e-Paper ESP866 Driver Board
USER MANUAL

PRODUCT OVERVIEW

- e-Paper ESP866 Driver Board is hardware and software tool intended for loading pictures to an e-Paper from PC/smart phone internet browser via Wi-Fi net.
- The hardware of the driver board is a small PCB with e-Paper driver and ESP8622 module. The PCB has two series of pins, which allow you to apply all of Arduino projects for ESP8266 boards.
- The software of the driver board is a one-page html-application providing picture correction service (is useful in that case if original colors and size aren't suitable for the currently used display) and uploading it to the e-Paper.

PRODUCT FEATURES

- No need to convert a picture to special image formats, it can be any image format supported by your browser.
- E-Papers have 2, 3, 4 hardware colors, but the driver board can mix them (by the Dithering) to obtain more color combinations for better image shade rendering of the original picture.
- The hardware of the driver board needs a connection to LAN, but it doesn't need the internet connection.

APPLICATIONS

The tool is intended to be the start point in developing of the electrically changeable sign based on e-Paper display. Possible applications are:

- Price tags in a supermarket;
- Small information screen in the customer service window (clerk's name);
- Advertising screen in lift near buttons of the control panel;

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SEVER_SIDE APPLICATION

The e-Paper Image Loader described in this document is a source code written in C language. To compile the source code of the e-Paper Image Loader you need the Arduino IDE. To run the driver board you need also a serial port monitoring software (you can use Arduino IDE's or other software with a serial port monitoring function), Wi-Fi router and PC / smart phone connected to the router.

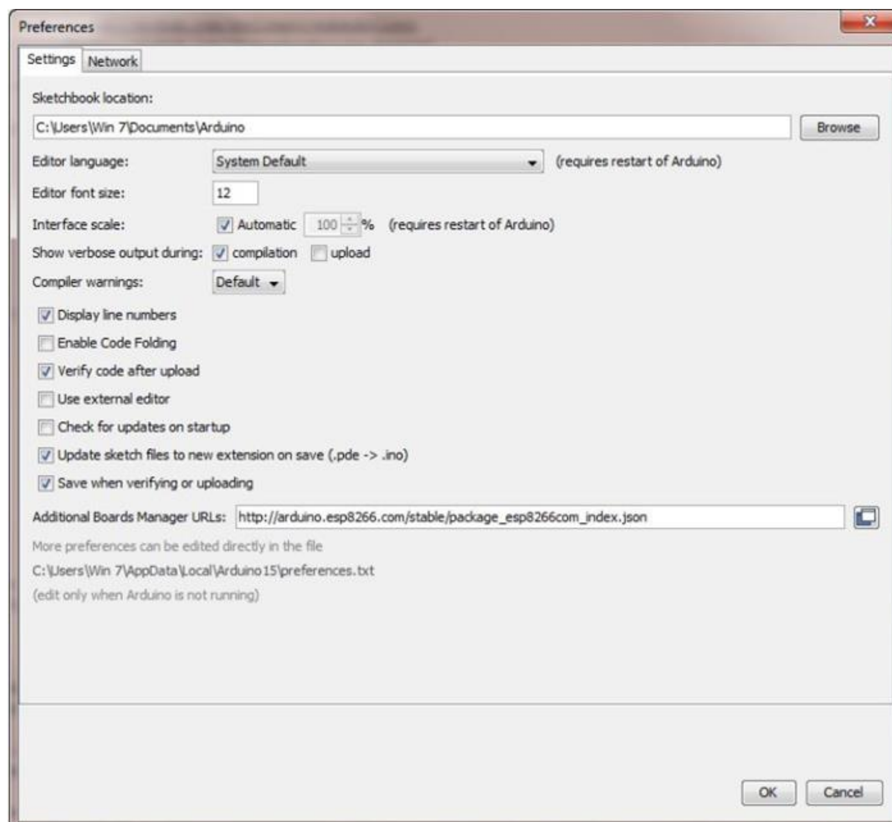
INSTRUCTION OF THE ARDUINO IDE

If the Arduino IDE with ESP8266 board is already installed, then skip this step.

1. Go to the https://www.arduino.cc/en/Main/Software site and install the IDE for your OS.

Note: the installation of the new version doesn't remove your projects or files.

2. In Arduino IDE open ***File->Preferences*** menu item, open tab ***Settings***, text http://arduino.esp8266.com/stable/package_esp8266com_index.json into to text box ***Additional Boards Manager URLs*** (figure 1) and click ***Ok***.



3. In Arduino IDE open ***Tools->Board:(Your current boars selection)->Boards Manager…***, find and/or install ***ESP8266 by ESP8266 Community***.

SOURCE CODE COMPILATION

The source code consists of following files:

- ***loader.ino*** is the main file. It has two functions: ***setup*** and ***loop***. If you need to add/initialize some other software components, do it in ***setup*** function.

- ***srvr.h*** describes functions of ESP8266 Wi-Fi server. To compile and run the loader as it is you just need to change constants ***ssid*** and ***password*** as in your Wi-Fi router.

```
/* SSID and password of your WiFi net -----------------------------------------*/
const char* ssid     = "your ssid";
const char* password = "your password";
```

- ***html.h, css.h*** and ***scripts.h*** contain functions sending the web page of the loader to a client's browser. Due to limited size of data sent to the client, the page is divided on a few small files, hasn't any comments, not useful spaces and some new line characters. Comments to the page content see in ***page*** directory of the source code.

- ***buff.h*** contains one byte-buffer and 3 functions for accumulating data of client's POST requests. The buffer is used for easier data converting from 1- ,2-bit pixel format of received image data to 1- ,2- ,4-bit pixel format of e-Paper's image.

- ***epd1in54.h, epd2in13.h, epd2.7.h, epd2in9.h, epd4in2.h, epd7in5.h*** contain initialization functions for correspondent displays including data about brightness and saturation of colors (lut-massives).

- ***epd.h*** contains functions controlling e-Paper states (initialization, color-channel selection, loading, refreshing and turning to the deep sleeping mode).

Note: the source code is written in C (without any classes) to easier porting to other compilers.

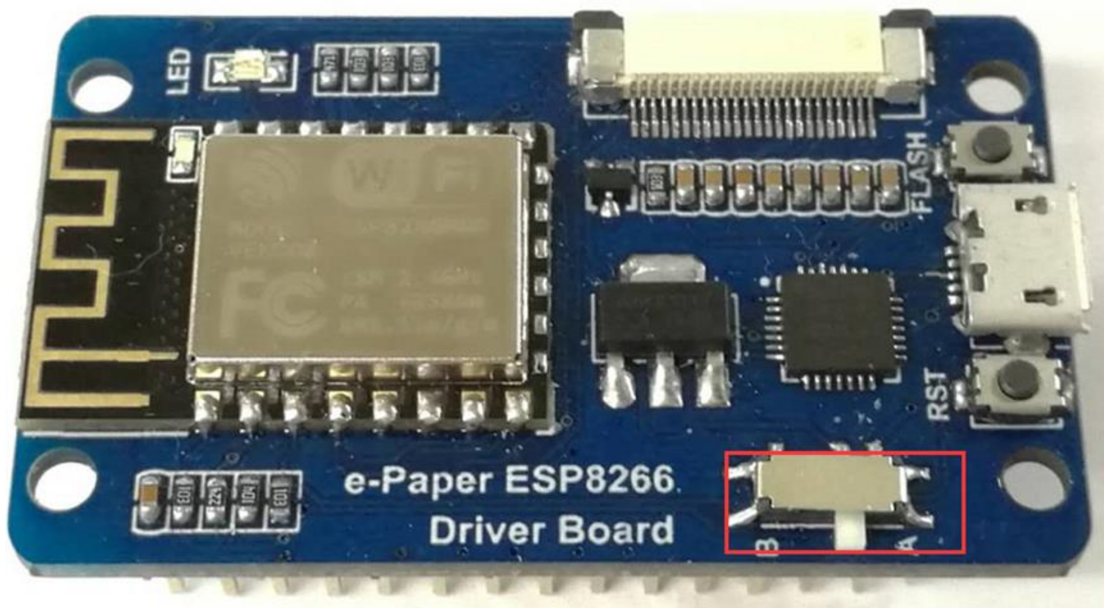
Connect one of supported e-Paper to the board, compile & flash the software to ESP8266 memory by clicking the button "Load" (figure 2).

Note: if you didn't change the code, you are trying to compile it the first time and the compilation is failed, check you chose right board in ***Tools->Board*** (figure 3).

Phoenix 2.0
NodeMCU 0.9 (ESP-12 Module)
• NodeMCU 1.0 (ESP-12E Module)
Olimex MOD-WIFI-ESP8266(-DEV)
SparkFun ESP8266 Thing

E-PAPER TYPE SETTING

Before you send some picture to your e-Paper, check please the trigger on the board is in proper state (Figure 4).



Find your type of display in table 1 and set the trigger to right position:

Trigger state	e-Paper type
A	1.54 inch, 2.13 inch, 2.9 inch
B	1.54 inch(b), 2.13 inch(b), 2.7 inch, 2.7 inch(b), 2.9 inch(b), 4.2 inch, 4.2 inch (b), 7.5 inch(b), 7.5 inch(b)

THE CLIENT-SIDE APPLICATION

The client-side application consists of 4 files: index.html, styles.css, processing.js (divided on 3 parts: ~A.js, ~B.js, ~C.js) and uploading.js. It allows the opening an image file, correcting its color gamma according to a display's type, and uploading the result to the server-side application.

USER INTERFACE

The application user interface has following controls (figure 5):

- ***Select image file*** – opens the file browser;
- ***Level: black***, ***Level: black and red***, ***Dithering: black***, ***Dithering: black and red*** - make a new picture based on opened image with proper size and colors;
- ***Upload image*** – makes a POST request with the type of e-Paper, sends it to the server-side application and waits response 'Ok', sends the processed image part by part;
- ***Device IP***: shows IP of server-side application;
- ***Boudns*** are source copying rectangle offset (***X***, ***Y***) and display size (***W***, ***H***) defined by radio buttons: ***1.5 inch e-Paper***… ***7.5 inch e-Paper(b)***;
- Viewers: ***Original image*** (drag & drop control), ***Processed image*** (is empty initially).

Note: ***Bounds W, H*** and ***Device IP*** are supposed to be not editable and updated automatically when you change e-Paper's type or the server, but they are changeable to allow you to test the software or to control a few boards just pasting their IP into ***Device IP*** text box.

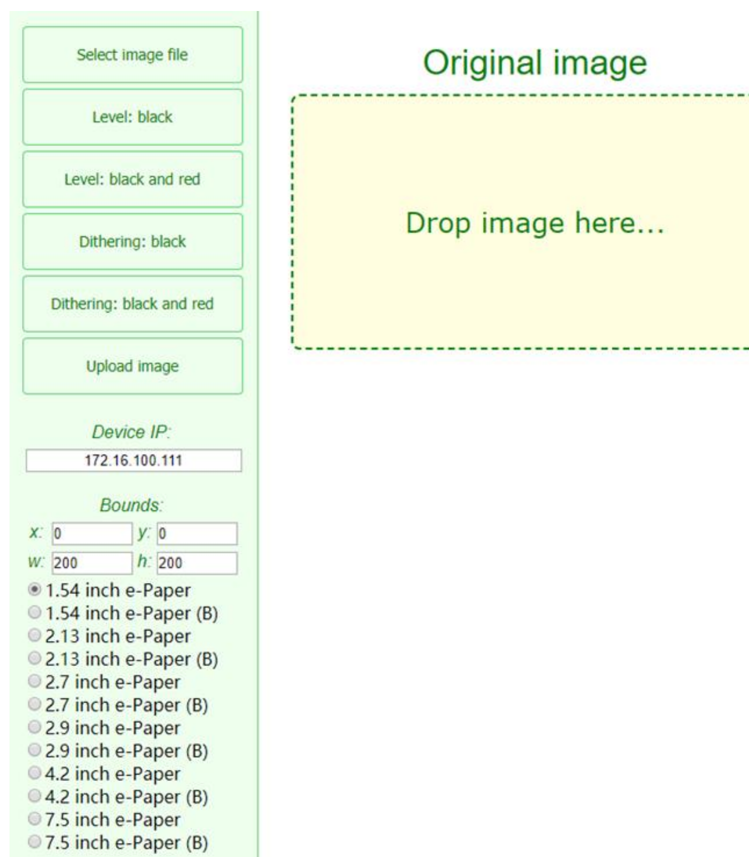


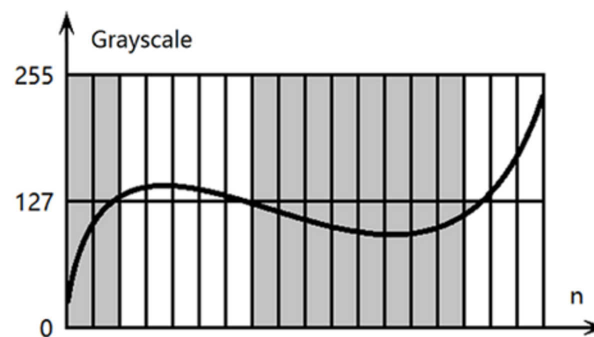
IMAGE PROCESSING

The client-side application provides two kinds of image processing: Level and Dithering.

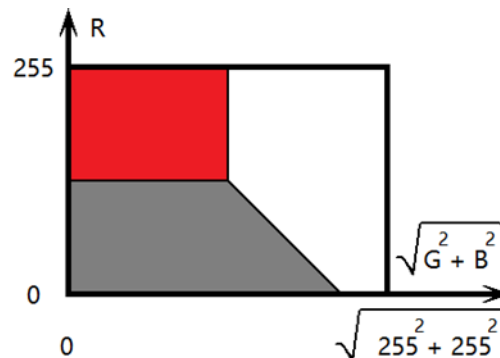
LEVEL

The Level supposes that that image can be divided on a few large regions, in which all of pixels have color 'close' to one of available colors: black, white or red and 'far' to others available colors. This kind of processing is suitable for 2- or 3-color schematics or texts.

For example, if pixel's color of a grayscale image is equals and less than 127, the assigned available color is black, otherwise is white (figure 6).



In case of colored image the green and blue channel are combined to green-blue or not-red channel which is 'orthogonal' to the red one. On the color diagram (figure 7) it is shown that pixels with high value of red channel and low value of green-blue channel is takes red color, otherwise black or white as in previous example.



Mathematically the definition of color is based on the discrepancy calculation – the sum of squares of channel differences between given and available colors. Pixels take available color which has minimal discrepancy with their color. In the code snipped below the available colors are stored in curPal array:

```
// Returns the discrepancy between given (r, g, b)
// and available colors
function getErr(r, g, b, avlCol)
{
    r -= avlCol[0];
    g -= avlCol[1];
    b -= avlCol[2];
    return r*r + g*g + b*b;
}

// Returns the index of available color
// which has minimal discrepancy with the given one
function getNear(r,g,b)
{
    var ind=0;
    var err=getErr(r,g,b,curPal[0]);

    for (var i=1;i<curPal.length;i++)
    {
        var cur=getErr(r,g,b,curPal[i]);
        if (cur<err){err=cur;ind=i;}
    }

    return ind;
}
```

DITHERING

In case of smooth colored pictures during the Level processing an image looses a lot of thin details expressed by smooth gradient of colors situated close to each other in the color diagram. The most of gradients cover large areas of pictures taken by camera, thus it is possible to express some shades by mixing closest available colors on those areas.

Eyes feel the average color of pixels in a small area. It means there are more seeming colors, but in other hand the picture seems noisy we well or as if it has low resolution. Good algorithms of color the mixing can prevent pixilation (creating clearly seen small grain-like areas in a picture). One of them is the Dithering.

The application uses the Floyd-Steinberg Dithering - most famous 2D error diffusion formula (was published by Robert Floyd and Louis Steinberg in 1976). It diffuses errors according the pattern shown in figure 8.

	X	7
3	5	1

(1/16)

Here X - is an error (scalar/vector difference between original and available grayscale/colored value of pixel). This error is distributed between right, right-bottom, bottom and left-bottom pixels, is just added to their values with factors 7/16, 1/16, 5/16 and 3/16 respectively. Thus the average original color stays within this small group of pixels. The algorithm doesn't change left, left-top, top and right-top pixels because they are already corrected at

previous iteration of the algorithm. See examples of the photographic image processing in figures 9, 10 and 11.

Figure 2 Original Image

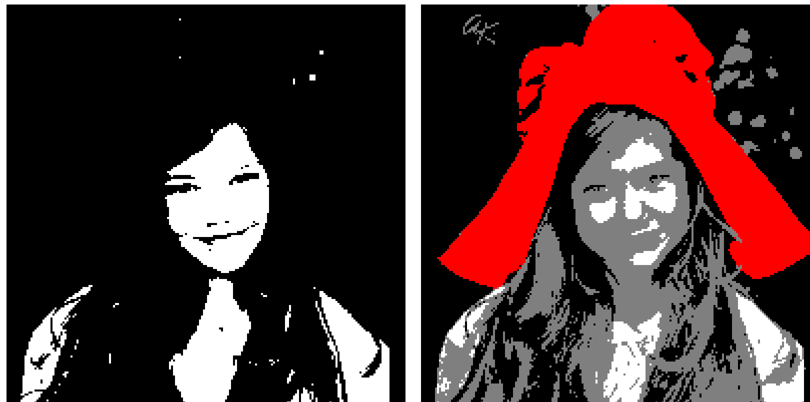


Figure 1 "LEVEL Black" and "LEVEL RED and Black"

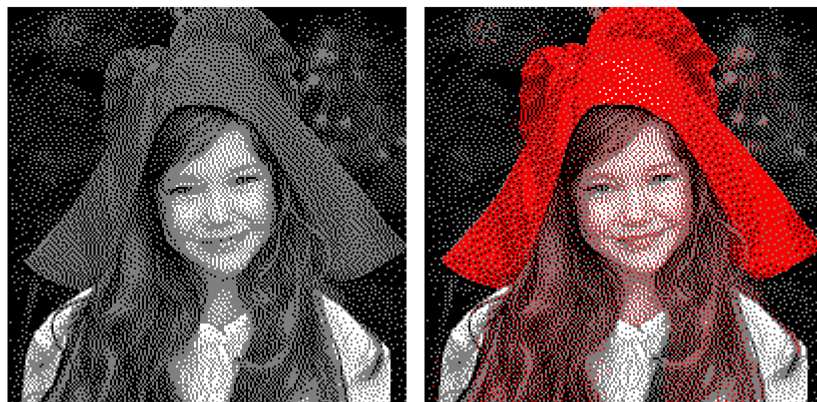


Figure 3 "Dithering: black" and "Dithering: black and red"

DATA TRANSMISSION PROTOCOL

The ESP8266 module is intended for sending short messages and can be used neither for video streaming, nor for sending large pictures. In this case the protocol allowing the data dividing and sending it part by part must be used. If you don't know well about Wi-Fi functionality or can't use it by some reason, but need to develop a tool for the file transmission

via HTML page and Wi-Fi net in haste then you can use the solution described in this document. It is based on POST request data transmission, but isn't "the bad practice" (as if it's based on GET request). Consider the data transmission mechanism of this solution, modificate it or add your own functions/commands if you need.

COMMANDS

The protocol of communication between image dividing code snippet on the client-side and data receiving code at the server-side includes 4 commands:

- EPDn – the initialization of n-type display (n is a character in range 'a'..'l');
- LOAD – the image data loading (black and/or red channel);
- NEXT – the switching from the black channel to the red one;
- DONE – the refreshing of display and turning into the deep sleep mode.

INITIALIZATION ALGORITHM

As it is shown in the diagram (figure 12), the event handler of "Upload image" button creates an object for sending commands and listening responses from server, sends EPDn-command. The server-side application receives the EPDn-command, initializes the e-Paper display and open monochrome or black channel for writing.

The memory writing commands (EPDn and NEXT) for white-black display is
EPD_SendCommand(0x24);//WRITE_RAM

and for white-black-red display is (black and red channels correspondently):

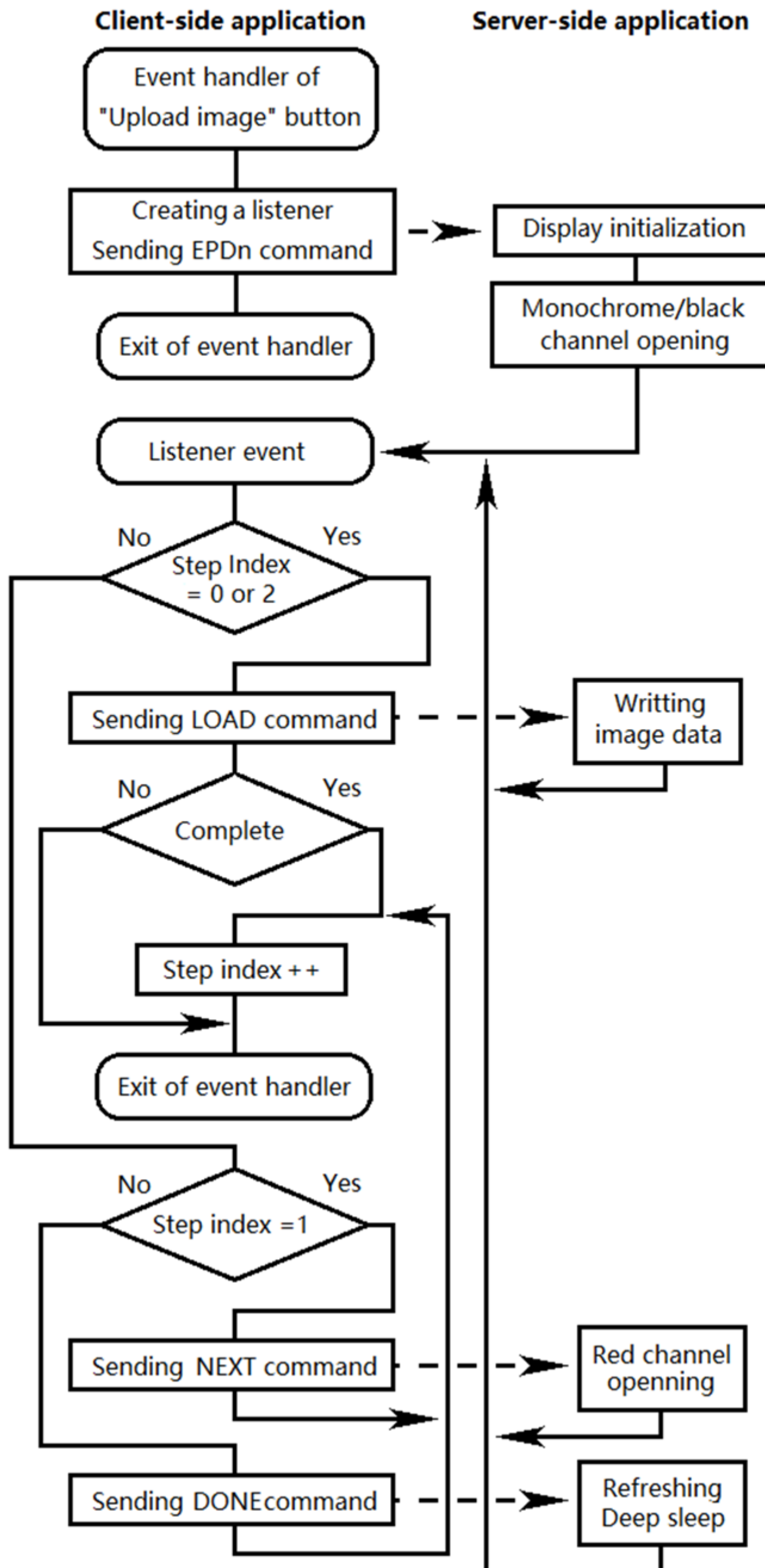
EPD_SendCommand(0x10); //DATA_START_TRANSMISSION_1,

EPD_SendCommand(0x13); //DATA_START_TRANSMISSION_2,

but there are exceptions:

- White-black displays 2.7 and 4.2 use the red channel (code 0x13) instead of monochrome channel (code 0x24);
- The display 7.5 loads the red and black data simultaneously.

Thus, when you copy code snippets from initialization functions pay attention how they write image data into display's memory!



Important: before the first writing of the image data into a display, one of commands: WRITE_RAM, DATA_START_TRANSMISSION_1 or DATA_START_TRANSMISSION_2 is required,

but 2.13-display can load data line by line only. It means before the image data writing of each line, the command WRITE_RAM must be executed.

DATA TRANSMISSION ALGORITHM

Every time the server gets some request, it sends the word “OK” (in case of known command), otherwise the index html page. This response initiates ***onload*** event of the ***xhReq*** object and the client-side application sends a command again according the step index ***stInd*** (see diagram above and file ***uploading.js***):

```
xhReq.onload = xhReq.onerror = function()
{
    if(stInd==0)return u_data(a,(epdInd==1)?-1:0,0,50);
    if(stInd==1)return u_next();
    if(stInd==2)return u_data(a,3,50,50);
    if(stInd==3)return u_done();
};
```

Here ***epdInd*** is the display type index ***n*** mentioned in EPDn command.

Note: for white-black displays steps 1 and 2 are missing.

The image data, which is sent as a POST request, is accumulated in the bytes buffer (see ***buff.h*** file of the server-side application):

```
/* Size, current position index and byte array of the buffer -----------------*/
#define Buff__SIZE 2050
int     Buff__bufInd;
char    Buff__bufArr[Buff__SIZE];
```

Here 2050 >= (about 1000 bytes of data reliablely sent to ESP8266 module + about 15 bytes in case of 3.12-display) x 2 chars per byte.

Note: You can send more data with the same size of the buffer, but this case you must modificate ***Buff__getByte*** function at the server-side application (file ***buff.h***) and ***byteToStr*** function at the client-side application (file ***uploading.js***). Another way to increase the data capacity of a request is to estimate auxiliary data of the request, but this way is complicate and effective enogh as the first one.

Actually, there is function ReadStringUntil in Arduino, which can accumulate and return whole string of a request, but it works very slovely. This code solution describes a while-loop, where the POST-request is accumulated character by character and every iteration of the the loop has the signature (last 4 characters in case of command and more characters in case of a file name as “styles.css” or “uploading.js”) checking to define what the client needs to obtain:

```
// While the stream of 'client' has some data do...
while (client.available())
{
    // Read a character from 'client'
    int q = client.read();

    // Save it in the buffer and increment its index
    Buff__bufArr[Buff__bufInd++] = (byte)q;

    // If the carachter means the end of line, then...
    if ((q == 10) || (q == 13))
    {
        // Clean the buffer
        Buff__bufInd = 0;
        continue;
    }

    // If data accumulated in buffer end with "styles.css", then
    if ((Buff__bufInd > 13) && Buff__signature(Buff__bufInd - 14, "/styles.css"))
    {

...
// If the buffer's length is larger, than 4 (length of command's name), then...
if (Buff__bufInd > 4)
{
    // It is probably POST request, no need to send the 'index' page
    isIndexPage = false;

    // e-Paper driver initialization
    if (Buff__signature(Buff__bufInd - 4, "EPD"))
    {
        ...
```

DATA PIXEL FORMAT

When your browser opens an image file, the pixel format is 24 bpp by default. The image processing reduces it to 1 bpp (white-black display):

0 – white;

1 – black;

or 2 bpp (white-black-red display):

0 – white;

1 – black;

2 – gray (1.54 inch b-type only);

3 – red.

Before the ***xhReq*** object sends a POST-request to the server, the client-side application packs image data into bytes or words. The bits order in these bytes/wordas is native display memory order or is suitable for fast conversion into the native orser. The table 2 shows this changes from the start of conversion to the writing of data into display's memory:

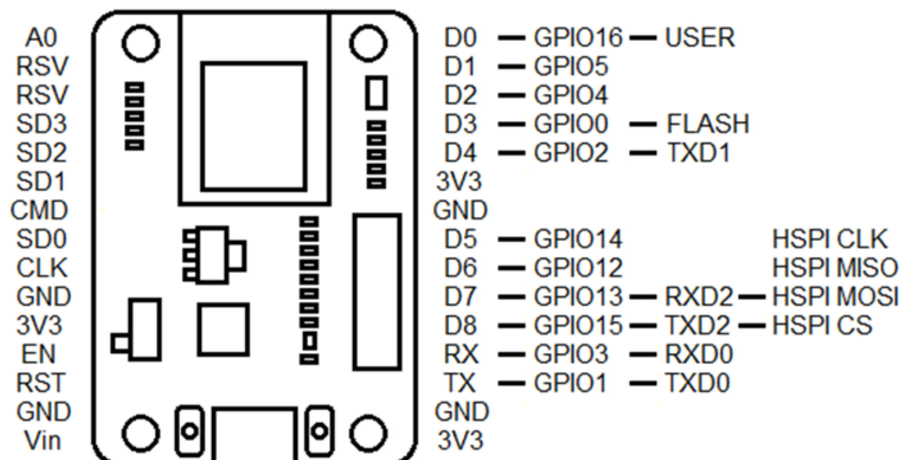
Display type (channel)	Transmission format (p – pixel, b - bits)	Native format
1.54 (black) 1.54b (red) 2.13 (black) 2.13b (both) 2.7b (both) 2.9 (black) 2.9b (both) 4.2 (black) 4.2b (both)	p:01234567 - b:76543210 0 – black or red; 1 – white.	p:01234567 - b:76543210 0 – black or red; 1 – white. ***Comment***: *there are no any changes*
2.7	p:01234567 - b:76543210 0 – black; 1 – white.	p:01234567 - b:76543210 0 – white; 1 – black (). ***Comment:*** *bitwise inversion*
7.5	p:01234567 - b:76543210 0 – black or red; 1 – white.	p:0 - b:7,6,5,4 (7 is high, 4 is low); p:1 – b:3,2,1,0; p:2 – b:15,14,13,12; p:3 – b:11,10,9,8;

		0000 (0) – black; 0011 (3) – white.
1.54b (black)	p:0 – b:1,0; p:1 – b:3,2; p:2 – b:5,4; p:3 – b:7,6; 00 (0) – black; 01 (1) – white; 10 (2) – gray; 11 (3) – red, is read as 10 (2).	p:0 – b:7,6; p:1 – b:5,4; p:2 – b:3,2; p:3 – b:1,0; 00 (0) – black; 01 (1) – gray; 11 (3) – white;
7.5b	p:0 – b:1,0; p:1 – b:3,2; p:2 – b:5,4; p:3 – b:7,6; 00 (0) – black; 01 (1) – white; 10 (2) – gray; 11 (3) – red.	p:0 - b:7,6,5,4 (7 is high, 4 is low); p:1 – b:3,2,1,0; p:2 – b:15,14,13,12; p:3 – b:11,10,9,8; 0000 (0) – black; 0011 (3) – white; 0100 (4) – red.

HARDWARE

The board of the E-Paper Image Loader is developed to control an e-Paper display by Wi-Fi net, but the EPS-8266 module allows performing a lot of other useful functions the same time: keep loaded images in SD-card or external flash memory, get data from sensors and display them in e-Paper, and so on. All of additional components need correspondent circuits: the e-Paper display circuits are on the board, other possible circuits are connected by 2 series of pins at the bottom of the board.

PINOUT



If you need to use some of EPS8266-Arduino project, just detouch your display, because it is connected to pins:

```
/* SPI pin definition --------------------------------------------------------*/
// SPI pin definition
#define CS_PIN          15
#define RST_PIN         5
#define DC_PIN          4
#define BUSY_PIN        16
```

If a display is detouched form the board, their display circuits situated in it don't make any influence on the ESP-8266 circuits.