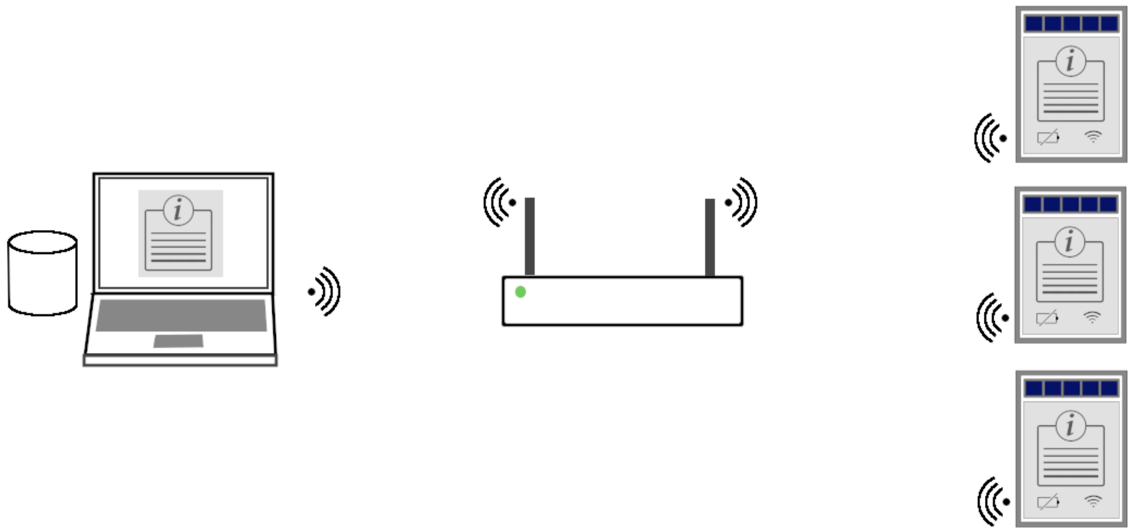
Solar Powered Electronic Paper Display

Wireless, battery-less, electronic paper displays ranging in size from 4.5” to 12.5”, powered by a solar cell-based power supply.

The display’s image may be updated several times per day from a local or remote web-server and is retained without power.



Electronic Paper Displays Updated over WiFi

Required Product Features

- Two or three colour, medium resolution displays ranging in size from 4.5” to 12.5”.
- Ability to continue to display image without power, following image update.
- Configurable from a hand held device using a web browser.
- Image update within one minute.
- Encrypted images.
- Use of standard WiFi connection allowing multiple displays on a local network.
- Image database accessible via a URL.
- Utilities that manage images in the image database.

Key Components

- Electronic Paper (E-Ink) display.
- Display electronics.
- Solar power supply with solar cells.
- Display housing.
- Server-based image database.

Research

The research focused on the following key areas:

- Energy requirements
- Type of display
- Solar power supply
- WiFi communications
- Display configuration
- Office web server
- Image encryption

Energy Requirements

The energy required by the display was separated into three phases:

- Configuration
- Image update
- Sleep mode

The anticipated major energy consumers were:

1. Communications via WiFi with the office web server.
2. Image decryption.
3. Image display.

Configuration

The solar power supply was unlikely to be able to provide the energy requirements for the configuration phase as this would require the display to be communicating with the set up device using its own mini web server.
Therefore, a USB connector is included in the display to allow an external power source to be used for the configuration.

Image Update

Updating the display's image is the critical energy consumer, since the display would be powered only via the solar power supply.
The larger the image file, the longer the display's WiFi would be continuously active. Once the file has been transferred, the WiFi can be switched off, saving power.
However, the display's processor will still be required to decrypt the image and then transfer it to the display itself.
The display type is important. The higher the resolution and the more colours, the longer the required time for update.

Sleep Mode

When a configured display is not updating, it should be sleeping in ultra low power mode. This allows the solar cells to recharge the power supply.

Summary

In order for the display to be solar-powered, it needs to operate in “burst” mode when updating and “recharging” mode when sleeping.
The solar power supply must be matched to the display resolution and number of colours.

Display Type

The electronic ink displays lend themselves to this application as they do not require power following image display. They are also light and thin.
Although they lack any backlighting, the position of the display, facing daylight, means that their reflective background should enable the image to be viewed with sufficient contrast.

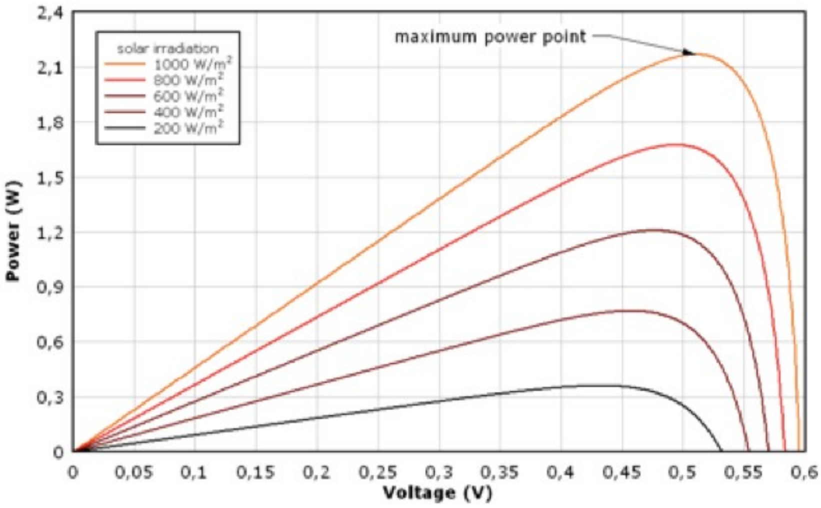
Solar Power Supply

The power supply has the following components:

1. Solar panels, containing an array of solar cells.
2. Overvoltage protection.
3. Super capacitor(s).
4. Voltage regulator.

Solar Panels

The newer mono-crystalline photovoltaic cells are suitable as they are more efficient than the amorphous types.
The peak voltage output of the panels needs to exceed that of the power supply output by a factor of at least two. This is because of the change in voltage output from the cells under different lighting conditions.



Graph showing solar cell power output for different irradiation levels

The above graph shows the wide variation in solar cell power output for outdoor light levels. Note that indoors, light levels may be well below 100 W/m^2.

Over voltage Protection

A simple zener diode with a current rating of twice the solar panels maximum output.

Super Capacitors

Essentially energy storage devices, the larger their value, the more energy they can store.
Rated voltage, size, cost and long term reliability are the determining factors in their selection.
One advantage of using super capacitors is their ability to supply a (relatively) large current very quickly.

Voltage Regulator

The voltage regulator converts the voltage output of the super capacitor stage into the voltage used by the display and its associated electronics. It must be rated well above the maximum current used by the display.

WiFi Communications

Using the 802.11g/n WiFi enables larger image files to be transferred between the office web server and the display using standard WiFi hubs.This also ensures that existing WiFi networks can be used to update the displays.

The typical data rate for 802.11g is 20 Mbps and 802.11n 40-50 Mbps.

Display Configuration

When the display is in configuration mode, it acts as a WiFi access point to which another wireless device (laptop, tablet or phone) can connect. The display's configuration web pages are accessed and used to set up the display. For example, setting the access credentials of the image server's WiFi network.
When configuration is complete, the display reverts to image update/sleep mode.

Office Web Server

The image database is accessed via the office web server.
The open source Apache web server is widely used and runs on a number of different platforms.An https (end to end encrypted) connection overloads the display microcontroller and therefore consumes too much energy and time.
Therefore, the standard http connection together with encrypted image files is a workable compromise.

Image Encryption

An encryption/decryption system designed for low power systems was selected. Since a symmetric key is used, the key must be changed for each image transfer.

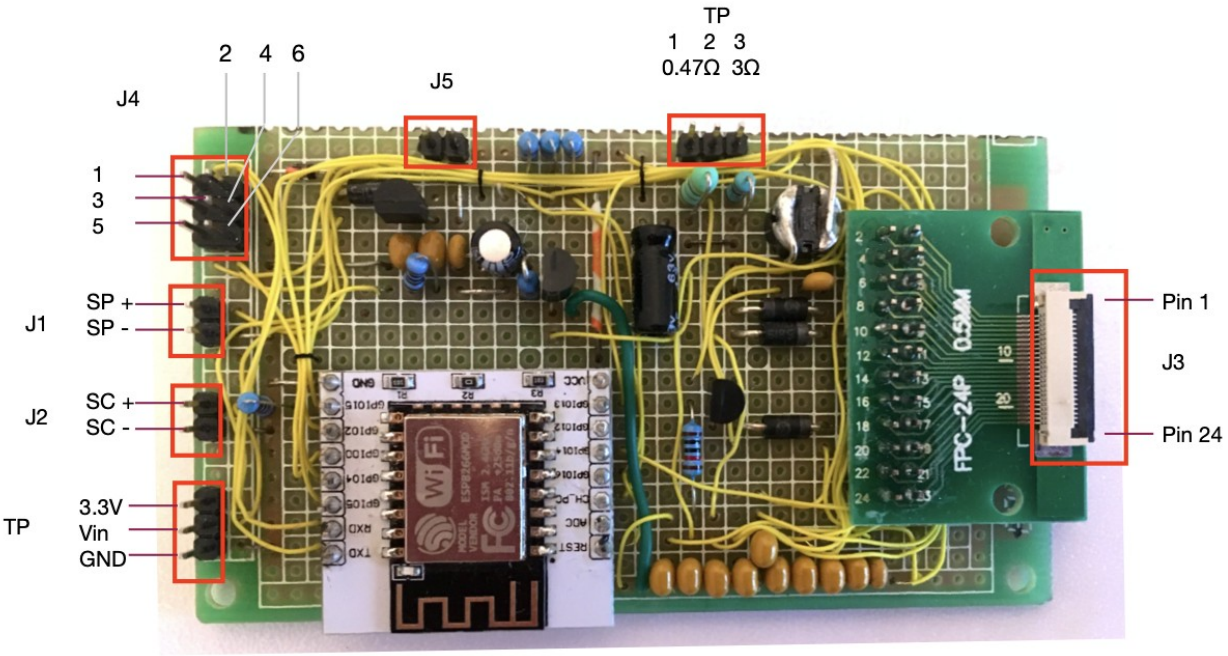
Prototype

The prototype consisted of a server running the Apache web server and a display controlled by an ESP8266 module.
The ESP8266 module has built in WiFi and 4Mb of flash memory.
The solar power supply used two small solar cell panels and a super capacitor.

Display Electronics

An extract from the prototype's hardware specification:

Prototype board with 24-way FPC connector. Allows testing of different display sizes.



J4 Pinouts

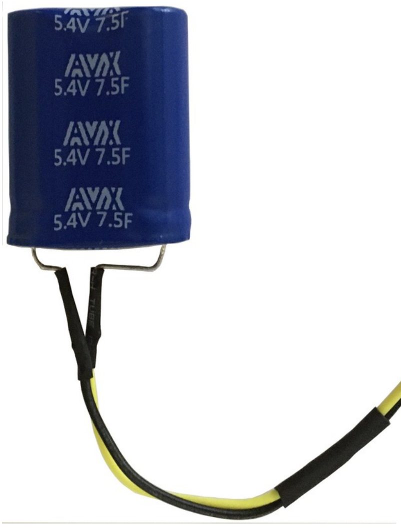
Pin	Function	Header Colour	Programmer Colour
1	Tx	Blue	Purple
2	Rx	Purple	Yellow
3	NC		
4	GND	White	Green
5	Reset	Black	Blue
6	GPIO0	Brown	Grey

The connectors for the solar panel J1 (SP) and super capacitor J2 (SC) are shown, together with the header for the USB-based programmer, J4.At the right hand side of the board is the 24-way FPC connector, J3, that goes to the E-Ink display.
Positioned at the lower left of the board is the ESP8266 module. The WiFi antenna is clearly visible.

The board measures approximately 5cm x 9.5cm and is small enough to fit inside a prototype display housing.

The board was used to test different sizes of display from 2.13” to 4.5”, all connected using the same 24-way FPC ribbon cable.

Super Capacitors



Super Capacitor

***Simulating a 12.5*” Display - Calculation of Super Capacitor Value**

The 12.5” display will be the largest display offered. Therefore the solar power supply must be rated to supply the energy required to update the entire display.

Using modified code from the 2.9” display, a large file was downloaded, decrypted and “displayed”. The display was simulated by updating the 2.9” display 34 times.

Using a stopwatch and an ammeter, the times and average currents where recorded for each stage of the display update cycle:

1. Connection to WiFi network.
2. Download encrypted image file.
3. Decryption of image file.
4. Display of image file.
5. Deep sleep.

Results:

Stage	**Average current (mA)**	**Duration (S)**
Connect to WiFi network	150	10
File download	75	30
Decryption	75	55
Display	75	55
Sleep	0	?

Total duration: 150 seconds.

Energy consumed: 3.34 mWH. (Using 3.3V as the display electronics regulated voltage).

The capacitance required to supply the energy is calculated using the formula below:

t = (C x (Vmax - Vmin))/I

Vmax = 5.1V (Maximum voltage from solar power supply)
Vmin = 3.3V (Minimum voltage from solar power supply)

t = (C x 1.8)/I

From the results table, there are two average currents, 150 mA and 75 mA. Using the durations for each current, t_1 and t_2 and re-arranging the above formula:

$C = (t_1 \times I_1) / 1.8 + (t_2 \times I_2) / 1.8$

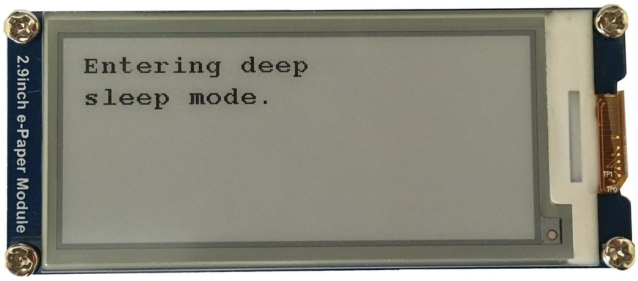
Substituting $t_1 = 10$, $I_1 = 0.15$
$t_2 = 140$, $I_2 = 0.075$

C = 6.7F (rated at 5.2V). This is equivalent to 8 3.3F 2.7V super capacitors.

Test Displays

Three sizes of display were tested: 2.13”, 2.9” and 4.5”. The firmware for each display was configured to suit the display resolution and capabilities before being downloaded to the board (flashing the ESP8266).

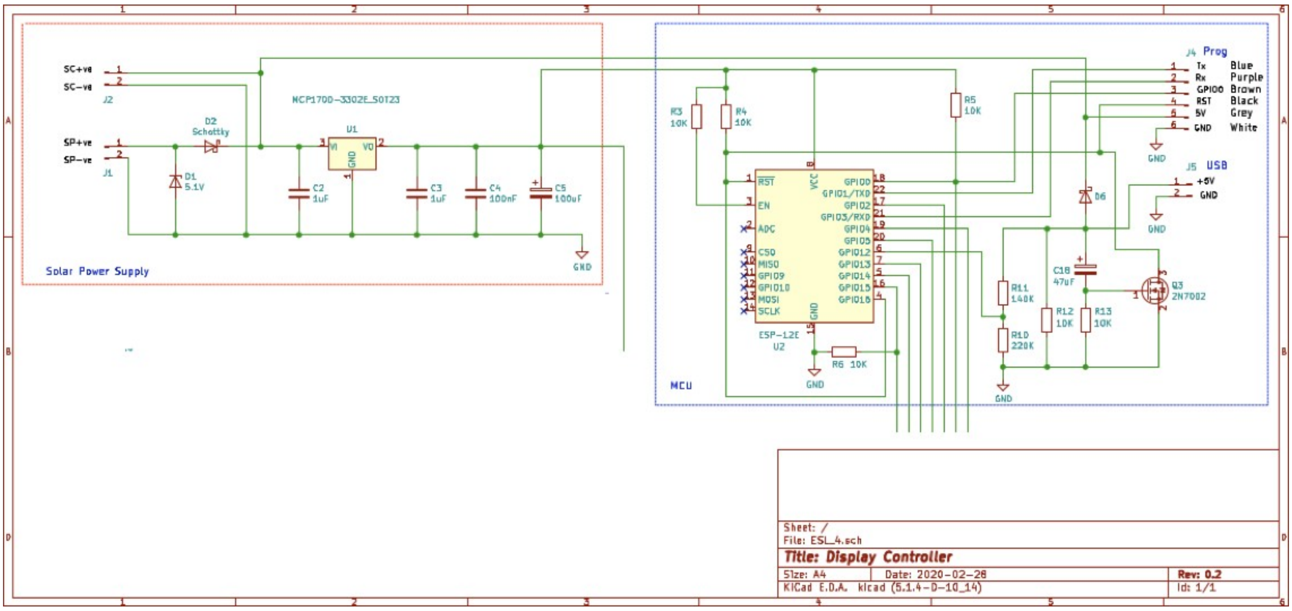
2.13” E-Ink Display



2.9” E-Ink Display

4.5” E-Ink Display

Circuit Diagram



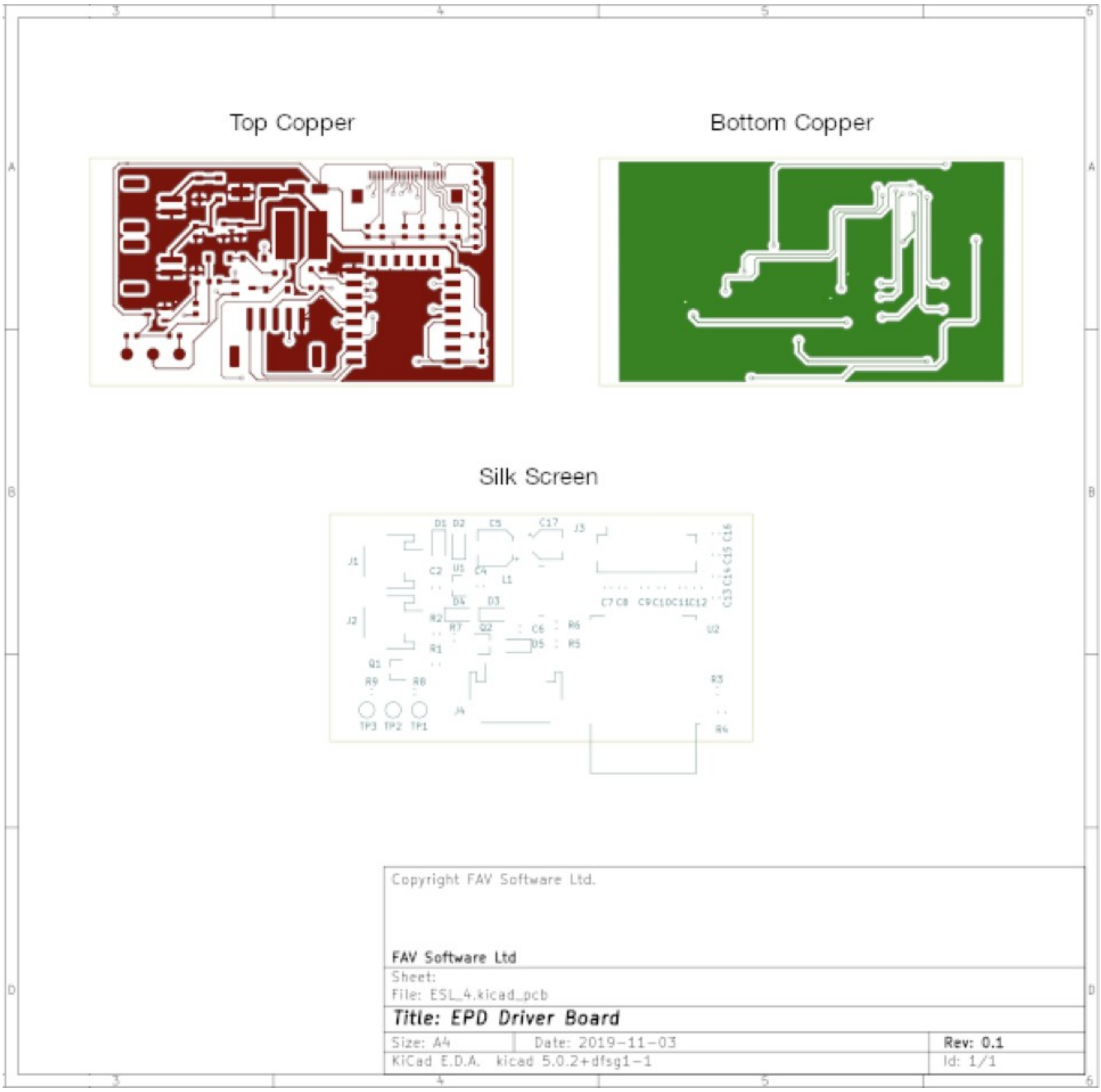
The circuit diagram shows the power supply and ESP8266 module. All of the components are widely available from multiple sources.

The solar cell panel (SP) and super capacitor (SC) are external to the board and may vary according to the display size.

Printed Circuit Board Design

Following successful testing using the prototype board, the next stage was to design the P.C.B.

Due to the relative simplicity of the circuit, a two sided board was designed.



Display Embedded Software

The Arduino IDE was used to program the ESP8266.
The WiFi communications, web server and display interface employed open source libraries.
Other modules were written in C++.

Programming the ESP8266 was via a USB port connected to an interface box that in turn was connected to the board via J4. (Refer to display electronics and circuit diagram).

Image Database

The image database is accessed via an Apache web server. Each image file is taken from a Microsoft bitmap .bmp format and converted into a raw image.

Prior to transmission to the display, the image file is encrypted using a mutually agreed key (between the display and the server).

The image conversion and encryption programs were written in C++ using the Netbeans IDE.