Plastic Logic Micro-Controller E-Paper Reference Manual

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2 Introduction

This document provides an introduction and overview to the code intended to be used by customers wishing to drive Plastic Logic displays and associated controller hardware from a single chip microcontroller platform. The MSP430 is the first reference target, based on customer interest. As delivered the code runs on a hardware reference platform, available from Plastic Logic, comprising a microcontroller processor board, a motherboard and display interface boards for a range of displays. The code runs a slide show demonstration to show how the hardware components work together to drive images on a display. The code requires no underlying operating system to function. Some commonly available C runtime library functions are used. The project is in active development and feedback is welcomed on new features or issues found in the code or documentation. Please send feedback via your sales/support representative.

3 Scope

This document does not attempt to describe the detailed operation of any particular microcontroller or Epson display controller as this information is readily available, or may require an NDA to disclose. Prior experience with embedded programming is expected and discussion will focus on the specifics of this code base. The code is able to drive a slideshow of pre-rendered images in the PGM file format to a chosen display. Due to restrictions on resources the code is not currently able to manipulate the images in any way. The code focusses on functionality and does not pretend to implement best practice for any specific microcontroller. Data transfer speed improvements are planned for subsequent releases. The code attempts to strike a balance between minimising microcontroller resource usage while preserving portability, good coding practices and the provision of good debug support (e.g. use of assertions).

4 Licensing

The majority of the software in this codebase was written by Plastic Logic and is currently licensed under a restrictive license for early adopters. For the avoidance of confusion: This software is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. Some key support functionality is provided by third parties who have their own licenses. The third party components are: FatFs – A FAT file-system driver. This is used to access configuration and image data stored on a micro SD card on the reference microcontroller hardware. The license for FatFS can be found here: http://elm-chan.org/fsw/ff/en/appnote.html#license, it is not restrictive. Sample code - This is sample source code made freely available by the microcontroller vendor. The copyright notices vary from source file to source file but are not restrictive other than limiting the use of such processor specific sample code to a given range of processor devices. Please see Appendix A for license text.

5 Glossary

CCS

Code Composer Studio, an integrated development environment from Texas Instruments that can be used to develop code for the MSP430 microcontroller

DAC

Digital to analogue converter. Converts a digitally-encoded value to an analogue signal

EPD

Electrophoretic display. Such displays retain the last image driven to them and only require power to change the image

EPDC

Electrophoretic display controller. A specialised display timing controller required for updating electrophoretic displays. The EPDC is responsible for applying the correct waveform to each pixel, according to the current and target images

FFC

Flexible flat cable (http://en.wikipedia.org/wiki/Flat_Flex_Cable)

GPIO

General-purpose input/output. A user-controllable pin that can be defined at runtime as either an input or an output

Hummingbird Z6

An evaluation board from Plastic Logic that interfaces between a Plastic Logic small display (e.g. S040_T1.1) and a host processor board (e.g. Parrot or Parrot + Ruddock2)

Hummingbird Z7

An evaluation board from Plastic Logic that interfaces between a Plastic Logic bracelet display (e.g. S049_T1.1) and a host processor board (e.g. Parrot or Parrot + Ruddock2)

HVPMIC

High voltage power management IC. A chip that converts a single (typically battery) voltage into the various higher voltages required by the display

I2C

Inter-Integrated Circuit, a standard two-wire multimaster serial bus intended for communication with low-speed peripherals

Mercury board

An interface board from Plastic Logic that connects a Plastic Logic 10.7" display (e.g. D107_T3.1) to a Raven board via a 50-way FFC

MSP430

A low-power microcontroller from Texas Instruments

Parrot board

An evaluation board from Plastic Logic containing a MSP430 microcontroller

PGM

A portable graphics file format

PIL

Python Imaging Library, adds image processing support to Python

PNG

A graphics file format which uses lossless data compression

Raven board

An evaluation board from Plastic Logic that interfaces between a Plastic Logic 10.7" display (e.g. D107_T3.1) and a host processor board (e.g. Parrot or Parrot + Ruddock2)

Ruddock2 board

An evaluation board from Plastic Logic that interfaces between the Parrot board and one of the display interface boards (Raven, Hummingbird Z6/Z7)

S1D13524

An EPD controller chip from Epson, designed for use with displays up to a resolution of 4096x4096 pixels. Also supports colour displays

S1D13541

A combined EPD controller chip and source driver from Epson, designed for use with displays up to a resolution of 854x480 pixels

SPI

Serial Peripheral Interface, a standard four-wire serial bus that operates in full duplex mode

USCI

Universal Serial Communication Interface. MSP430 serial communications interface that supports multiple serial communication modes with one hardware module

VCOM

Display-specific common electrode voltage. Each Plastic Logic display is supplied with the correct voltage that must be applied by the control electronics

Waveform

A display-specific datafile that defines how the display updates

Z6

See Hummingbird Z6

Z7

See Hummingbird Z7

6 Getting Started

This section covers setting up the hardware and software so that a given display type can be driven. Please follow the steps outlined in order to setup and build the software.

6.1 Hardware Setup

The software requires a processor board, Ruddock2 (optional if using the Parrot processor board), a display interface board and a display to match the interface board. If using the Parrot board and the optional Ruddock2 board, ensure that: 1. The P5 â€œI2C isolateâ€■ 2-pin header on the Ruddock2, has no link fitted 2. The P4 2-pin header on the Ruddock2, has a link fitted 3. The switch SW7 on the Ruddock2 is set to ON 4. 5V power supply, 200mA for small displays, 2A for large displays, is used and the P16 3-pin header on the Parrot has a link fitted on position "JACK" (1-2) The processor board plugs into the Ruddock2 using the two parallel headers, note the processor board outline in the silk screen on the Ruddock2 for correct orientation. The display interface board connects to the Ruddock2 serial interface connector (the smaller of the two FFC connectors) using a flexi-cable. If using a Parrot oard, the display interface board can be connected directly to the Parrot using a flexi-cable. Finally the display itself connects to the display interface board either directly in the case of the small displays or via a Mercury board using a 50-way flexi-cable.

6.2 Code Composer Studio Setup

The Plastic Logic reference code project uses Texas Instruments' Code Composer Studio IDE v5.5. This section details the steps necessary to set up Code Composer Studio to build and debug the code.

1. Get the source code, either by downloading an archive or cloning the repository:

```
git clone https://github.com/plasticlogic/pl-mcu-epd.git
```

Important

This project uses **DOS line endings**. The `.gitattributes` file tells Git to automatically convert text file line endings to DOS at commit time. To avoid complications on Unix-like operating systems (Linux, MacOSX...) please configure your text editor to use DOS line endings.

2. Install Code Composer Studio from TI on MS Windows or GNU/Linux

3. Create new CCS project

- Open the menu **File** -> **New** -> **CCS Project**
- Project name: **pl-mcu-epd** (for example)
- Project location: Ensure the location is different to that of the cloned repository
- Output: **Executable**
- Device family: **MSP430**
- Variant: **MSP430F5438A** (for PL Parrot v1.x boards)
- Connection: **TI MSP430 USB1** (uses an MSP-FET430UIF USB-JTAG interface)
- Project template: **Empty Project**

4. Import the source code

• Open the menu **File** -> **Import** -> **General**

• To import a clone repository, choose **File System**

• To import a source archive, choose **Archive File**

Note

When using a source archive, the source will need to be moved out of the extra sub-directory that is created.

• Browse to select your pl-mcu-epd cloned repository or archive file

• Select all the files (checkbox near pl-mcu-epd)

• Click on **Finish**

5. Compiler configuration

• Open the menu **Project** -> **Properties**

• Click on the **Show Advanced Settings** link in the bottom left of the properties window

• The following project settings need to be modified:

• **CCS Build** -> **MSP430 Compiler** -> **Debug Options**

Debugging Model: Should be set to **'Full Symbolic Debug'**

• **CCS Build** -> **MSP430 Compiler** -> **Advanced Options** -> **Language Options:**

Check the box for **Enable Support for GCC Extensions**

• **CCS Build** -> **MSP430 Compiler** -> **Advanced Options** -> **Library Function**

Assumptions:

Set the level of printf support to **nofloat**

• **CCS Build** -> **MSP430 Compiler** -> **ULP Advisor:**

Disable the following items by unchecking the associated box:

2: Software (SW) delay

5: Processing/power intensive operations

• **CCS Build** -> **MSP430 Compiler** -> **Advanced Options** -> **Diagnostic Options:**

Check the box for **Emit Diagnostic Identifier Numbers**

• **CCS Build** -> **MSP430 Linker** -> **Basic Options**

Set C system stack size: 160

Heap size for C/C++ dynamic memory allocation: 1000

• **C/C++ General** -> **Paths and Symbols**

Includes: Add the following paths to the includes list (check all three boxes in the creation dialog window)

/${ProjName}/msp430

/${ProjName}

Includes: Re-order the includes list so that the order is as below:

/${ProjName}/msp430

${CCS_BASE_ROOT}/msp430/include

/${ProjName}

${CG_TOOL_ROOT}/include

6. Setup `config.txt`

Finally, a `config.txt` file must be placed on the SD-Card. A sample config file is supplied for each supported display type. More information on the various code configuration options can be found in the section Configuring the Code.

6.3 Configuring the Code

The code includes a number of features and demonstrations that can be configured at run time via the use of settings in the `config.txt` file.

6.3.1 Configuration of the display interface board type and display type

The following example defines a Raven board with D107_T3.1 display:

```
# Set one of the following to 1 to manually select the platform.
# This will be used if no platform can be discovered at runtime.
# CONFIG_PLAT_RAVEN < Raven board
# CONFIG_PLAT_Z6 < Hummingbird Z6.x board
# CONFIG_PLAT_Z7 < Hummingbird Z7.x board
board CONFIG_PLAT_RAVEN
# Set this to manually specify the display type when it could not be detected
# at run-time. This is especially useful for displays without an EEPROM such
# as S049_T1.1. */
display_type D107_T3.1
```

6.3.2 Configuration of how display-specific data is used

All Plastic Logic displays require display-specific information such as waveform data and VCOM voltage. Some displays contain an EEPROM that can be used to store this information; alternatively the information can be provided on the SD card. The following settings define where the information will be read from:

```
# Each display has a type and some associated data such as a VCOM voltage and
# waveform library. This can either be stored in the display EEPROM or on the
# SD card. The display type may also be manually specified with
# CONFIG_DISPLAY_TYPE.
#
# Set data_source to one of the following values in order to choose where the data
# should be read from:
# CONFIG_DISP_DATA_EEPROM_ONLY, < Only use display EEPROM
# CONFIG_DISP_DATA_SD_ONLY, < Only use SD card
# CONFIG_DISP_DATA_EEPROM_SD, < Try EEPROM first, then SD card
# CONFIG_DISP_DATA_SD_EEPROM < Try SD card first, then EEPROM
data_source CONFIG_DISP_DATA_EEPROM_SD
```


6.3.3 Configuration of I2C master

A number of components are configured and accessed via I2C. The following setting defines the device used as the I2C master:

```
# Default I2C master mode used with CONFIG_HWINFO_DEFAULT
# I2C_MODE_NONE, /* invalid mode */
# I2C_MODE_HOST, /* use the host */
# I2C_MODE_DISP, /* use SPI-I2C bridge on the display (S1D13541) */
# I2C_MODE_S1D13524, /* use SPI-I2C bridge on the S1D13524 */
# I2C_MODE_SC18IS6XX, /* not currently supported */
i2c_mode I2C_MODE_HOST
```

The code also includes a number of features and demonstrations that can be configured at compile time via the use of preprocessor directives in the `config.h` file.

6.3.4 Configuration of how hardware information is used

The Plastic Logic display interface boards (Raven, Hummingbird Z6/Z7) contain an EEPROM that can be used to store board-specific calibration data and other relevant information. The following settings define whether or not the code will use this information and whether or not to use a default if the information is not available:

```
/** Set to 1 to use the VCOM and hardware info stored in board EEPROM */
#define CONFIG_HWINFO_EEPROM 1
/** Set to 1 to use default VCOM calibration settings if HW info EEPROM data
* cannot be used (either not programmed, or hardware fault, or
* CONFIG_HWINFO_EEPROM is not defined). If set to 0, the system will not be
* able to work without valid EEPROM data. */
#define CONFIG_HWINFO_DEFAULT 1
```

6.3.5 Configuration of serial interface

A serial interface is supported via the USB port (the Parrot board is fitted with a TUSB3410 USB to serial port controller). Alternatively a FTDI active serial-to-USB cable can be plugged into a pin header on the Parrot board. The code can be configured to route all standard output to the serial port rather than back to the debugger. This allows debug output still to be seen when no debugger is attached. The following setting defines whether `stdout` and `stderr` are sent to the serial port or the debugger:

```
/** Set to 1 to have stdout, stderr sent to serial port */
#define CONFIG_UART_PRINTF 1
```

6.3.6 Power mode demonstration

The following setting can be used to configure a demonstration of power state transitions:

```
/** Set to 1 to use the power state transition demo rather than the slideshow */
#define CONFIG_DEMO_POWERMODES 1
```

6.3.7 Pattern demonstration

The following settings can be used to display a checker-board pattern of the specified size:

```
/** Set to 1 to use the pattern demo rather than the slideshow */
#define CONFIG_DEMO_PATTERN 1 /** Not intended for S049_T1.1 displays */
#define CONFIG_DEMO_PATTERN_SIZE 32 /** Size of checker-board */
```


6.4 SD Card Setup

The micro SD card for the processor board must be formatted as a FAT/FAT16 file-system (not FAT32). The SD card contents (initialisation data and images) can be retrieved from the Plastic Logic GitHub repository (https://github.com/plasticlogic/pl-mcu-sd-card.git). Unzip this archive and place the resulting files on the SD card so that the root directory of the file-system contains the folders `D107_T3.1`, `S040_T1.1`, etc. The supplied content provides a safe set of configuration data for each type of display. In order to obtain the best image quality the waveform binary file, `waveform.bin` (for S1D13541) or `waveform.wbf` (for S1D13524), and the text file `vcom`, containing the VCOM voltage in mV, must be replaced with data specific to the display used. These files are located at:

```
0:/<Display-Type>/display/waveform.bin
0:/<Display-Type>/display/waveform.wbf
0:/<Display-Type>/display/vcom
```

Place the micro SD card in the micro SD card socket on the processor board.

6.5 Running the Code

Once the code has been configured and built in Code Composer Studio, the resulting binary can be transferred to the Parrot board using the MSP-FET430UIF USB-JTAG programmer. Depending on the configuration, you should now be able to see one of the following: • A slideshow of stock images from the `0:/<Display-Type>/img` folder being shown on the display until execution is halted (with or without power sequencing). The slideshow will skip any files that do not have the extension ".pgm"

• A sequence of images defined by the `0:/<Display-Type>/img/slides.txt` file
• A checkerboard image

6.5.1 Error codes

If a fatal error occurs while running the code, the type of error is indicated via the status LED. Specifically the status LED will be flashed on/off a number of times, followed by a delay, after which the pattern will repeat. The error types are as follows (see also `assert.h`):

Flashes	Description
1	General error initialising GPIO
2	Error initialising MSP430 comms
3	Error reading HWINFO EEPROM. Could be a comms error or a content error
4	Error initialising I2C (Epson)
5	Error reading display information. Could be many errors (comms error, content error, missing or invalid file, etc). Also depends on preprocessor settings
6	Error initialising HVPSU. Most likely to be a comms error, but could indicate a failed PMIC
7	Error initialising EPDC. Could be many errors (comms error, EPDC failure, failed to load init code, failed on one of several commands needed to initialise the EPDC, failed to load waveform, etc)
8	Failed while running application. Multiple causes for this, depending on application that is running. Most likely failures are due to missing/invalid files or hardware problems such as POK or comms failure
9	Failed assert statement (debug use only)
10	Failed to read the config file
0 (off)	Undefined error
0 (on)	No error

Additional information relating to the error can be obtained by inspecting `stderr` via the debugger or the serial port (depending on how `CONFIG_UART_PRINTF` has been defined).

6.6 Toolchains

6.6.1 Code Composer Studio

Code Composer Studio has been used extensively during development of the code in conjunction with the MSP-FET430UIF USB/JTAG programmer. Both have proved to be extremely reliable in use. There is a free version of the tools which restrict the size of code they will generate to 16KB. The full version can be evaluated free for 90 days. The current configuration of the code is too large to fit within the 16K limit, however by removing some features, e.g. Fat file system support then the free version may be sufficient. A very useful feature of the IDE is the ability to use standard printf type functions and have the output displayed in a console window within the IDE. In order for this to work the amount of memory set aside for the stack and heap must be increased and the â€œcioâ€■ functionality must be enabled in the project build configuration. A small amount of source code in the platform common layer was taken from Plastic Logicâ€™s equivalent Linux drivers. The code uses anonymous unions extensively and in order to get the code to compile it was necessary to add a compiler flag (`--gcc`) to tell it to behave more like gcc.

6.6.2 msp430-gcc

There is an open source msp430 tool chain available â€“ msp430-gcc. Some work has been done to support this tool chain but the work is not yet complete. Much of the code compiles cleanly however there are some issues related to pragmas used to declare interrupt handlers. Full support for this tool chain will depend on customer demand.

7 Preparing Your Own Images

7.1 Image Format

For simplicity the code only supports image files in the PGM graphics file format. For details see: http://en.wikipedia.org/wiki/Netpbm_format .

Note
There are two different PGM formats - ASCII (magic number: P2) and binary/raw (magic number: P5). The code only supports the binary/raw format. This is a simple, uncompressed, file format that can be generated with GIMP or using the Python Imaging Library (PIL). Both GIMP and PIL are available for Windows and Linux. When displaying images as a slideshow (i.e. without a `slides.txt`), the image files are expected to match the full display size so that the contents can be transferred directly from storage to the display controller. In the case of the S049_T1.1 bracelet displays the pixel data must also be reordered (see Image Conversion Tools below).

When displaying images using a `slides.txt` sequence file the images can be any size up to the full display size, but must have a width that is exactly divisible by 2. The SD card content provided contains the original source PNG images which were used to create the PGM files.

7.2 Image Conversion Tools

The source code contains a python script, `tools/prepare_pgm.py`, which uses the Python Imaging Library (PIL) to support the translation of PNG files to PGM format. The script can also reorder the pixel data as required for S049_T1.1 displays. The script requires Python version 2.7.5 and a compatible version of the Python Imaging Library (PIL), and works in both Linux and Windows. Python 2.7.5 can be downloaded from the following URL: https://www.python.org/downloads/ For Windows, use the 32-bit or 64-bit 2.7.5 installer as appropriate for the host machine. For Linux, use either of the source tarballs for 2.7.5. Installation instructions can be found within the tarball. The Python Imaging Library can be found here: http://pythonware.com/products/pil For Windows, use the most recent "Windows only" PIL for Python 2.7. When installing PIL, ensure the destination directory is the same as the Python 2.7.5 installation directory. For Linux, use the most recent PIL source kit. Again, installation instructions can be found within the tarball. Execute the script from the command line in either operating system, passing the image to be converted as the first argument. If the target device is using a S049_T1.1 display, pass `--interleave` as the second argument in order to generate the correct pixel data ordering.

For example:
```
python prepare_pgm.py image.png --interleave
```
For the above example, the output will be a file called `image.pgm`. The output files should be copied to the SD Card in the img folder of the appropriate display type folder, e.g.:
`0:/S049_T1.1/img/image.pgm`

7.3 Sequence File

An optional plain text file named `slides.txt` can be put in the image directory `0:/<Display-Type/img>` to tell the software to run a specific sequence instead of simply going through all the images found. If the file is found, the software will use it; otherwise the standard slideshow will be run. This sequence supports regional updates, image compositing by copying areas of existing files and can fill rectangles with a uniform grey level. Then the waveform type and area coordinates are specified for each update, enabling more advanced operation of the system.

7.3.1 File format

The format of the file can be summarised with the following characteristics:

• each line corresponds to a single command

• each line is processed sequentially

• commands can not be nested and there is no flow control

• each line has a maximum length of 80 characters (fixed by buffer size in software)

• only ASCII characters can be used in the file

• line endings can be either DOS or Unix like

• each line is composed of values separated by commas and any number of spaces

• not all commands take the same number of arguments, so lines can have varying numbers of values

• a line starting with a hash sign `#` is a comment and is ignored by the software

• blank lines are allowed

• there is no limit to the length of the file other than what the file system infrastructure permits

The software will not keep more than one line in memory at a time, and it will automatically jump back to the beginning of the file when it has processed the last line to keep playing the sequence continuously. It is worth noting that copying areas of image files into the EPD frame buffer can take a significant amount of time compared to the duration of a display update. Drawing operations are separated from display updates, which take little time to start, so it is still possible to achieve some basic animation effects with appropriate sequencing of the drawing and display update commands.

7.3.2 Supported commands

update, WAVEFORM, UPDATE_MODE, LEFT, TOP, WIDTH, HEIGHT, DELAY

Update the display with the given `WAVEFORM` (see Waveform identifiers) with the `UPDATE_MODE` (see Update Modes) in the area starting with the (`LEFT`, `TOP`) pixel coordinates and the given `WIDTH` and `HEIGHT`. The software will wait until the update request has been processed by the controller, and then wait for `DELAY` milliseconds.

Note

`WIDTH` must be exactly divisible by 2 and the specified rectangle must not exceed the bounds of the display.

power, ON_OFF

Turn the display power either on or off based on the value of `ON_OFF`, which can be either `on` or `off`. When turning the power off, the software will wait for any on-going update to complete.

fill, LEFT, TOP, WIDTH, HEIGHT, GREY_LEVEL

Fill a rectangle starting with the (`LEFT`, `TOP`) pixel coordinates and the given `WIDTH` and `HEIGHT` with the given `GREY_LEVEL` which is a number between 0 and 15 - 0 being black and 15 white.

Note

`WIDTH` must be exactly divisible by 4 and the specified rectangle must not exceed the bounds of the display.

image, FILE, LEFT_IN, TOP_IN, LEFT_OUT, TOP_OUT, WIDTH, HEIGHT

Copy an area from an image file `FILE` starting to read from (`LEFT_IN`, `TOP_IN`) pixel coordinates into the EPD buffer at (`LEFT_OUT`, `TOP_OUT`) pixel coordinates with the given `WIDTH` and `HEIGHT`.

Note

`WIDTH` must be exactly divisible by 2 and the specified rectangles must not exceed the bounds of the image file or the display.

sleep, DURATION

Sleep for the given `DURATION` in milliseconds.

7.3.3 Example sequence

The following listing shows a sample sequence for S040_T1.1 400x240 displays:

```
# Fill the screen with white and trigger a refresh update
#
# x, y, w, h, gl
fill, 0, 0, 400, 240, 15
power, on
update, 2, 0, 0, 0, 400, 240, 50
power, off
# Load some image data in 4 different areas
#
# file, i_x, i_y, o_x, o_y, wid, hgt
image, 01_N.PGM, 290, 65, 290, 20, 100, 120
image, 06_N.PGM, 150, 50, 10, 10, 140, 180
image, 11_N.PGM, 150, 0, 155, 0, 130, 90
image, 13_N.PGM, 20, 20, 150, 150, 240, 80
# Update the same 4 areas with a small delay in between each
#
# waveform, update mode, left, top, wid, hgt, delay
power, on
update, 2, 0, 290, 20, 100, 120, 50
update, 2, 0, 10, 10, 140, 180, 50
update, 2, 0, 155, 0, 130, 90, 50
update, 2, 0, 150, 150, 240, 80, 50
power, off
```


7.3.4 Waveform identifiers

The following waveforms are always available in Plastic Logic's waveform libraries:

Waveform ID	Grey levels	Description	Length (ms) *
`2`	16	All pixels are updated.	670
`4`	2	All b&w pixels are updated.	250
`0`	2	Use only to wipe the screen when the image content is lost.	1300

* At typical room temperature. For full specification see the relevant display datasheet. They all have a unique numerical identifier which can be different in each waveform library. To get the identifier of a waveform for a given path string, use the function `pl_epdc_get_wfid()` (`pl/epdc.h`, `pl/epdc.c`) in your application.

7.3.5 Update modes

The following update modes are always available in Plastic Logic's waveform libraries:

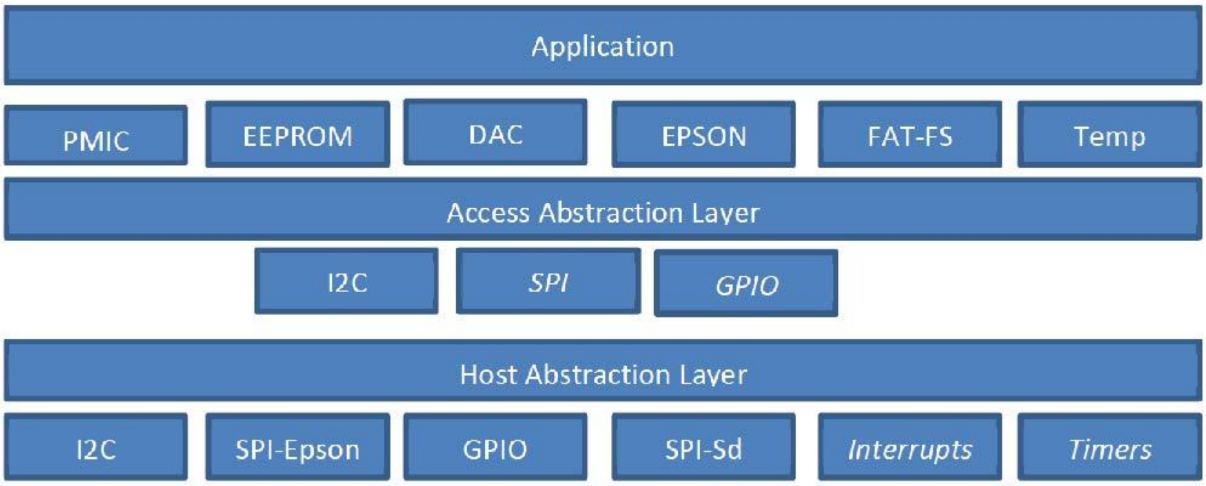
Update Mode	ID	Description
`Full`	0	All pixels are updated.
`Partial`	2	Only changing pixels are updated.

The update modes might be combined with all Waveform IDs except ID 0.

8 Code Structure

8.1 Overview

The diagram below shows an overview of the code base.



Things to note are:

1. The **Application** sits right on top of the common components. There is no layer that abstracts a complete display system that can be manipulated by calling methods on it.

2. The **Access Abstraction Layer** exists because the Epson controllers contain a number of resources, e.g. I2C master, SPI master, and on chip GPIOs that the Application layer may want to use. This abstraction layer allows the application to access either a host CPU resource or one contained in the Epson controller without needing to know its location once initialised. Currently only support for I2C is implemented.

3. The **Host Abstraction Layer** allows for porting to different CPUs, either members of the same family or different architectures. Interrupts and Timers are not mandatory for the sample code to work.

8.2 Platform Neutral Components

8.2.1 File System

The micro SD card uses a FAT/FAT16 file system for data storage (not FAT-32). In order to minimise code and data size the FatFs driver is configured to support Read-Only operations, to reuse memory aggressively and not to support long filenames. This has some small impact on access time and transfer speed for the data within files. Long filenames can be used when writing files to the SD card from a PC however the FatFs code can only use the 8.3 compatible filenames. These names can be displayed under Windows by entering `dir /x`

e.g.:
`21/05/2011 07:01 8,863,336 NVWGF2~1.DLL nvwgf2umx.dll`

SD Card path	Contents
`0:/<display-type>`	Root of the subtree for the selected display type
`0:/<display-type>/bin/Ecode.bin`	Epson controller initialisation file for display type

`0:/<display-type>/img/*.pgm`	Image files to be displayed
`0:/<display-type>/img/slides.txt`	Optional sequence file
`0:/<display-type>/display/vcom`	VCOM voltage for display
`0:/<display-type>/display/waveform.bin`	Waveform for the display (S1D13541)
`0:/<display-type>/display/waveform.wbf`	Waveform for the display (S1D13524)

The VCOM and waveform data for each display should be stored on the display's EEPROM where applicable (Type 19 displays have no EEPROM). The Plastic Logic reference code uses the data stored on the EEPROM by default and will search on the SD card if the EEPROM does not contain valid data. This behaviour can be changed by modifying the `CONFIG_DISP_DATA_xxx` preprocessor definitions in the config header file (`config.h`). For the best results, it is advisable to use the EEPROM-based data as this is tuned for each display.

8.2.2 EPDC API and Epson implementations

The `pl/epdc.h` header file defines an abstract interface to an E-Paper Display Controller implementation. There are currently two Epson implementations (S1D13524 and S1D13541), which internally share some overlap. This will generate the appropriate SPI data transfers and control various GPIOs to operate the EPDC. Utility functions provide higher level functions on top of command transfer layer. These functions support initialisation code and waveform loading, frame buffer RAM fill, image data transfer and power state transition control.

Note

Epson name the SPI data signals with respect to the controller. Hence DI (DataIn) => MOSI, and DO (DataOut) => MISO. To prepare the controller for operation it is necessary to send two files to it: 1. A controller initialisation file which customises the controller's behaviour to the type of display it is going to drive, e.g. resolution, driver configuration, clock timings. 2. A waveform data file which provides display specific timing information required to maximise the performance and image quality of a display.

8.2.3 Epson S1D135xx I2C Interface

The Epson controllers provide an SPI to I2C bridge that can be used to communicate with I2C peripherals instead of using an I2C interface on the host processor. The I2C interface abstraction defined in `pl/i2c.h` allows higher level software to communicate using either method once an interface has been initialised. The bridge results in a slower overall I2C data rate than a host I2C interface would achieve due to the overhead of communicating over SPI to manage the transfer. However, in normal use the amount of I2C traffic is limited to one-time device configuration.

Note

Some peripherals, the MAXIM 17135 PMIC specifically, have inbuilt timeouts which can be triggered when Epson command tracing is taking place and the Epson I2C bridge is in use.

8.2.4 Temperature Measurement

The accurate measurement of temperature is important to obtain the best image quality from the display. The temperature is used to select the correct waveform used to drive the display.

It is common for display updates to take longer at lower temperatures due to the physical attributes of the display media. The S1D13524 and S1D13541 have differing methods of handling temperature measurement. These are exposed in the code as “modes” (`pl_epdc_temp_mode` in `pl/epdc.h`):

1. **Manual** – The application software will obtain the temperature from some other component, e.g. the PMIC and pass it to the controller.

2. **Internal** – The display controller will use its built-in temperature sensor, if it has one, to measure the temperature. The S1D13541 controller contains such a temperature sensor, which requires an external NTC thermistor to be fitted (as shown on the Z6 and Z7 reference schematics).

3. **External** – The display controller will communicate directly with an LM75-compatible I2C temperature sensor to obtain the temperature.

To trigger the acquisition or processing of temperature data the controller's `update_temp()` function is called (either `s1d13524_update_temp()` or `s1d13541_update_temp()`). On completion a new temperature will be in effect. On the S1D13541 controller an indication that the waveform data must be reloaded is given if the temperature measured has moved outside the range of the currently cached waveform data. Currently the Internal mode is implemented for the S1D13541 and the External mode is implemented for the S1D13524. The code contains appropriate hooks for implementing the Manual mode if required.

8.2.5 VCOM Calibration

The accurate setting of the VCOM voltage is essential to obtaining the best image quality from the display. Each display has associated with it a VCOM voltage that must be used – specified in millivolts. In order to translate from mV to the required VCOM DAC value a software component takes the requested VCOM value and the power supply calibration information and returns a value to be written to the DAC register. The calibration data is determined by measuring a sample of power supplies using a defined calibration procedure. The output of the calibration procedure must be made available to the VCOM software module when it is initialised (`vcom_init()` in `vcom.c`). The display interface boards either store this data in an EEPROM on the board or it is measured once and stored in the code. The VCOM calibration procedure is described in the document “How to integrate VCOM calibration” available from Plastic Logic.

8.2.6 Putting it all Together

The source code contains examples of how to drive a number of different display interface boards. The `main.c` file contains hardware definitions and the `main_init()` function which goes through a top-level initialisation sequence. This is common to all Plastic Logic reference hardware combinations. It calls functions in `probe.c` to determine any run-time configuration and initialise the software and hardware accordingly. When porting to a specific product design, typically the `main_init()` function and associated hardware definitions (i.e. GPIOs) would be tailored to only take care of the hardware features available on the product. The `probe.c` functions are here mainly for run-time dynamic configuration, which may not be applicable to a fixed and optimised product so initialisation function calls may be typically be picked from `probe.c` and called directly in `main_init()`.

8.3 Host Abstraction Layer

The host abstraction layer isolates the platform neutral code from the underlying platform hardware. The abstraction layers are kept as self-contained and thin as practical. While interrupts and timers are listed their availability is not required to create a working system.

8.3.1 Host GPIO Interface

The GPIO interface provides a way to reserve and define a GPIO pin on the host processor at run time. On small microcontrollers pins are typically either GPIOs or connected to a single special purpose hardware unit e.g. an I2C unit. Some, or all, of the GPIOs supported may be able to generate interrupts. The GPIO interface records which GPIOs are already defined but not the mode in which they are configured. This allows the code to trap errors where a pin is defined multiple times, or used before being defined. GPIO pins are typically used to control the power sequence hardware and manipulate signals in the serial and parallel interface to the Epson controller.

8.3.2 Host I2C Interface

The host I2C interface provides access to an I2C interface physically attached to the host processor. Only a single I2C interface is supported by the code. A host I2C interface may not be required if the system is configured to use the Epson SPI-I2C bridge feature instead. Examples of devices connected to I2C include the HVPMIC, temperature sensors, and EEPROMs.

8.3.3 Host SPI Interface – Epson

The host SPI-Epson interface provides access to an SPI interface that is connected to the Epson controller when it is operating in serial interface mode. On short cables this interface has been operated at 20MHz successfully. In general the Epson controller should be placed on its own SPI bus due to the need to keep the chip selected for the entire duration of the image data transfer operation which may be up to 1MB.

8.3.4 Host SPI Interface – SD Card

The host SPI-SDCard interface provides access to an SPI interface that is connected to the SD Card. The SD Card is operated at 20MHz. If additional hardware is available in the host processor the SD Card could be operated in 4 bit parallel mode for improved data transfer speed.

8.3.5 Host Interrupt Interface

The interrupt interface supports the processing of interrupts. The code currently does not use interrupts but the first usage will be for notifying the code that the Epson is ready to accept a new command by the assertion of the HRDY line. The abstraction is still to be defined

8.3.6 Host Timer Interface

The timer interface provides platform specific timer implementations. Currently delays are coded as busy loops. A more power efficient mechanism will follow in a future release.

8.4 MSP430 Specific Host Interfaces

8.4.1 GPIO Interface

This is the reference implementation for the GPIO host interface and can be found in `msp430/msp430-gpio.c`. It supports the configuration of all features on all pins that can be configured. It is only possible to configure one pin at a time in a port. It is not possible to define the configuration of multiple pins in a port with one call – e.g. when defining an 8 bit bus as output or input. The code attempts to verify the request as much as it can. Much of the error checking code can be disabled once the porting process to a new platform has been completed and the platform configuration is stable.

8.4.2 I2C Interface

A single I2C interface is supported. I2C is only supported in USCI modules and the chosen UCSI module is defined in the `msp430/mlsp430-i2c.c` source file by setting the macros `USCI_UNIT` and `USCI_CHAN` as required. The code will then reconfigure itself to reference the correct I2C unit. In addition to specifying which UCSI module to use the I2C SDA and SCL pins need to be connected to the USCI unit by defining the appropriate pins as `PL_GPIO_SPECIAL` in the `pl_gpio_config_list()` call.

8.4.3 SPI Interface – Epson

SPI is supported in both USCI_A and USCI_B modules and the chosen USCI module is defined in the `msp430/msp430-spi.c` source file by setting the macros `USCI_UNI` and `USCI_CHAN` as required. The code will then reconfigure itself to reference the correct SPI unit. In addition to specifying which USCI module to use the SPI_CLK, SPI_MOSI and SPI_MISO pins need to be connected to the USCI unit by defining the appropriate pins as `PL_GPIO_SPECIAL` in the `pl_gpio_config_list()` call. Note that it is possible to use both the USCI_A and USCI_B units, i.e. USCI_A0 and USCI_B0 are physically different hardware units. A single SPI interface is supported for Epson controller communications. Multiple controllers can be connected to this bus and are selected using their chip select lines as required. This interface runs at 20Mbps reliably. Due to the need to keep the Epson chip selected for the duration of the image data transfer the Epson controller must be placed on a separate bus to the SD card so that multiple blocks can be read from the SD card.

8.4.4 SPI Interface – SD Card

SPI is supported in both USCI_A and USCI_B modules and the chosen USCI module is defined in the `msp430/msp430-sdcard.c` source file by setting the macros `USCI_UNI` and `USCI_CHAN` as required. The code will then reconfigure itself to reference the correct SPI unit. In addition to specifying which USCI

module to use the SPI_CLK, SPI_MOSI and SPI_MISO pins need to be connected to the USCI unit by defining the appropriate pins as `PL_GPIO_SPECIAL` in the `pl_gpio_config_list()` call. Note that it is possible to use both the USCI_A and USCI_B units. i.e. USCI_A0 and USCI_B0 are physically different hardware units. A single SPI interface is supported for transferring data from the micro SD card slot. This interface runs at 20Mbps reliably.

8.4.5 UART Interface

UART mode is supported in the USCI_A module and the code handling this can be found in the `msp430\msp430-uart.c` source file. In the sample code, the UART interface is used only to handle `stderr` and `stdout`, and then only if `CONFIG_UART_PRINTF` is defined (in `config.h`). In Code Composer Studio it is not possible simply to override putc() and puts(), and instead a device has to be registered (see `msp430_uart_register_files()`).

8.4.6 Porting the Existing Code to another MSP430 Processor

Porting the existing code to a design which requires a different pin out is relatively straightforward. The necessary configuration information is mainly contained in the `main.c` file. To reconfigure the reference code follow the sequence below:

1. Determine which USCI units will be used in the new configuration. Ensure the unit is suitable for its intended purpose

2. Determine which pins are associated with the chosen USCI units

3. Determine which pins will be used for the Epson SPI signals HRDY, HDC, and RESET

4. Determine which pin(s) will be used for the Epson SPI chip select

5. Determine which pins may be necessary to control the power supplies

6. In each of the `msp430/msp430-spi.c`, `msp430/msp430-sdcard.c`, `mps430/msp430-i2c.c` and `msp430/msp430-uart.c`

a. Define `USCI_UNIT` and `USCI_CHAN` as required b. Modify the definitions for the pins so they match the chosen UCSI unit, e.g.:

```
#define USCI_UNIT B
#define USCI_CHAN 0
// Pins from MSP430 connected to the SD Card
#define SD_CS MSP430_GPIO(5,5)
#define SD_SIMO MSP430_GPIO(3,1)
#define SD_SOMI MSP430_GPIO(3,2)
#define SD_CLK MSP430_GPIO(3,3)
```

7. In `main.c`, define the Epson SPI interface signals, e.g.:

```
// Remaining Epson interface pins
#define EPSON_HDC MSP430_GPIO(1,3)
#define EPSON_HRDY MSP430_GPIO(2,7)
#define EPSON_RESET MSP430_GPIO(5,0)
```

8. In `main.c`, define the power control and Epson chip select pins, e.g.:

```
#define B_HWSW_CTRL MSP430_GPIO(1,2)
#define B_POK MSP430_GPIO(1,0)
#define B_PMIC_EN MSP430_GPIO(1,1)
#define EPSON_CS_0 MSP430_GPIO(3,6)
```

Recompile the code and it has now been retargeted to the new pin assignments.

9 Supported Hardware

9.1 Hardware Components

This section lists the hardware components commonly found on boards intended to drive Plastic Logic displays that require software drivers.

9.1.1 Maxim 5820 DAC

The 5820 DAC is a general purpose I2C 8bit DAC used to set the VCOM voltage on some boards. It can be turned off to save power. The need for an external DAC has largely been removed from new designs by the ability to use the VCOM DAC provided in the PMIC instead.

9.1.2 Microchip EEPROMs

The code supports I2C EEPROMs up to 64KB in size. The code currently supports two I2C EEPROM types:

1. **24LC014 –** this is a small 128B EEPROM fitted to later display interface boards and is used to store power supply calibration data. This permits accurate VCOM voltages to be achieved when the display interface board is swapped. It also stores other hardware configuration information.

2. **24AA256 –** this is a 32KB EEPROM found on some display types. It is intended to store waveform information so that the necessary information to drive a display travels with the display. This allows the system to ensure the correct waveform information is used for the display. Since waveforms can exceed 32KB in size, the data stored on this EEPROM is compressed using the LZSS compression algorithm. EEPROM types can be added by extending the table that defines the device characteristics (in `i2c-eeprom.c`) and extending the enumeration of EEPROM types (in `i2c-eeprom.h`).

9.1.3 LM75 Temperature Sensor

The LM75 temperature sensor is a configurable I2C temperature sensor that can measure temperature autonomously at programmable intervals. It can be used when the temperature measuring facilities of the PMICs cannot be used for some reason. The measured temperature register can be read automatically by the Epson controllers.

9.1.4 Maxim MAX17135 HVPMIC

The Maxim PMIC is used on boards primarily intended to drive the 10.7” displays. Its key features are:

- I2C interface for configuration of power sequence timings
- Hardware signals for PowerUp/Down, PowerGood and PowerFault
- I2C commands for PowerUp/Down and power supply monitoring
- Inbuilt 8bit VCOM DAC
- Inbuilt LM75 compatible temperature sensor with automatic temperature sensing

9.1.5 TI TPS65185 HVPMIC

The TI PMIC is used on boards intended to drive the small displays. Its key features are:

• I2C interface for configuration of power sequence timings

• Hardware signals PowerUp/Down, PowerGood and PowerFault

• I2C commands for PowerUp/Down and power supply monitoring

• Inbuilt 9bit VCOM DAC

• Inbuilt LM75 compatible temperature sensor with on demand temperature sensing.

9.2 Epson Controllers

Epson have a range of controllers designed to support the output of images onto electrophoretic displays (EPD). The controllers differ in the size of display they can support, whether they have external or internal frame buffer memory, on-board or external power supplies and support for colour displays. The controllers can be accessed via SPI or a 16-bit parallel data bus. In addition to the main EPD functionality the controllers contain a varying collection of useful hardware units that may be required in a system fitted with an electrophoretic display. For example, an I2C master, SPI master, GPIO ports, and internal temperature sensor. Which options are available will ultimately depend on the controller selected and how it is connected to the display and other system components. The code supports the Epson **S1D13524** and **S1D13541** controllers in various configurations. The S1D13524 controller supports large (up to 2560x2048 greyscale pixels or 2560x2048 RGBW colour sub-pixels) displays and is fitted to a circuit board with its external SDRAM. The S1D13541 controller supports smaller displays (up to 854x480 pixels greyscale) and is physically bonded to the display module.

9.2.1 Power State Management Epson S1D13541

The Epson S1D13541 controller can be configured to one of several power states; helping to minimise power use when appropriate.

These power states are:

• **Power Off**

• Clock chip disabled

• 3V3 power to S1D13541 disabled

• **Standby**

• Can be set from SLEEP or RUN mode

• Clock chip enabled

• Power save status bit set to 0

• Source/gate driver powered off

• **Run**

• Can be set from SLEEP or STANDBY mode

• Clock chip enabled

• Power save status bit set to 1

• Source/gate driver powered on

• **Sleep**

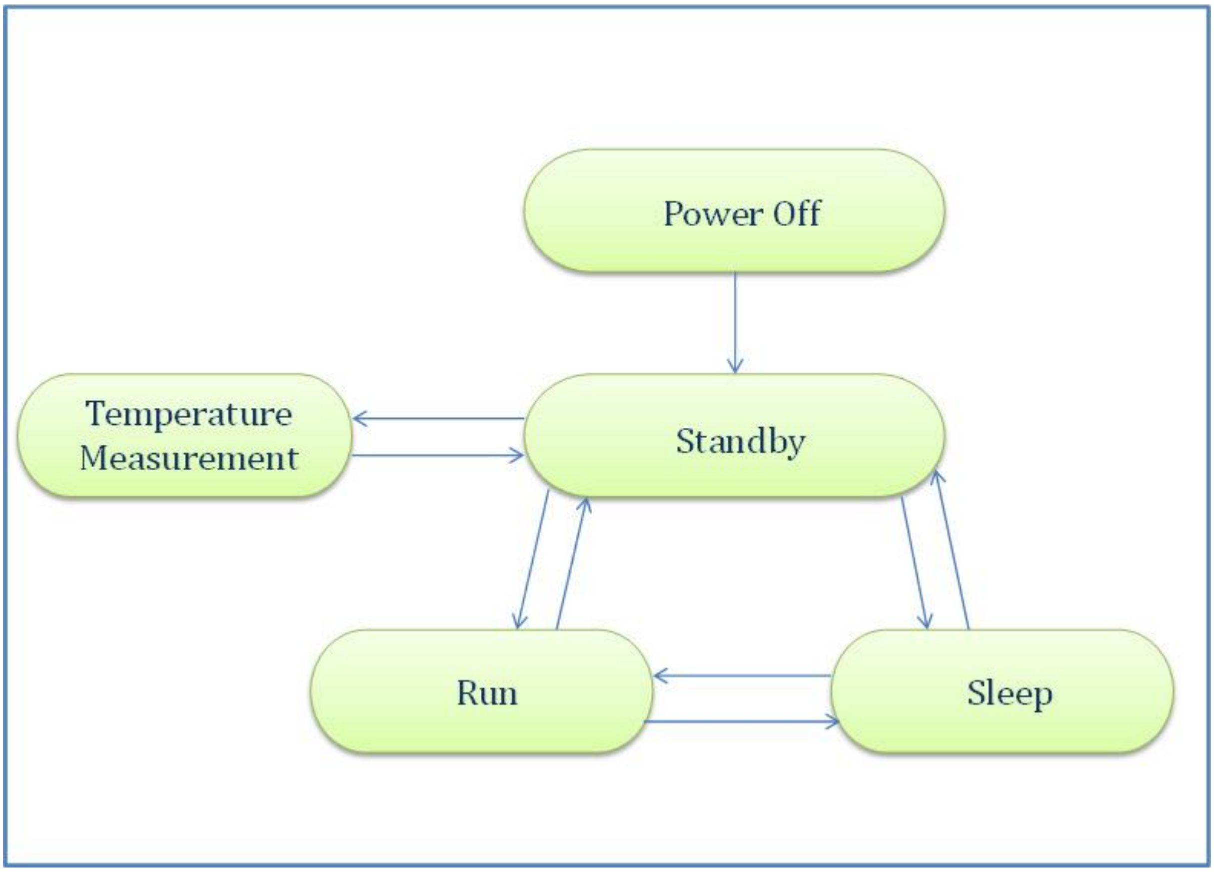
• Can be set from RUN or STANDBY mode

• Clock chip disabled

• Source/gate driver powered off

• Power save status bit set to 0

The figure below shows the possible power state transitions.



Below is a breakdown of the actions that must be taken for each of the power state transitions.

9.2.1.1 Run -> Standby

1. STBY command (CMD(0x04), no parameters) issued to Epson controller
2. Wait for HRDY = 1

9.2.1.2 Sleep -> Standby

1. Set CLK_EN GPIO true to re-enable clock
2. Set REG[0x0006] bit 8 to 1 for normal power supply
3. STBY command (CMD(0x04), no parameters) issued to Epson controller
4. Wait for HRDY = 1

9.2.1.3 Run/Standby -> Sleep

1. SLP command (CMD(0x05), no parameters) issued to Epson controller
2. Wait for HRDY = 1
3. Set REG[0x0006] bit 8 to 0 for minimum power supply
4. Set CLK_EN GPIO to false to disable clock

9.2.1.4 Standby -> Run

1. RUN command (CMD(0x02), no parameters) issued to Epson controller
2. Wait for HRDY = 1

9.2.1.5 Sleep -> Run

1. Set CLK_EN GPIO to true to re-enable clock
2. Set REG[0x0006] bit 8 to 1 for normal power supply
3. RUN command (CMD(0x02), no parameters) issued to Epson controller
4. Wait for HRDY = 1

9.2.1.6 Run/Standby/Sleep -> Power Off

1. SLP command (CMD(0x05), no parameters) issued to Epson controller 2. Set CLK_EN GPIO to false to disable clock
2. Set 3V3_EN GPIO to false to disable 3V3 power supply

Note

Any data in the image buffer will be lost when going into off mode. If the current displayed image is to be retained when powering back up, the contents of the image buffer should be copied to a suitable location (e.g. an SD card) before continuing with the power off. This image can then be loaded back into the image buffer when coming out of power off mode.

9.2.1.7 Power Off -> Standby

Note

After each of the following commands, the host should wait for HRDY to be 1 before continuing.

1. Set 3V3_EN GPIO to true to enable 3V3 power supply
2. Set CLK_EN GPIO to true to enable clock
3. INIT_CMD_SET command (CMD(0x00 + Epson Instruction Code Binaries)) issued to Epson controller
4. INIT_SYS_STBY command (CMD(0x06, no parameters) issued to Epson controller
5. Set Protect Key Code to REG[0x042C] and REG[0x042E]
6. BST_WR_MEM command (CMD(0x1D) + Waveform Storage Address) to start loading waveform data
7. WR_REG command (CMD(0x11), 0x154 + Waveform) to load waveform data
8. BST_END_MEM command (CMD(0x1E), no parameters) to end loading waveform data
9. RUN command (CMD(0x02), no parameters) issued to Epson controller
10. UPD_GDRV_CLR command (CMD(0x37), no parameters)
11. WAIT_DSPE_TRG command (CMD(0x28), no parameters)
12. S1D13541 is initialised into known state

The EPD Panel and Image Buffer should now be initialised to a known state; either the standard white initialisation waveform, or image data copied to a safe medium before power off was called.

9.2.1.8 Power State Demo

A power state demo can be launched using the Plastic Logic reference code by including the following in

`config.h`:

```
#define CONFIG_DEMO_POWERMODES 1
```

This demo will transition through the power states with the following behaviour:

- Go into RUN mode
- Load an image into the image buffer
- Update the display
- Go into SLEEP mode for 2 seconds
- Go into STANDBY mode for 2 seconds
- Go into RUN mode
- Update the display (with image data retained from the previous update)
- Go into POWER OFF mode (CLKI and 3V3 disabled) for 2 seconds
- Go through power on initialise

9.3 Plastic Logic Evaluation Hardware

9.3.1 Display Types

The code supports the following Plastic Logic display types. Additional displays will be supported as required.

Display Type	Resolution	Notes
D107_T2.1	1280x960	External Controller Requires the Mercury display connector board
D107_T3.1	1280x960	External Controller Requires the Sojus7.2 or Sojus 7.3 display connector board
S047_T2.1	800x450	External Controller Requires the Helios display connector board
S040_T1.1	400x240	Bonded Controller 4.0" @115ppi
S049_T1.1	720x120	Bonded Controller 4.9" @150ppi
S079_T1.1	768x192	External Controller Requires the Hermes 2.0 display connector board
S115_T1.1	1380x96	External Controller Requires the Hermes 2.0 display connector board
D054_T1.1	680x155	Bonded Controller 5.4" @130ppi

9.3.2 Parrot - MSP430 Processor Board

The Parrot board docks with the Ruddock2 motherboard to provide access to the display interfaces. It has the same form factor and connector pin out as a BeagleBone allowing the processors to be easily swapped for evaluation or development work. The Parrot board can also be used without the Ruddock2 by connecting it directly to the Z6, Z7 or Raven boards via the 24-pin "serial" interface.

The board has the following features:

- MSP430F5438A, clocked at 20MHz
- A 32KHz oscillator for low power operation
- micro SD card socket
- On-board reset switch
- JTAG programming header (an adapter may be required to mate with the MSP-FET430UIF programmer)
- All 100 processor pins available on debug headers
- On-board power regulation and power socket (can also be powered from USB)
- The board has 1 LED for power good and another connected to a pin on the processor for status indication
- 24-pin "serial" interface to Z6, Z7 and Raven boards
- Provision for an SPI daisy-chain of MSP430 boards using 2 SPI channels (upstream and downstream)

9.3.3 Ruddock2

The Ruddock2 board is a motherboard that sits between a processor board, currently either BeagleBone or a microcontroller (MSP430) and the display interface board. It provides signal routing from the processor to the interface connectors together with some LEDs and switches that can be used to configure the software or create a user interface. The board allows the Epson serial, parallel and TFT interfaces to be used depending on the interface board and controller selected. The processor board can disable all power from the Ruddock2 under software control allowing hardware components, e.g. display interface boards, to be safely exchanged. The board has a 128B EEPROM which can be used as non-volatile storage if required.

9.3.4 HB Z6/Z7

The Z6 and Z7 are intended to drive a S1D13541 small display controller which is bonded to the display itself. The boards differ in the display connector used. The Z7 board is used to drive the S049_T1.1 bracelet display and the Z6 is used to drive all other Plastic Logic small displays. The boards have a TI PMIC and a 128B EEPROM for storing power supply calibration data. The VCOM DAC in the PMIC is used to set the VCOM value for the display. All versions of the Z7 board have the provision to turn off 3V3 power to the display controller; this feature is absent on version 6.1 of the Z6 but has been introduced as of version 6.3, along with the ability to control the clock enable and PMIC wake signals.

9.3.5 Raven

The Raven board is designed to drive 10.7” D107_T2.1, D107_T3.1 and S047_T2.1 displays. The board has an Epson S1D13524 controller and associated memory, a Maxim PMIC, a 128B EEPROM for storing power supply calibration data and an LM75 temperature sensor. The VCOM DAC in the PMIC is used to set the VCOM value for the display. The board has input connectors that allow it to be controlled via the Serial host interface (SPI) or Parallel host interface. Additionally the signals to support data transfer using the TFT interface are available. The board has 5 test pads which bring out the 5 Epson GPIO pins found on the S1D13524.

10 Relevant Data Sheets and Additional Resources

10.1 Plastic Logic Documents

Detailed schematics and design documents are available from Plastic Logic for all of the boards supported by this software. Other relevant documents are:

Electronics for small displays

An overview of the electronics required to drive a small displays

Plastic Logic Software Manual

A detailed description of the EEPROM data formats and some associated software tools

How to integrate VCOM calibration

A detailed description of calibrating and setting the VCOM voltage

10.2 Third Party Datasheets and Resources

TI TPS65185 HVPMIC

http://www.ti.com/product/tps65185

Maxim MAX17135 HVPMIC

http://datasheets.maximintegrated.com/en/ds/MAX17135.pdf

LM75 temperature sensor

http://www.ti.com/lit/ds/snos808o/snos808o.pdf

Maxim MAX5820 DAC

http://datasheets.maximintegrated.com/en/ds/MAX5820.pdf

Microchip 24LC014 EEPROM

http://ww1.microchip.com/downloads/en/DeviceDoc/21809G.pdf

Microchip 24AA256 EEPROM

http://ww1.microchip.com/downloads/en/DeviceDoc/21203Q.pdf

Epson S1D13524 EPDC (NDA required for full datasheet)

http://vdc.epson.com/index.php?option=com_docman&task=doc_download&gid=1768&Itemid=99

Epson S1D13541 EPDC (NDA required for full datasheet)

no public datasheet

TI MSP430 tools and software

http://www.ti.com/lsds/ti/microcontroller/16-bit_msp430/tools_software.page

11 Appendix A - License Text

The license text for third party components is reproduced below:

11.1 FatFs

```
/*---------------------------------------------------------------------------/
* / FatFs - FAT file system module R0.08a (C)ChaN, 2010
* /---------------------------------------------------------------------------/
* / FatFs module is a generic FAT file system module for small embedded systems.
* / This is a free software that opened for education, research and commercial
* / developments under license policy of following terms.
* /
* / Copyright (C) 2010, ChaN, all right reserved.
* /
* / * The FatFs module is a free software and there is NO WARRANTY.
* / * No restriction on use. You can use, modify and redistribute it for
* / personal, non-profit or commercial products UNDER YOUR RESPONSIBILITY.
* / * Redistributions of source code must retain the above copyright notice.
* /
* /---------------------------------------------------------------------------/
*/
```

11.2 Texas Instruments

```
/* --COPYRIGHT--,BSD_EX
* Copyright (c) 2012, Texas Instruments Incorporated
* All rights reserved.
*
* Redistribution and use in source and binary forms, with or without
* modification, are permitted provided that the following conditions
* are met:
*
* * Redistributions of source code must retain the above copyright
* notice, this list of conditions and the following disclaimer.
*
* * Redistributions in binary form must reproduce the above copyright
* notice, this list of conditions and the follo wing disclaimer in the
* documentation and/or other materials provided with the distribution.
*
* * Neither the name of Texas Instruments Incorporated nor the names of
* its contributors may be used to endorse or promote products derived
* from this software without specific prior written permission.
*
* THIS SOFTWARE IS PROVIDED BY THE COPYRIGHT HOLDERS AND CONTRIBUTORS "AS IS"
* AND ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO,
* THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR
* PURPOSE ARE DISCLAIMED. IN NO EVENT SHALL THE COPYRIGHT OWNER OR
* CONTRIBUTORS BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL,
* EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO,
* PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS;
* OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY,
* WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR
* OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS SOFTWARE,
* EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.
*
******************************************************************************
*/
```