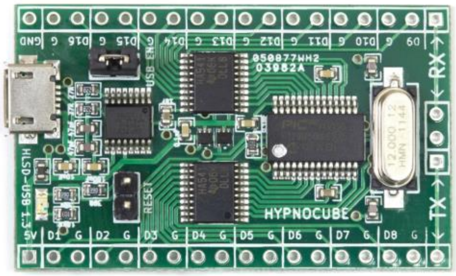
Hypnocube LED Serial Driver



The **HypnoLSD** is a USB or UART to WS2812[1] LED strand driver that simplifies interfacing, reducing costs and need for custom controllers. Each **HypnoLSD** controls thousands of LEDs at real time rates, enough for commercial designs, artwork, hobbyist needs, lighting projects, and more. The **HypnoLSD** board takes standard USB or UART input, buffers images internally, and handles the sensitive timing needs of the WS2812 LEDs, keeping images synchronized. The small factor board and low design requirements aid rapid prototyping at the hobbyist breadboard level up to integration into commercial designs.

This document shows how to use it in designs.

Quick Start

A quick test of a newly obtained **HypnoLSD** module is to hook up a short (1-200 length) strand to the data and ground pins on port 1 (connect ground first, correctly, then the data line next). Add power to the module by plugging a USB charger or other USB source to the USB plug, and make sure the USB jumper is set USB, not UART, which should cause the built in LED to light, then blink once per second. For the next test, remove power, connect a LED strand (be sure to connect to port 1, ground then data), add power to the strand, and add power the module. Wait a few seconds for built in patterns to be drawn on the LED strand. Default length will draw patterns on up to 250 LEDs.

Next, remove power, connect a USB cable to a PC (and make sure you have the FTDI drivers) open a terminal program (such as Putty), change the serial connection terminal settings to 9600 baud, 8 bits, no parity, and 1 stop bit (8N1), and add power to the **HypnoLSD**. You should see a startup message. Entering "help" (with no quotes) followed by a newline (pressing ENTER on most PC terminal programs) will show a list of commands. Experiment with them. Letting the command terminal sit idle a few seconds will return to drawing demo images.

Download the Windows software from http://hypnocube.com/product/led_serial_driver/ and play with it. It allows GUI control of the various commands as well as the ability to set colors.

To run from any serial port, such as an Arduino, Raspberry Pi, etc., disable the USB jumper, connect to the ground, the proper UART transmit and receive signals, send the bytes "**`draw\r\n`**", wait a millisecond or so, then send colors bytes (**but change any 254 to 255 before sending**, 254 has special meaning in draw mode!), 3 per LED, followed by a 254 to end the image. Repeat as much as you want. This should draw colors on the LEDs on the first strand. For more strands or longer strands, or faster rates, read the rest of this document.

[1] The **HypnoLSD** also supports the newer WS2812B, which is essentially the same chip, but under testing we noticed some power differences. We added a second regulated voltage to the **HypnoLSD** to handle both well. It also handles the WS2811 driver chips, which is the WS2812 without the integrated LEDs.

Overview

The **HypnoLSD** module has several features to enable large scale projects. Various settings such as baud rate, specialized timing controls, image size, and a user ID that can be programmatically queried can be stored in on-chip FLASH to allow programs to distinguish different physical modules. There is a jumper that can be installed to reset the FLASH settings to defaults in case of error. A diagnostic LED flickers to denote behavior, which can also be disabled programmatically.

The module has a micro USB connection which uses a FTDI USB to UART bridge, so the device should show up as a COM port on a computer when connecting to the USB port. If not, you need to find drivers from the FTDI website for your PC. If you want to connect with a UART directly (from smaller or embedded chips), set the USB/UART jumper on the module to disable the USB, and connect to the RX, TX, and GND pins accordingly. The UART supports higher baud rates, which may be needed for larger high frame rate designs.

There are 16 ports, labeled 1-16, each with a data and ground line. These connect to strands to run, starting with strand 1, then 2, etc., allowing control of up to 16 LED strands.

Electrical Interface

There are two ways to power the **HypnoLSD** module: 1) USB power through the micro-B USB jack, and 2) by the 5V pin and GND pin. LED strands should be connected to port 1, then port 2, etc., in order. This is the order the drive code sends out signals.

Wires from the **HypnoLSD** module to the LEDs should be kept as short as possible to prevent signal problems. Some report ~100 ohm resistors in series as helping, but we have not tested it. If long lengths need to be run, making the USB cable longer is a better option.

The LED strands should be powered each 200-300 or so LEDs, since it appears that the power drop on longer strands causes signaling issues, even with the signal reshaping the WS2812 supports. We also noticed color drops as the strands went further without power, so you may need to test your LED setup to determine needed power connections. Power consumption should max at 60 mA/LED site (as all white, which is actually three LEDs at 20 mA each). When we tested, we found that each LED site (3 LEDs) used under 60mA, and dropped off nearly linearly as the color (0-255) viewed dropped.

Programming Interface

This section lists programming commands, how to send images, and technical details for optimizing software for high performance display.

Overview

The **HypnoLSD** allows controlling to 1-16 strands of LEDs, arranged however the user desires, at baud rates from 9,600-12,000,000. The reason for choosing different numbers of strands and baud rates is to allow fast image updates in different scenarios. The number of strands controlled is called **width**. The length of the strands is called **length** (also called **height** in the module), and the resulting LEDs are treated as a width by length image buffer of red, green, and blue bytes. Internally all strands are treated as the same length, so it is best if your design has the same physical fixed length. If not, you must still send bytes to the module as if the LEDs were a rectangular grid.

The **HypnoLSD** allocates 30,000 bytes of RAM as an image buffer, which is partitioned according to the width. Due to technical details, the maximum LED strand length allowed varies as width as follows:

Strands (width)	Max length	Total pixels	Bytes used	Bytes unused	% used
1	10,000	10,000	30,000	0	100.00
2	5,000	10,000	30,000	0	100.00
3	3,125	9,375	28,125	1,875	93.75
4	2,500	10,000	30,000	0	100.00
5	1,875	9,375	28,125	1,875	93.75
6	1,250	7,500	22,500	7,500	75.00
7	1,250	8,750	26,250	3,750	87.50
8	1,250	10,000	30,000	0	100.00
9	625	5,625	16,875	13,125	56.25
10	625	6,250	18,750	11,250	62.50
11	625	6,875	20,625	9,375	68.75
12	625	7,500	22,500	7,500	75.00
13	625	8,125	24,375	5,625	81.25
14	625	8,750	26,250	3,750	87.50
15	625	9,375	28,125	1,875	93.75
16	625	10,000	30,000	0	100.00

The signaling protocol to the LEDs runs at 800khz, with 24 bits per pixel, so can light 800,000/24=33,333 pixels per second. For 30 frames per second (fps) animation, this amounts to a maximum strand length of 1111. More strands allows updating more LEDs per second.

The input baud rate limits the speed at which data can be sent into the **HypnoLSD**. The signaling is 8 data bits, no parity, and one stop bit, called 8N1, and results in transmitting one byte per 10 baud. This means a 9600 baud connection will transfer 960 bytes per second. A 1,000,000 baud connection can transfer 100,000 bytes per second. In general you should select the slowest usable baud rate that meets your design criteria.

Example 1: highest performance is sixteen strands of length 625 (so width is 16), giving 625*16=10,000 LEDs. The **HypnoLSD** can refresh length 625 in 800,000/(625*24)=53 times a second. Filling 10,000 pixels takes 30,000 bytes (one for each of red, green, and blue), and a 12,000,000 baud connection can transmit (12,000,000/10)/(30,000)=40 frames per second. So in this case the baud rate is the limiting factor (40 < 53), but 40 frames per second is a good animation rate.

Example 2: Suppose you want to run 4,000 LEDs at 40 frames per second. This requires 4000*40*3=480,000 bytes per second, or a minimum of 4,800,000 baud input. The only supported speeds above this are 6 and 12 Mbaud. Next, for output, the rate of 800,000/(24*40)=833 shows that at most 833 LEDs can be on a strand. 4000/833=4.8 means at least 5 strands should be used. This could be 5 strands of length 800 (cutting it close) or 8 strands of length 500. Thus parameters of 6,000,000 baud and 8 strands of length 500 would be a good design choice.

The **HypnoLSD** operates in two different modes: command mode and drawing mode. In command mode, commands are sent as ASCII commands. In drawing mode, sequences of bytes are interpreted as colors to send out to serial LEDs. Upon powering up, the **HypnoLSD** defaults to 9600 baud, 8N1, and command mode, where ASCII commands are used.

Command Mode

Commands are case-sensitive ASCII text, followed by the control characters **\r\n**, which are line feed (**\r** = **0x0D** hexadecimal = **13** decimal) and new line (**\n** = **0x0A** hexadecimal = **10** decimal).

After each is completed, the text "**OK\r\n**" is returned. Any error sends a line with "**ERROR:** " followed by error text, then "**\r\n**", then the "**OK\r\n**". Commands ignore input while processing, so you must wait for the final "**OK\r\n**" before sending another command. Most commands execute quite quickly and a millisecond wait should suffice if you don't want to read the feedback messages.

In the following command table, entries of the form **nnnn** denote decimal integers.

Command	Result
help	Return basic help text.
version	Return version as major.minor format.
info	Print system info.
stats	Show debugging stats for checking memory integrity, connection quality, etc.
sizes	Show max length for each width.
get speed	Get the current baud rate information.
set speed nnnn	Change the baud rate divisor to **nnnn** in 0 to 65535. See below.
get size	Get the current buffer size width x length
set size wwww hhhhh	Set the buffer size. **wwww** is width 1 to 16; **hhhh** is length 1 to max for this width. Use the **sizes** command to find the max length for each height. Default is width 1, length 250.
get id	Get the current user identification value 0-65535.
set id nnnn	Set an identification value 0-65555, useful for multi-controller designs. Default 0.
get bitdelay	Get the bit timing delay 0-65535 on each bit output. Default to 0.
set bitdelay nnnn	Set the bit timing delay 0-65535 on each bit output.
draw	Enter drawing mode. See the drawing section.
dump image nnnn	Dumps buffer RAM for debugging. **nnnn** is 1 to 30,000.
test conn nnnn rrrrr	Testing mode. **nnnn** is size for each pass of 1 to 30,000, and **rrrr** is the repeat value in 1 to $2^{31}-1$. After this, send one copy of the buffer of length **nnnn** to test, then **rrrr** copies that are checked against the original. When done, the error counts are returned if anything did not work.
reset stats	Reset the stats counters. Useful for debugging.
save settings	Saves settings to flash memory so they do not need set each time. The settings saved are User ID, connection rate, width, length, diagnostic LED on/off status, and demo delay. Do not set this too often as the flash will wear out over time. The PIC documentation gives a 20,000 cycle erase lifespan, so after about 20,000 writes the device is out of specification. If the FLASH gets corrupted values, then default values apply. The reset jumper allows an external reset of default.
timings	This dumps some timing values for frame drawing code, used for debugging.
skewtest a b c d e	Test skew timing on strand. Used for debugging.
Latchtest nnnn mmmm	Test minimal latch timing. Used for debugging.
rundemo m nnnn	Run built in demo **m** (1 to max demo from **info** command) for **nnnn** milliseconds (1 to 65535). Demo 0 means do all demos. 0 milliseconds means to run the given demo until a byte is seen in the command channel.
demodelay mm	Set the delay before a demo runs to **mm** seconds (0-99). 0 means never show demos. Defaults to 5 seconds. In command mode, if bytes are not seen for this long, then built in demos run on any connected strands according to the current image size.
LED n	Enable/disable the onboard diagnostic LED flickering. If **n**=0, LED is always off. If **n**=1, the LED flickers. The LED turns on at power up, flickers once per second in command mode, and then toggles each SYNC executed in drawing mode. Defaults to 1.

Baud Rate Calculations

The baud rate of the **HypnoLSD** module is changed by setting a clock divisor through the "**`set speed nnnn`**" command where **nnnn** is a divisor in the range 0 to 65535. The resulting baud rate is given by 12,000,000/(**nnnn**+1). This results in rates from 12,000,000 baud (when **nnnn**=0) down to 183.1 baud (**nnnn**=65535). However, going below 9,600 baud is not recommended as it is untested (and probably not useful).

Desired Rate	Actual Rate	Divisor	% Error
9600	9600	1249	0
19200	19200	624	0
38400	38338.66	312	0.16
56000	56074.77	213	-0.13
57600	57692.31	207	-0.16
115200	115384.62	103	-0.16
250000	250000	47	0
300000	300000	39	0
375000	375000	31	0
400000	400000	29	0
480000	480000	24	0
500000	500000	23	0
600000	600000	19	0
750000	750000	15	0
800000	800000	14	0
1000000	1000000	11	0
1200000	1200000	9	0
1500000	1500000	7	0
2000000[2]	2000000	5	0
2400000[2]	2400000	4	0
3000000	3000000	3	0
4000000[2]	4000000	2	0
6000000[2]	6000000	1	0
12000000[2]	12000000	0	0

Note the actual baud rate might not be the desired baud rate, in which case you should check the error and tolerances of your devices. Most devices support a few percent error between desired and actual baud rates. A few common baud rates and best divisors are in the baud rate table.

Note at the higher baud rates there is not as much selection due to running out of divisors.

When selecting a baud rate, make sure your driving device can handle it as well.

The **HypnoLSD** with the built-in USB to UART bridge uses a FT230X from FTDI[3]. The spec sheet[4] describes the available baud rates from 183 to 3Mbaud. The achievable baud rates are given by 3,000,000/(n+x) where n is an integer in 2 to 16384 and x can be any of the 8 values {0, 0.125, 0.250, 0.375, 0.500, 0.675, 0.750, 0.875}. A final case of n=1 and x=0 gives the top speed of 3Mbaud. When using Windows, Linux, or Mac OSX the values should be set transparently in the OS driver when the serial port is opened.

NOTE: Note that the HypnoLSD module speeds above 3Mbaud can be reached by using the UART interface (on the non-USB version) combined with devices based on the FT232H chip from FTDI. They sell a breakout board that we have tested for high speed connections.

Demos

Six demos are integrated into the module to help debugging and to provide simple test patterns. They are

1. Solid color, slowly changing
2. Solid color blocks slide towards module.
3. A "plasma" of colors fades and evolves over the LEDs.
4. "Splats" of color are displayed, and each fades out slowly.
5. Eight different color blobs chase each other over the length of the strand.
6. Random flickering dots

[2] Not reachable on the USB to UART version of the module. Needs a separate high-speed UART.
[3] http://www.ftdichip.com/
[4] http://www.ftdichip.com/Support/Documents/DataSheets/ICs/DS_FT230X.pdf

Drawing Mode

In drawing mode, colors are sent as triples of colors, thought of as red, green, and blue, written RGB. However, the order of bytes sent in is the same order the go to the LED strand, and most strands take order green, red, blue (GRB), so the order you write them may need modified to match LED requirements.

Each byte value can be 0-255, except byte 254 is reserved as a synchronization byte, called SYNC. This means whenever you want to send color 254, you should change that to 255. This is done in case a buggy UART connection loses or mangles a byte, so the image can be resynchronized. Color 254 was chosen because the visual difference between 254 and 255 is negligible.

The color order is to fill width first, then next value for the length, repeat. When all bytes for the current frame are sent, send a SYNC byte, which marks the end of a frame and denotes to the output code that it can begin. In fact, each SYNC byte increments an internal counter, and each frame of output that is started by the internal code decrements this counter.

A SYNC byte also tells the writing code to start at the top of the image buffer for the next byte.

Entering two SYNC bytes in a row exits drawing mode back to command mode.

Detailed Control

There may be some uses where careful timing of the input and output streams needs synchronized for robust images, no tearing, or to sync with other needs such as video.

Internally, the code has a RAM buffer for the image consisting of 30,000 bytes laid out in a special manner allowing efficient code to manage it quickly. In drawing mode, this buffer is simultaneously being written into with incoming data (from the USB or UART interfaces) and read from to get outgoing data (to the LEDs). It is possible for reading/writing to step on each other during a frame, which can result in a “tearing” of images. The SYNC byte (254) which marks the end of a frame also allows careful timing control to avoid any accidental stepping on each other.

At all times the reader (for LED output) and writer (for incoming data from UART or USB) are walking through memory, top to bottom, trying to do their jobs. When a SYNC is sent, a 32-bit SYNC counter is incremented, the low order byte is output to the UART so you can track it, and the writer is restarted from the top, with the first color channel (R in RGB, or G in GRB, etc.). Whenever the reader reaches the end of whatever it is doing, it checks this counter, and if it is not greater than zero, the reader has a delay until it checks again. Whenever the SYNC counter is greater than zero, the reader decrements the counter, and sends (low order counter byte + 64) to the UART port. The +64 is to help track what is going on in your code.

Note that the reader does not send these output bytes if there are already bytes being transmitted from a previous round. If your baud rate is too slow some output bytes will be skipped.

Once these bytes are seen, the reader starts at the top, reading from the top of RAM and sending the data to the LEDs.

Here is the important timing detail: The reader processes output at 800kbits per second (on each strand since it’s done in parallel). After one pixel of output is sent, it is safe to write one pixel of input. If your writer fills pixels into RAM faster than they are output by the reader, then you will catch and pass the reader. So if you're finding some tearing of your images, think through this and try to make a proper delay to sync the images. The internal code timing is rock solid, so doing some testing should demonstrate what delays you may need to prevent the input and output from stepping on each other. In practice we have yet to see any problems with this.

Long Strand Issues

When strands get longer, the signal shaping in the WS2812 modules begins to have problems keeping a solid image. With the default timing, we have successfully run 2500 length strands with no problems, in a 4x2500 configuration. For longer strands, such as the 2x5000 or 1x10000 configuration, we had to add small delays on output timing to prevent signals from "bunching up" and dropping signal. This is accomplished by the **`set bitdelay`** command. The default bitdelay of 0 outputs equal spaced timing for each bit, longer delays lengthen the mandatory low between bits.

The delay needed depends on the wiring, especially if there are long connectors between some LEDs. We have found signals seems to get messed up more often where there are long wires between LEDs, where soldering patterns change, etc. For a 10K display we created using 8 panels, each with 1250 LEDs in series, we were able to drive all 10K as one strand using a bit delay between 6 to 99. Larger values resulted in garbage. Arranged as two 5K strands, we were able to use a bit delay of 2. In practice use the lowest value that allows your display to work reliably.

For details see our article "Design and Implementation of Serial LED Gadgets."[5]

Gallery

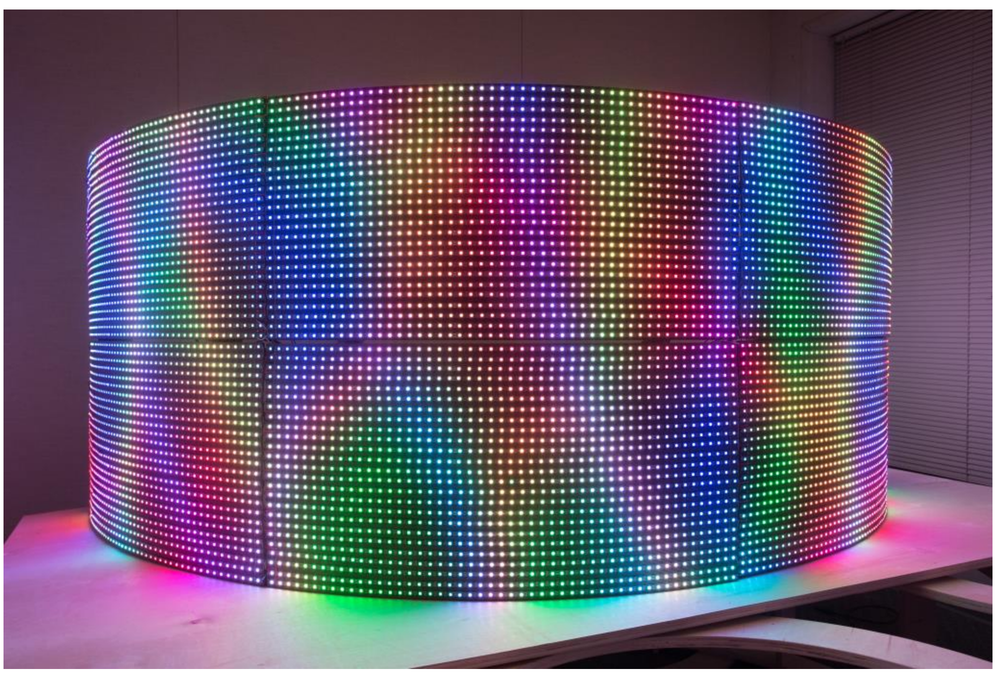


Figure 1 - 10,000 LED curved panel

[5] http://hypnocube.com/2013/12/design-and-implementation-of-serial-led-gadgets/

Figure 1 shows 10,000 LEDs arranged in eight curved panel pieces we made to test all of the **HypnoLSD** features. We set it up to test all combinations of strand counts and lengths to make sure the device can handle many configurations. A video of it running graphics demos we created is available at https://www.youtube.com/watch?v=SzpcPrnh9LY.

Other projects we have made for testing include Christmas lights, 60x16 panel, a conical hat, and numerous other small devices. If you build interesting projects using this device send us a description and images if you want, and we will try to add them to our website and future versions of this document.

Happy hacking ☺

Appendix A - Sample Code

Here are a few code samples to show how to use the **HypnoLSD**.

Sample software can be obtained from http://hypnocube.com/product/led_serial_driver/.

C# Sample

```
using System;
using System.IO.Ports;
using System.Text;
using System.Threading;

namespace Hypnocube.LSD.Sample1
{

    // TODO - explain C# for newbs
    // Don't need to delete like C++
    // We tried to remove most C#-isms from the below to make the code
    // easier to port to C or JAVA. We removed normal XML commenting,
    // implicit variables, the default static class for Main, TODO
    // This C# should work in Linux under mono, Windows, and Mac under mono (TODO)
    class Program
    {
        // This is the string used to mark end of a command to the device
        const string CommandEnd = "\r\n";

        // This is the value of a sync byte used for sending images.
        // Images cannot have this byte in them - we recommend replacing
        // such bytes any with value 255.
        const byte SyncByte = 254;

        // This is a sample program, showing how to set up the device and
        // perform various options
        void SampleProgram(string[] args)
        {
            // get the name of the port we will use
            string portName = "COM8";
            if (args.Length == 1)
                portName = args[0];

            // wrap this in try/catch blocks to catch errors
            try
            {
                // open the serial port at the default rate of 9600
                OpenPort(9600, portName);

                // get attention of the device by sending a few empty lines
                // Also helps in case the built in demos were running.
                WriteString(CommandEnd);
                WriteString(CommandEnd);
                // wait a moment.
                Delay();

                // Ask for the version
                WriteString("version" + CommandEnd);
                Delay();

                // to draw images quickly, we will use a higher baud
                // rate of 115200 (most serial device should support it)
                // This requires a "divider" of 103. (See manual for values).
                int divider = 103;
                WriteString("set speed " + divider + CommandEnd);
                Delay();

                // must close and re-open port
                ClosePort();
                Delay();
```

```
            OpenPort(115200, portName);
            Delay();

            // see if port changed - should see this message
            // if not, increase the delay. Or comment out the code
            // that changes speed, and see if everything works.
            WriteString("get speed" + CommandEnd);
            Delay();


            // now, let's draw some images!
            imageWidth = 4;     // 4 strands wide
            imageHeight = 30;  // 30 pixels tall
            WriteString("set size " + imageWidth + " " + imageHeight + CommandEnd);
            Delay();
            WriteString("get size " + CommandEnd);
            Delay();

            DrawImages();

            // make sure to get the console again
            WriteString(CommandEnd);
            // wait a moment.
            Delay();

            // return to 9600 speed so we don't have to reset the hardware
            // to run this sample again
            divider = 1249; // divider value for 9600 baud
            WriteString("set speed " + divider + CommandEnd);
            Delay();
            ClosePort();
            Delay(); // we put more delays here since 9600 is slow
            OpenPort(9600, portName);
            Delay();

            // check help screen for fun
            WriteString("help" + CommandEnd);
            Thread.Sleep(5000); // wait 5 seconds for all data to come back

            // close port
            ClosePort();
            Delay();

            Console.WriteLine();
            Console.WriteLine();
            Console.WriteLine("Finished running sample code. Press a key to exit.");
            WaitForKeypress();

        }
        catch (Exception e)
        {
            Console.WriteLine("EXCEPTION: " + e.Message);

            // The most common exception is an invalid port name, so
            // we'll output them all here.
            Console.WriteLine("Available port names are:");
            foreach (string name in SerialPort.GetPortNames())
                Console.WriteLine("Port: " + name);

        }

    }

    // since the device is not terribly fast, we recommmend
    // delays between commands in console mode. In drawing mode
    // these are not needed.
    void Delay()
    {
        // 200 millisecond delay
```

```
        Thread.Sleep(200);
    }

    // here is our serial port. Various languages and OSes
    // have different ways of dealing with them.
    SerialPort port;

    // We will open a port given the name and desired baud rate.
    // The device defaults to 9600 baud, 8N1, no handshake, so we
    // set that in here. Since we also want faster signaling than
    // 9600, we allow the baudrate as a parameter.
    void OpenPort(int speed, string portName)
    {
        // if we already have a port, Close it first
        if (port != null)
            ClosePort();

        // create a new port with desired parameters
        port = new SerialPort
        {
            BaudRate = speed,
            DataBits = 8,
            Parity = Parity.None,
            StopBits = StopBits.One,
            Handshake = Handshake.None,
            // C#/.NET needs to change the default encoding on a serial port
            // to get bytes back and forth without interference.
            // This encoding will do it.
            Encoding = Encoding.GetEncoding("Windows-1252")
        };

        // we attach some listeners (think function pointer)
        // to catch errors and returned bytes
        port.DataReceived += DataReceived;
        port.ErrorReceived += ErrorReceived;

        // set the port name, such as "COM2" in windows
        port.PortName = portName;

        // And try to open it.
        // This throws an exception if it cannot be opened.
        port.Open();
    }

    // close the serial port
    void ClosePort()
    {
        if (port != null)
        {
            // remove listeners
            port.DataReceived -= DataReceived;
            port.ErrorReceived -= ErrorReceived;
            if (port.IsOpen)
                port.Close();
        }
        // set to null for safety
        port = null;
    }

    // we send all string commands to the port through here,
    // because strings in C# are unicode, and we must send
    // ASCII strings
    void WriteString(string format, params object[] args)
    {
        byte []  bytes = Encoding.ASCII.GetBytes(String.Format(format, args));
        WriteBytes(bytes);
    }

    // Write an array of bytes to the port.
```

```
void WriteBytes(byte[] data)
{
    if (port.IsOpen)
        port.Write(data, 0, data.Length);
}

// the image width (# of strands 1-16)
int imageWidth;
// the image height (length of a strand)
int imageHeight;
// the image will be stored here as it is constructed, then
// once set, will be sent at once
// The image is stored width first, then height. Each pixel is
// 3 bytes of red, green, blue color (RGB).
byte [] buffer;

// given a coordinate i,j and color red,green,blue,
// set a pixel in the buffer
void SetPixel(int i, int j, int red, int green, int blue)
{
    // pixels go in buffer as:
    int index = (i + j*imageWidth)*3;
    // check bounds
    if (index < 0 || buffer.Length <= index)
        return; // out of bounds. Ignore
    // set the red, green, and blue components
    buffer[index++] = (byte)red;
    buffer[index++] = (byte)green;
    buffer[index]   = (byte)blue;
}

// Fill image with one color. Useful for clears
void Fill(int red, int green, int blue)
{
    for (int i =0 ; i < imageWidth; ++i)
        for (int j = 0; j < imageHeight; ++j)
            SetPixel(i, j, red, green, blue);

}

// this is a very important function. It copies the buffer
// to the device, but first it ensures no SYNC bytes are in the
// image. It replaces any SYNC bytes in the buffer with 255, then
// appends a SYNC byte to notify the gadget that the image is done.
// Finally, it transfers the data over the serial port to the gadget.
// NOTE: the gadget must be in drawing mode for this to work.
void TransferImage()
{
    // remember - we cannot send a sync byte in the image, so
    // we'll remap in place
    for (int i = 0; i < buffer.Length; ++i)
        if (buffer[i] == SyncByte)
            buffer[i] = 255;
    buffer[buffer.Length - 1] = SyncByte; // image ends with a sync byte
    // draw it
    WriteBytes(buffer);
}

// we track drawing mode so we can print returned bytes differently
bool drawing = false;

void DrawImages()
{
    // each pixel needs three bytes for RGB
    // we add one byte to append a SYNC byte
    buffer = new byte[imageWidth * imageHeight * 3 + 1];

    // enter draw mode
    drawing = true;
```

```
            WriteString("draw" + CommandEnd);
            Delay();

            Console.WriteLine("Press a key for red");
            WaitForKeypress();

            // Fill buffer with red
            Fill(255,0,0);

            // send the image to the device
            TransferImage();

            // green
            Console.WriteLine("Press a key for green");
            WaitForKeypress();
            Fill(0, 255, 0);
            TransferImage();

            // blue
            Console.WriteLine("Press a key for blue");
            WaitForKeypress();
            Fill(0, 0, 255);
            TransferImage();

            Console.WriteLine("Press a key for a plasma");
            WaitForKeypress();

            // do a demo of something more complex
            ShowPlasma();

            // clear image before exiting
            Fill(0,0,0);
            TransferImage();

            // exit drawing - spec calls for 2 sync bytes, but we send three to make sure :)
            byte [] syncs = new byte[] {SyncByte, SyncByte, SyncByte};
            WriteBytes(syncs);
            Delay();
            drawing = false;
        }

        // show a plasma colored demo until a key is pressed
        void ShowPlasma()
        {
            Console.WriteLine("Press a key to exit plasma");

            int frame = 0;
            while (Console.KeyAvailable == false)
            {
                // fill the image
                for (int i = 0; i < imageWidth; ++i)
                    for (int j = 0; j < imageHeight; ++j)
                    {

                        // compute some colors based on position and frame
                        double angle = frame/10.0;
                        double c = Math.Sin(
                            angle +
                            Math.Sin(i/10.0+angle/10.0) +
                            12*Math.Cos(j/27.0+i/30.0)
                            );
                        // c is in -1 to 1, so map to 0-255 for red
                        int red = (int)(((c + 1) / 2.0 * 255.0));

                        // do similarly for green and blue
                        c = Math.Sin(
                            1.1*angle +
                            1.2*Math.Sin(i / 13.0 + angle / 12.0) +
                            7 * Math.Cos(j / 22.0 + i / 27.0)
```

```
                        );
                    int green = (int)(((c + 1) / 2.0 * 255.0));

                    c = Math.Sin(
                        0.9*angle +
                        1.7*Math.Sin(i / 9.0 + angle / 13.0) +
                        9 * Math.Cos(j / 31.0 + i / 28.0)
                        );
                    int blue = (int)(((c + 1) / 2.0 * 255.0));


                    SetPixel(i,j,red,green,blue);
                }

            // send the image to the device
            TransferImage();


            // Wait a moment to avoid moving too fast :)
            //Thread.Sleep(100);

            // next frame - causes change over time
            ++frame;
        }

        // read any keypresses before returning
        while (Console.KeyAvailable == true)
            Console.ReadKey(true);
    }

    // wait for a key to be pressed.
    // this differs in many languages/OSes, but
    // the same C# code should work.
    void WaitForKeypress()
    {
        // wait for keypress
        while (Console.KeyAvailable == false)
            Delay();
        // absorb keypresses
        while (Console.KeyAvailable == true)
            Console.ReadKey(true);
    }

    // when the serial port sees data, it comes to here, and is output
    // to the console. The color depends on if we're in drawing mode or
    // not.
    private void DataReceived(object sender, SerialDataReceivedEventArgs e)
    {
        SerialPort senderPort = (SerialPort) sender;
        int bytesToRead = senderPort.BytesToRead;
        byte [] data = new byte[bytesToRead];
        senderPort.Read(data, 0, bytesToRead);
        ConsoleColor foregroundColor = Console.ForegroundColor;
        if (drawing == true)
            Console.ForegroundColor = ConsoleColor.Cyan;
        else
            Console.ForegroundColor = ConsoleColor.Yellow;
        foreach (byte b in data)
        {
            // if the byte is printable ASCII, show it as such, else
            // show the byte value in brackets []
            if ((32 <= b && b < 128) || b == 8 || b == 10 || b == 13)
                Console.Write((char) b);
            else
                Console.Write("[" + (int)b + "]");
        }
        // restore the foreground color
        Console.ForegroundColor = foregroundColor;
    }
```

```
        // serial port errors come through here and are output in red.
        void ErrorReceived(object sender, SerialErrorReceivedEventArgs e)
        {
            ConsoleColor foreground = Console.ForegroundColor;
            Console.ForegroundColor = ConsoleColor.Red; // set an error color
            Console.Error.WriteLine("Port error {0}", e.EventType);
            Console.ForegroundColor = foreground;
        }

        // C# console programs start here
        static void Main(string[] args)
        {
            // create a new instance of this program
            Program program = new Program();

            // and run it
            program.SampleProgram(args);
        }

    }
}
```

Appendix B – Software/hardware version history

Software

- 1.0 - Nov 2013 – June 2014
  Original (unshipped) version.
- 1.1 – July 2014
  Fixes a rare timing glitch that locks up the chip.

Hardware

- 1.0 – Nov 2013
  Initial internal release
- 1.1 - July 2014
  First commercial release. Adds voltage correction to make strands more reliable.

Appendix C – Document History

- 0.1 - Sept 2013
  Preliminary Release before hardware available
- 1.0 - Feb 2014
  Second preliminary release.
- 1.1 - July 2014
  Final release.
  Hardware and software ready.
  Gallery and code samples included.

END OF DOCUMENT