has two main material films for industrial applications that are different from the FPLs used in e-readers (e.g. Amazon Kindle). The name of two FPLs are Aurora and Spectra. It can be subdivided into the following different FPL types which have been mass supplied for vendors to make as EPD modules:

EoL: End of life, discontinued.

FPL group	FPL name	Alias name	Colors	Operating Temperature
Aurora	Aurora Ma	V230(EoL)	Black, White	-20°C to +10°C
	Aurora Mb	V231	Black, White	0°C to +50°C
	Aurora -25	V430	Black, White	-25°C to +30°C
Spectra	Spectra Red	R1.1(EoL) R1.2, R2.0	Black, White, Red	0°C to +40°C
	Spectra Yellow	Y1.2	Black, White, Yellow	0°C to +40°C

Table 1 E ink imaging films

Notes:

1) Spectra model isn't suitable for Fast or Partial Update because the red-color (or yellow-color) pigments need to show up gradually over time given slow visual experience.

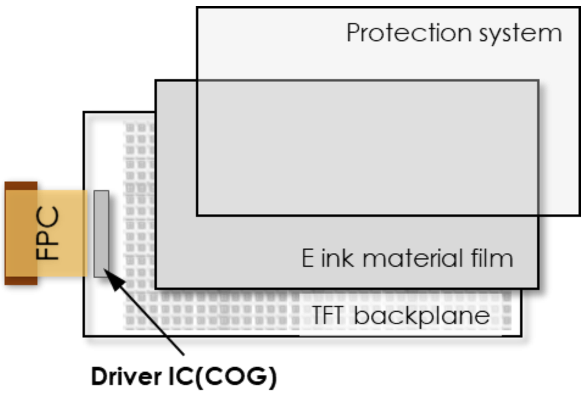
2) The lower temperature, the slower refresh rate of EPD screen. For this reason, EPD is not suitable for operation in lower ambient temperature, especially under 0°C.

3) We would highly suggest selecting the EPD with **Aurora Mb (V231)** film (black and white only) to carry out Fast or Partial Update and better to operate your device in **room temperature** to give the best visual experience and optical performance in such use cases.

1.3 Driver IC (CoG) and driving waveform

Driver IC is a timing controller (Tcon) to output different sources/data and control the gates per pixel on EPD. It's always bonded on TFT backplane which is also called **CoG** (Chip on Glass).

The output image on an EPD is realized by controlling the pixel electrode voltage, thus affecting motion of charged particles in the neutral suspension. A voltage sequence applied to the pixel electrode is called a **driving waveform**. Different manufacturer of EPD selects different driver IC and the E ink FPL is always varied batch by batch. Therefore, each design of a driving waveform is completed manually and always need to be tuned from different batch of FPL. Simultaneously, under different temperature conditions, more sets of driving waveform matched with different temperature conditions are required. The motion of particles in an EPD device will be inadequate or overdriven when the driving waveform does not match with the temperature conditions. If so, user will see image ghosting or blurred pixels are easily generated, which may affect the output image quality. The design of the driving waveform will determine the image quality of the EPD.



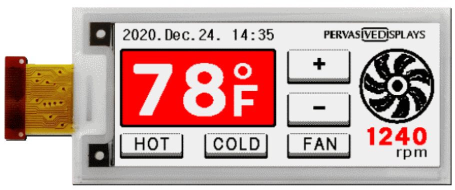


Figure 1 Layer structure of EPD module

Charge pump, a kind of DC to DC converter (DC/DC) that uses capacitors for energetic charge storage to raise or lower voltages. A positive charge pump and a negative charge pump to provide adjustable regulated output voltages. EPD needs charge pumps to step up the voltages to supply different voltage levels to drive different color pigments in EPD module. When the DC/DC is embedded in the CoG and driving waveform is pre-programmed in CoG, we call it internal timing controller (**iTC**) ,and similarly, if the DC/DC circuit is arranged outside the EPD module and driving waveform is controller from MCU, we call it external timing controller (**eTC**).

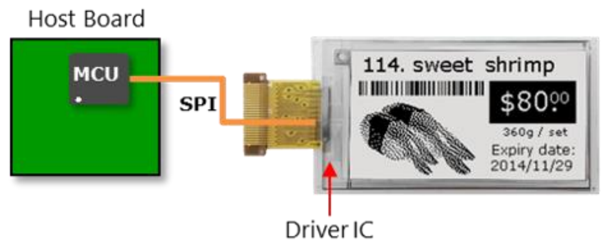
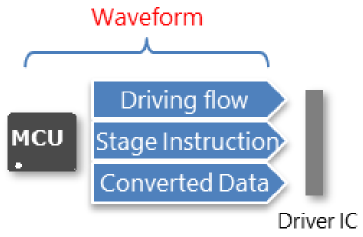
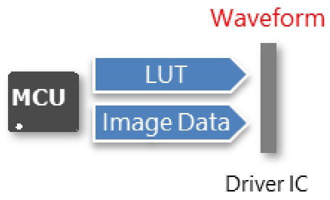
<table>
<tr><td></td><td colspan="2">
</td></tr>
<tr><th></th><th>eTC (external Tcon)</th><th>iTC (internal Tcon)</th></tr>
<tr><td>Driver type</td><td>
</td><td>
</td></tr>
<tr><td>Driving waveform</td><td>Controlled by MCU</td><td>Embedded in driver IC (CoG)</td></tr>
<tr><td>Customization / Design flexibility</td><td>Higher</td><td>Normal</td></tr>
<tr><td>Design-in effort</td><td>Normal</td><td>Easier</td></tr>
<tr><td>Power consumption</td><td>Lower</td><td>Normal</td></tr>
<tr><td>Explanation</td><td>Following our driving guide, developers can fully control the driving flow and stage from the MCU.
Developers need to send converted image data at each specific stage.</td><td>The driving waveforms (LUTs, lookup tables) have been pre-programmed in the driver IC. Developers just need to send image data and update command to complete the screen refresh.
If developers need special support to change the waveforms, extra LUTs can be sent externally.</td></tr>
</table>

Table 2 eTC vs. iTC

Notes:

1) PDi provides both approaches of timing controller for EPD modules. The eTC model is PDi's unique structure, which is different from the vendors on the market.
2) The EPD with either eTC or iTC is able to carry out Fast or Partial Update, just the driving waveform are totally different of Global Update.
3) The driving waveforms in this document are 1-bit greyscale which means black and white colors only.

1.4 Global Update, Fast Update and Partial Update

Every EPD manufacturer or design house (vendor) will design their own driving waveforms or get the existing waveforms from E ink company directly to drive their produced EPD modules. Because of this, you will find the effect of screen flashing varies from every vendor. Not only that, but the optical quality performance of each vendor is different, the power consumption either.

In this section, we will start introducing Global Update, Fast Update and Partial Update. Note that PDi's waveform stages may be different from what you've seen from other vendors. PDi always fine tune the driving waveforms and LUTs of EPD modules by own technologies and patents.

- **Global Update** (also known as "Full Update" or "Global Refresh") to update display from original image to new image and looks like every pixel of entire display has been refreshed and updated with flickering effect.
- **Fast Update** (also known as "Fast Refresh") is the process to update display from original image to new image directly and the new image is always a full image but looks like only the pixels to be changed are refreshed and the rest of pixels are not changed. Fast Update still keeps sending full new image and driver IC will work on the image data comparison to carry out the local changes.
- **Partial Update** (also known as "Local Update" or "Partial Refresh"). The difference between Fast Update and Partial Update is Partial Update will need to define an area (window) to be updated and system side will send image data of the specific area only (not a full image) then using the same driving waveform to carry out the local update.

Find the difference of image data among Global Update, Fast Update and Partial Update at next page.

Notes:

1) In this application guide, we will introduce **Fast Update** only.
2) The main difference between Global Update and Fast Update is Fast Update will reduce the driving stages and shorten the stage time to carry out faster refresh than a Global Update. Find the comparison in Table 5.
3) The Partial Update driving will need special configuration and driving approach to define the partial window (the area to be changed) before sending the specific size of image data. For more information of Partial Update, you can contact PDi for further support.

	Original image on screen	Final image on screen
	1 2 3 4	1 2 3 5
Update types	**Image data**	**Updated on screen**
Global Update	1 2 3 5	1 2 3 5
Fast Update	1 2 3 5	1 2 3 5
Partial Update	5	1 2 3 5

Table 3 The difference of image data among updates

- **Two buffers**: pre-storing the original image in memory (1st buffer) and compares with the new image (2nd buffer) to get the target data bytes to be refreshed on EPD. Once the image is updated on EPD, the new image will be defined as original one.
- **One buffer**: refreshing the new image on EPD directly without compensating from the original image.

Assume we will refresh EPD screen from image 1 to image 2 as follows:

Image 1 (original)	Image 2 (new)
1	2

Table 4 Update images

Find the differences and explanations among Global Update, Fast Update and other Updates next page.

Approach	Image 1	Stage 1	Stage 2	Stage 3	Stage 4
Global Update (two buffers)	1 Original image	1 Inverse original image	Full white image	2 Inverse new image	2 New image
	Global Update features full refresh on every pixel. Each pixel needs to be compensated (inversed from original image and inversed from new image) and reset (full white screen) to keep almost the same moving distance for every particle in the capsule of FPL. It helps for improving ghosting (will introduce later) effect and extend the lifetime of FPL.				
Global Update (one buffer)	1 Original image	Toggle black/white	2 New image	N/A	
	In this case, when new image is sent to driver IC, the waveform will toggle between full black and full white images continuously. After completed with the stage 1 period, the waveform will send targeted image to complete driving period of the stage 2. This approach will reduce half of driving time and achieve the compensation with reset of every particle in the capsule of FPL too.				
Fast Update (two buffers)	1 Original image	2 New image	N/A		
	As you can see the approach in this case, the Fast Update looks like it is sending new image to screen directly. However, there is neither compensation nor reset stages in between. Such operations will cause the particles in FPL to be overdriven in an unbalanced state. Over a long period of time, ghosting image may appear, and at worst, the EPD module will have a short lifetime or even cause damage that cannot be recovered to original optical performance.				

Table 5 Global Update vs. Fast Update

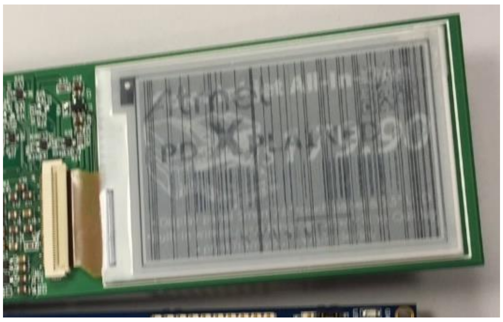
In the later sections, we will introduce how to correct drive the waveform for Fast Update.

Why Fast Update needs two buffers?

Fast Update needs to compare with original image and new image to get different image data and sends the appropriate driving data bytes to EPD. Either storing images in the Flash or allocating two memory banks to implement the data comparison. iTC and eTC will use different approaches. Find Section 2 for more details.

What will happen if incorrect driving or overdriving with the EPD?

You will see similar vertical lines (see the picture) or the ghosting images (find in section 0).



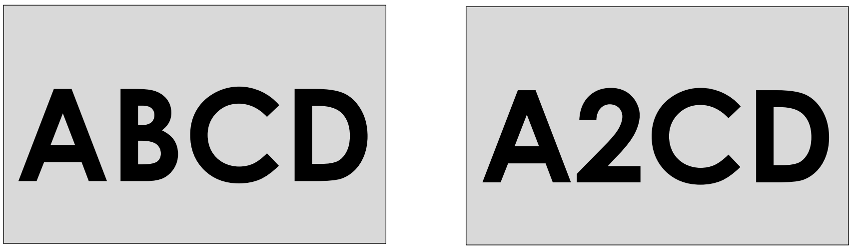
Consequences:

- Overlapping images obviously after powering off
- Reduce the lifetime of EPD
- Hard to clear the ghosting images permanently
- Abnormal behaviors in lower temperature

1.5 Ghosting image

Ghosting is the effect of seeing artifacts of a previous image on the display. EPDs are by nature prone to ghosting effects if the driving waveform was not well-behaved implemented. The ghosting image looks like a grey shade of the previous object is embedded in the new object.

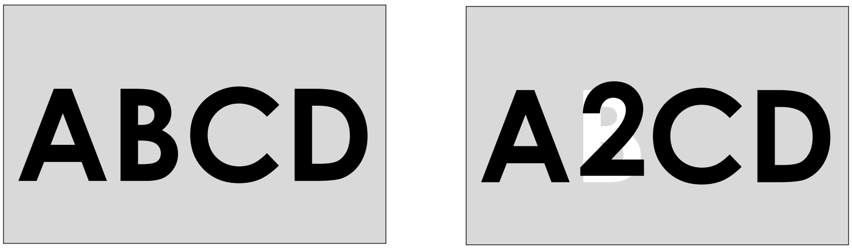
This example is what we expected to see the "2" was changed from "B" properly.



Before update   After update

Figure 2 Update patterns

When you see the phenomenon like the example below after new image is updated, it's ghosting effect. Sometimes you will see the colors are mixed.



Before update   After update

Figure 3 Ghosting phenomenon after image is updated

To avoid seeing the ghosting image, following the instructions in section 2 will reduce or eliminate this phenomenon.

2. Implementing Fast Update

2.1 Data comparison of Fast Update

In section 1, we've understood the Fast Update needs two data buffers to store image data. One is for original (previous) image and the other is for new image. For data comparison, find the table below:

Fast & Partial Update		Previous Image	
		Black	White
New Image	White	**White**	**Nothing** (do not change)
	Black	**Nothing** (do not change)	**Black**

Table 6 Data comparison of Fast Update & Partial Update

- If the new data byte is same as previous data byte, send "Nothing" data byte.
- If the new data byte is different from the previous data byte, send the new data byte.
- Once new image is updated on EPD, the result image becomes the original one in order to be compared with upcoming new image.

The key is to ask driver to send Nothing data byte for the targeted pixel if the existing color won't be changed. The driver will keep the same voltage level to maintain the particles at the same pixel position. Find below is an example to compare the images pixel by pixel and get different data bytes that will be driven.

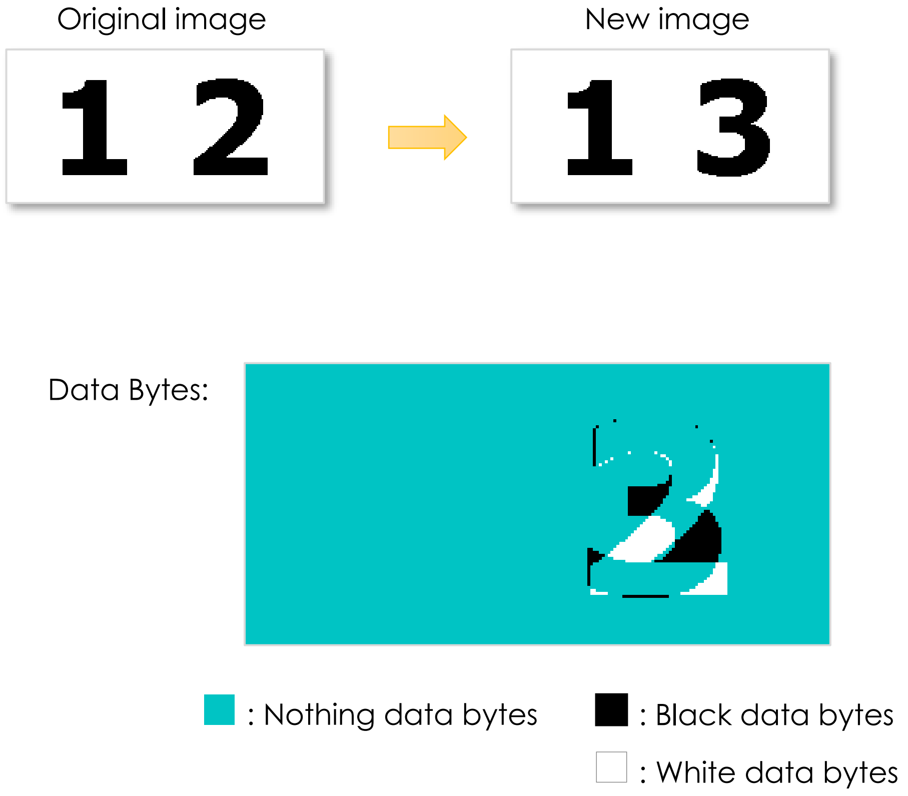


Figure 4 image data bytes after compared pixel by pixel

2.2 Preparing images

2.2.1 Sending image data to eTC driver

Refer to Figure Figure 4 image data bytes after compared pixel by pixel, for an eTC EPD to prepare the image data, MCU side needs to get the original image, prepare the new image and get the compared result to generate the (1)Black data bytes, (2) White data bytes and (3) Nothing data bytes. Afterwards, according to the data bytes, MCU sends the corresponding data bytes to eTC driver pixel by pixel to complete a stage driving.

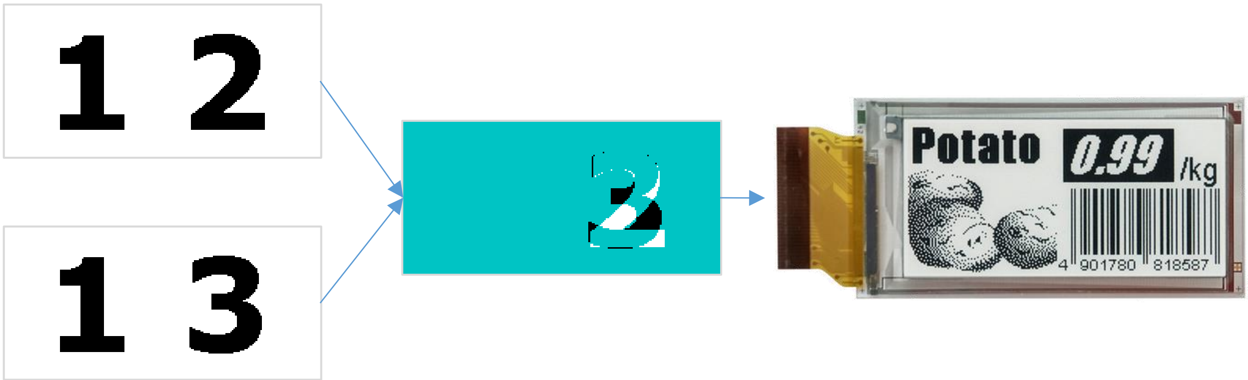


Figure 5 Image data sending to eTC driver

Developer always has to convert the output data bytes in advance from original and new images before sending to eTC driver.

2.2.2 Sending image data to iTC driver

The LookUp Tables (LUTs) is an array to store the driving parameters of timings, data bytes, color options, cycle times and more. LUTs have been programmed in the iTC driver IC of EPD, hence developer just needs to send image data with very few commands to realize the Fast Update.

Figure 6 Image data sending to iTC driver

The comparison works have been defined in the LUTs. Developer will need to send previous and new images together with the update command for applying Fast Update LUT to iTC driver.

2.3 Frame time and Stage time

The EPD module described in this document is an active dot-matrix display. It is interlaced of several sources and gates design. Per a resolution of 200 * 96 EPD, it is composed of 96 sources and 200 gates also means one line has 200 dots. One frame is from (1,1) to (200, 96) which is a complete screen size.

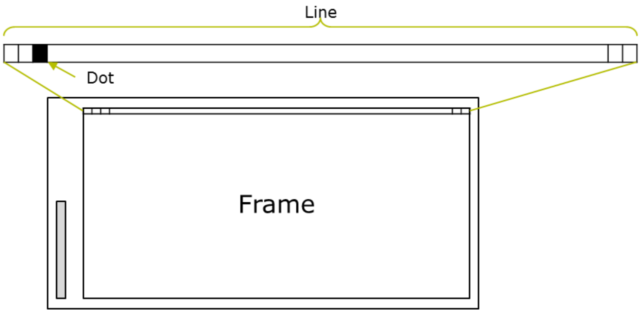


Figure 7 Frame, Line and Dot of an EPD

A frame time is the duration to complete one update frame and a stage time is a total duration to update the defined number of frames.

EPD needs the particles in ink to be driven with the targeted voltage level for multiple times to push it at the targeted position steadily. The more update frames in an update stage, the better optical performance and particles fixity.

2.3.1 Determine the frame time of eTC driver

Per PDi's experiments, we recommend the stage time needs **400ms** above to achieve the more stable and better visual experience.

For eTC EPDs, in terms of suggested 400ms of stage time, you have to send frames in a stage as more as you can. You can get the frame time of MCU from your code then you will understand how many frames at least to be sent in a stage. For example, if you get MCU frame time is 55ms from your test code, you have to send 8 frames at least (55 * 7 =385, 55 * 8 = 440) to complete a stage update.

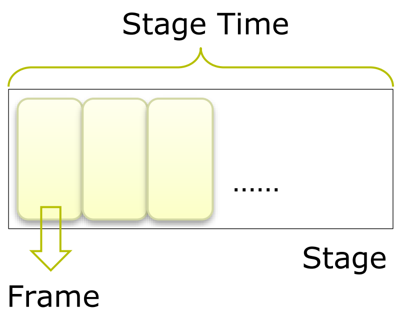


Figure 8 Frames in a stage for eTC driver

You will easily see ghosting image, decaying quality or fading effect if sending fewer update frames in suggested stage time.

2.3.2 Set the Stage time of iTC driver

iTC driver has defined the duration of a stage time which is programmed in the driver IC. It will continue to run the update frames according to its performance until sufficing the defined stage time. In most cases, the number of frames of iTC will be greater than that of eTC in a defined stage. Because of this, the optical performance of iTC driver is usually better than eTC driver in a fixed stage time.

- To get the LUTs of Fast Update for iTC driver, you have to contact PDi and will need to sign NDA with PDi for further support.
- If you would like to reduce the stage time or change the configuration of LUTs, you have to get supports from EPD vendor and understand how to set the new LUTs to send them from MCU bypass the programmed LUTs. Contact PDi if you need such support.

2.4 Flowchart for Fast Update

The charged particles in the ink material are in unbalanced state while fast refreshing continuously. They need either compensation or inversed image to clean the ghosting effect, maintain the optical performance and extend the lifetime of EPD module. With regards to this, you have to take count of Fast Update times or the EPD has been stopped refreshing for a period of time without any changes (the diamond shape in red below) and place a standard Global Update timely. Find the figure below is the suggested EPD driving flow chart of Global and Fast Update.

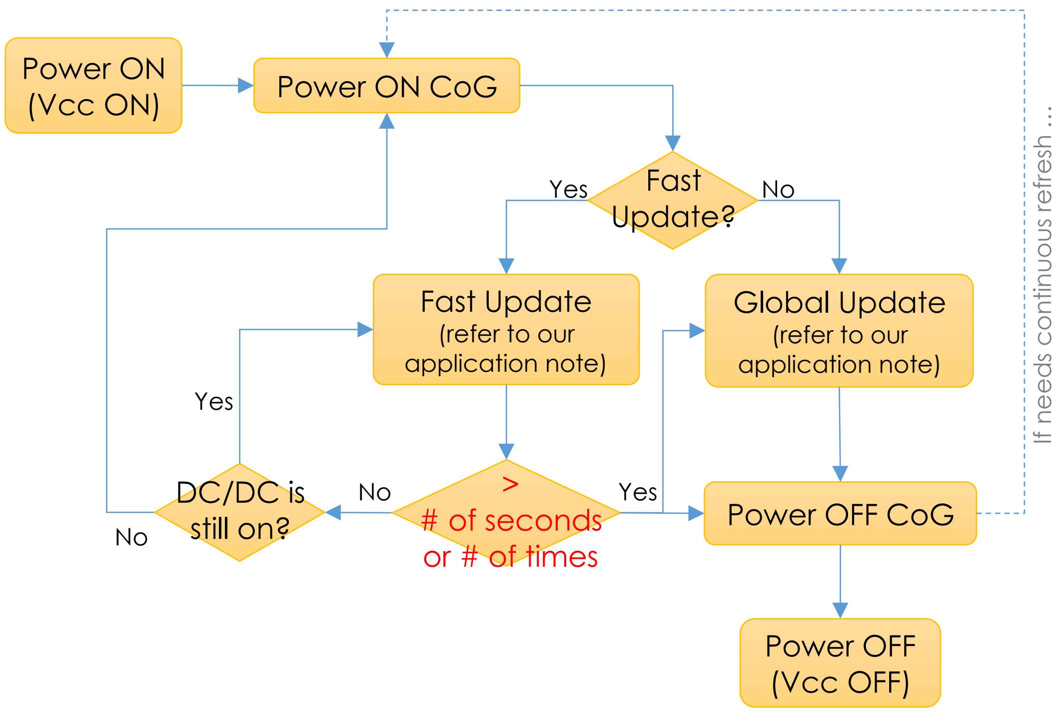


Figure 9 Driving flow chart of Global and Fast Update

Per our experiments, we highly recommend that
(1) after 15 Fast Updates of eTC / 50 Fast Updates of iTC,
(2) 30 seconds without any screen changes (e.g. idle state),
(3) ghosting effect starts to appear on screen,
(4) totally different template or scene,
you are better to run a standard Global Update or power off the CoG to wait until next cycle is coming. The (2) depends on your use case. All the criteria also depend on your acceptance of image quality or tolerance of ghosting images.

iTC driver features shorter period of power on or off the CoG. If the duty cycle of your product is low, we would suggest you could consider power off the CoG, and then turn on the CoG per new Fast Update to reduce the standby current. The duration of power ON + OFF CoG of iTC driver is around 100ms or less mostly.

2.5 Graphic Library

To implement Fast Update or Partial Update, you will need to send images continuously but most of the time the pixels to be changed are usually in small areas or from some fixed objects. If there is no graphic generating tool or image production engine to handle these small changes, the output effect will be greatly reduced and will increase the system load.

There are already many graphic libraries on the market that are dedicated to being used for LCD, touch panel, etc. You can check if the graphic library supports 1-bit grayscale color which fits perfectly for EPD Fast Update. The most commonly primitive objects such as line, circle, rectangle, progress bar, textbox, slider, scroll bar, button, checkbox, radio button, icon, etc. It also allows user to set font type, format and size. For such graphic library, there is a driver layer (resource converter engine) to put pixel from the application layer through working with primitive objects to generate the full image and can be sent to driver IC of EPD to output on display.

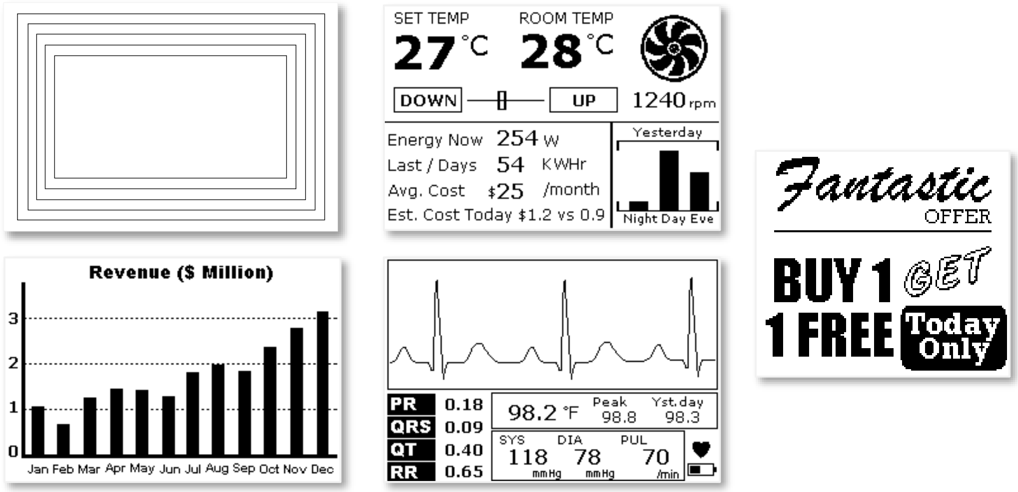


Figure 10 Resource objects of graphic library

💡 Contact us if you need support for the graphic library to accelerate your design progress on Fast Update and Partial Update applications.

3. Pros and cons of Fast/Partial Update

3.1 Pros of Fast/Partial Update

- **Better user experience**

  In most of the cases, the flashing (toggling) among inversed, black and white images of Global Update causes observer is unconformable requires keeping looking at the screen. The direct Fast/Partial Update on screen has eliminated this issue and provides better visual experience.

- **Faster update time**

  In the case of Global Update, typically, there are four image stages to complete an update cycle. Excluding the power-on and power-off stages, the refresh time of Fast Update is 1/4 of Global Update.

- **Less power to move particles in FPL**

  Since there is only a portion of pixels are moved (changed) from Fast/Partial Update, the power applied on FPL is less than that from Global Update if we based on one refresh.

- **Integrate diverse applications**

  Fast/Partial Update features quick refresh and visual experience which helps integrate for example: smart home, IoT device, industrial appliance, retail's shelf talker, information signage and more. When integrating with touch panel on top, the applications can be extended to HMI, HVAC, portable device, badge and any device for user interaction. Thanks to EPD's bi-stable technology and low power consumption, the EPD will maintain the content without power consuming to fulfill the low duty cycle scenario and is also able to react shortly.

3.2 Cons of Fast/Partial Update

- **Ghosting of previous image**

  Because the characteristic of FPL material (varies batch by batch), it's difficult to make the optical quality of every EPD identical and the reflectance of either black or white may be different. In this case, user will see the output phenomenon like Figure 3 ghosting effect, degraded image or decayed contrast ratio.

- **More power budget for calculation**

  Even though less energy is needed to drive the particles in FPL for Fast/Partial Update, you will need more calculations to count the coordination and image data from inputs, and it may need more power than ordinary case (i.e. Global Update) to prepare the data for EPD. Note that the power is ON mostly and DC/DC is also up to take immediate actions for Fast/Partial Update, and every pixel is refreshed or compared from color image data or nothing data bytes. Hence, excluding the power periods, it is possible that requires more total power budget to finish a complete cycle of Fast/Partial Update.

- **Current leakage under direct sunlight**

  Because EPD uses TFT backplane with ITO electrodes, TFT would be occurred current leakage under sunlight illumination. TFT can't hold voltage and the data is getting down when current leakage happened. Once this effect is happened, user will easily see blurred images or decayed optical quality. Global Update will always refresh every pixel of entire EPD with four stages per update cycle and power off the EPD every time to stop the leakage occurs. Nevertheless, the Fast/Partial Update is just to refresh the pixels to be updated with one stage. Due to this feature and there is current remains on the TFT (not always power off CoG/EPD), it's easy to see the current leakage and ghosting happened on the unchanged pixels/area of EPD under direct sunlight illumination when Fast/Partial Update continuously. For this reason, Fast/Partial Update is not suitable to perform under direct sunlight. It's better to select semi-outdoor or shielding environment to implement Fast/Partial Update.

- **Slow refresh in low temperature**

  Per EPD's characteristic, the lower ambient temperature, the slower refresh rate of screen changes. The particles will need more powerful driving, but the refresh time is still slower and slower due to the characteristics of EPD and lower temperature. It will affect the user's visual experience and reduce the convenience of operation.

Glossary of Acronyms

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
TFT	Thin-Film Transistor

Revision History

Version	Date	Page (New)	Section	Description
Ver. 01	2013/10/18	All	All	First issued
Ver. 02	2014/12/01	6, 9, 11 5 10 12	All 1.1 2.21 2.3	Add FAQ Add Note Add Figure 2.2 Add suggested stage time description
Ver. 03	2021/1/7	All	All	Rewrite the whole document Add iTC driver for Fast Update

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