Electronic Display Logic Board

Marquette University Senior Design 2018–2019, Group E44

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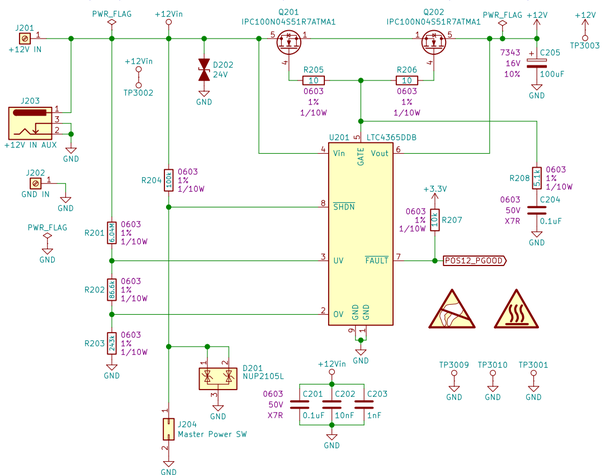
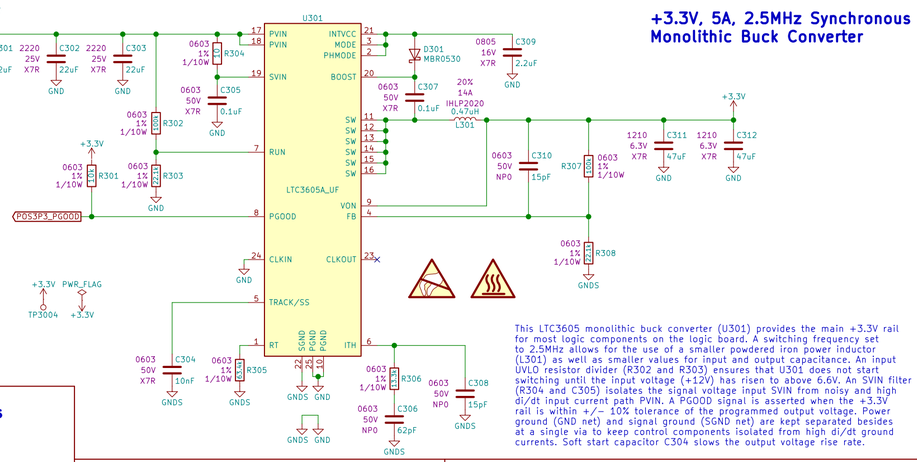
+12V Power Input, Reverse Polarity Protection, Gating

The input protection circuit ensures that downstream components on the logic board won't be damaged when subjected to abnormal input voltage. The LTC4365 (U201) monitors the input voltage, and when the applied input voltage is above 10V and below 14V, it allows MOSFETs Q201 and Q202 to conduct. If the applied intput voltage is outside of this range or connected in reverse, Q201 and Q202 are turned off, and downstream circuits are protected. Soft start filter R208 and C204 slow down the gate drive charge pump from U201, and ensure that the +12V voltage (and inrush current into the logic board) rise at a controlled and stable rate. A toggle switch connected to J204 allows the entire logic board to be powered down manually. Tank capacitor C205 provides an on-board DC source for downstream components when the input voltage is connected through large lead inductances. A PGOOD signal is asserted when input voltage is within range.

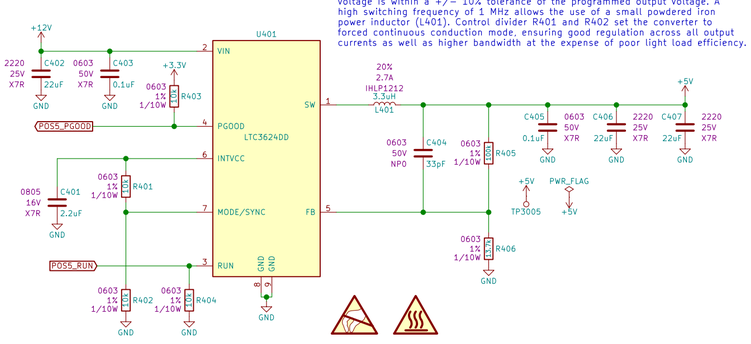


+3.3V, 5A, 2.5MHz Synchronous Monolithic Buck Converter



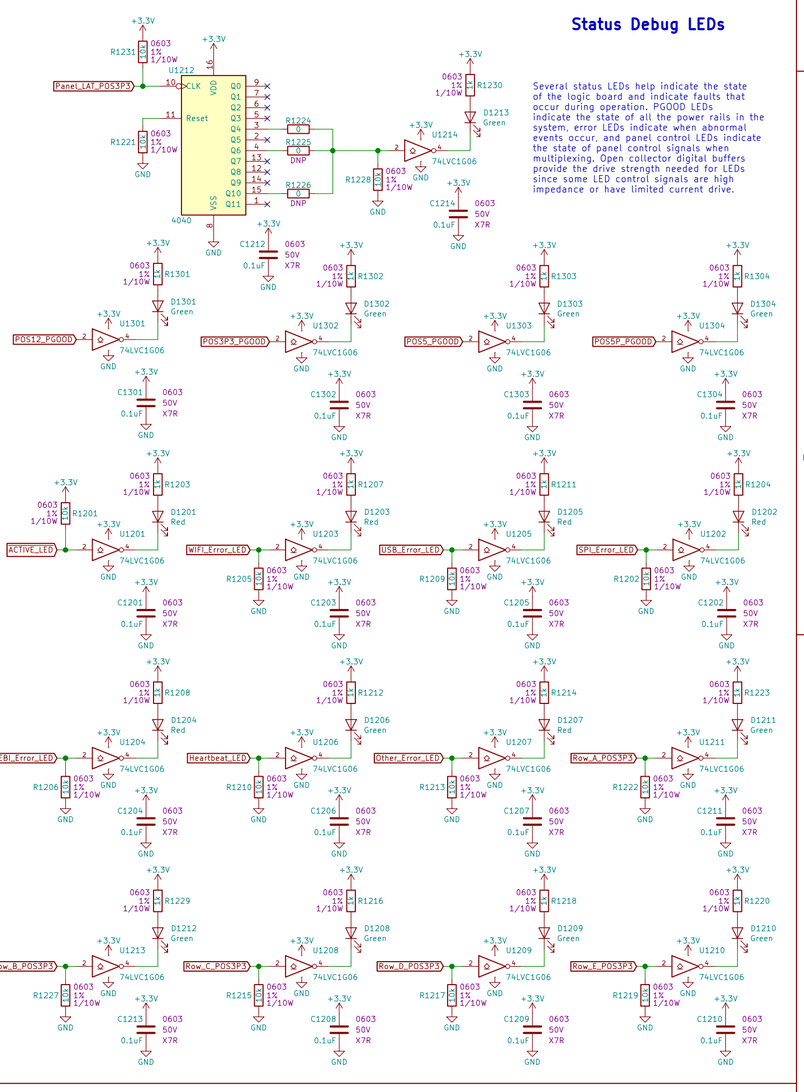
This LTC3605 monolithic buck converter (U301) provides the main +3.3V rail for most logic components on the logic board. A switching frequency set to 2.5MHz allows for the use of a smaller powdered iron power inductor (L301) as well as smaller values for input and output capacitance. An input UVLO resistor divider (R302 and R303) ensures that U301 does not start switching until the input voltage (+12V) has risen to above 6.6V. An SVIN filter (R304 and C305) isolates the signal voltage input SVIN from noisy and high di/dt input current path PVIN. A PGOOD signal is asserted when the +3.3V rail is within +/- 10% tolerance of the programmed output voltage. Power ground (GND net) and signal ground (SGND net) are kept separated besides at a single via to keep control components isolated from high di/dt ground currents. Soft start capacitor C304 slows the output voltage rise rate.

+5V, 2A, 1MHz Synchronous Monolithic Buck Converter



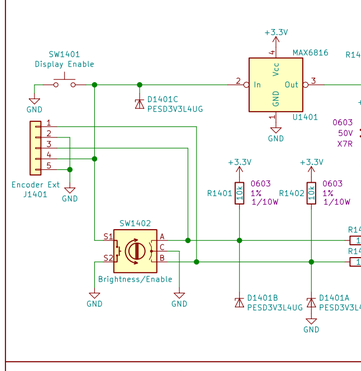
The LTC3624 monolithic buck converter (U401) regulates the +5V rail used for panel data level shifters. It provides a stable voltage that allows the logic board output signals to match the CMOS logic levels of the data shift registers and control signal gates on the LED panels that the logic board is controlling. This helps ensure that all signals driven by the logic board are correctly interpreted as logic high and logic low by the LED panels. This converter can be enabled and disabled by the microcontroller, and a PGOOD signal is asserted when output voltage is within a +/— 10% tolerance of the programmed output voltage. A high switching frequency of 1 MHz allows the use of a small powdered iron power inductor (L401). Control divider R401 and R402 set the converter to forced continuous conduction mode, ensuring good regulation across all output currents as well as higher bandwidth at the expense of poor light load efficiency.

Status Debug LEDs



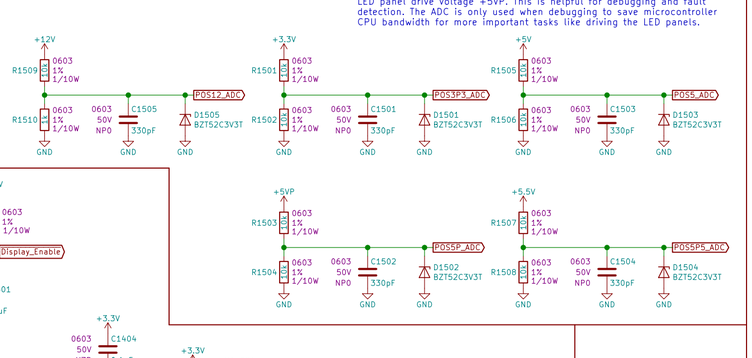
Several status LEDs help indicate the state of the logic board and indicate faults that occur during operation. PGOOD LEDs indicate the state of all the power rails in the system, error LEDs indicate when abnormal events occur, and panel control LEDs indicate the state of panel control signals when multiplexing. Open collector digital buffers provide the drive strength needed for LEDs since some LED control signals are high impedance or have limited current drive.

Brightness Selection Rotary Encoder



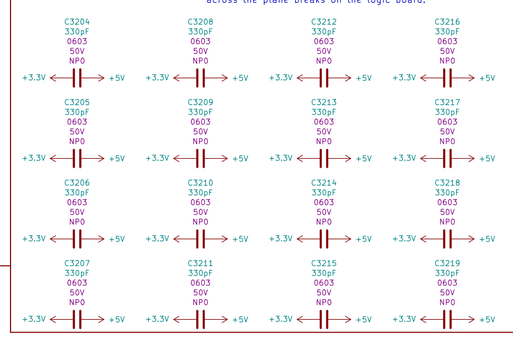
A rotary encoder allows users to control the brightness of the LED panels. A sequential logic circuit makes firmware development for interpreting the encoder signals easier. A pushbutton debouncer IC ensures that the pushbutton to the microcontroller is clean when the encoder pushbutton is pressed. Turning the rotary encoder allows the panels to be dimmed, while pressing the encoder pushbutton allows the screen to be turned on and off.

Voltage Monitoring ADC Dividers/Filters



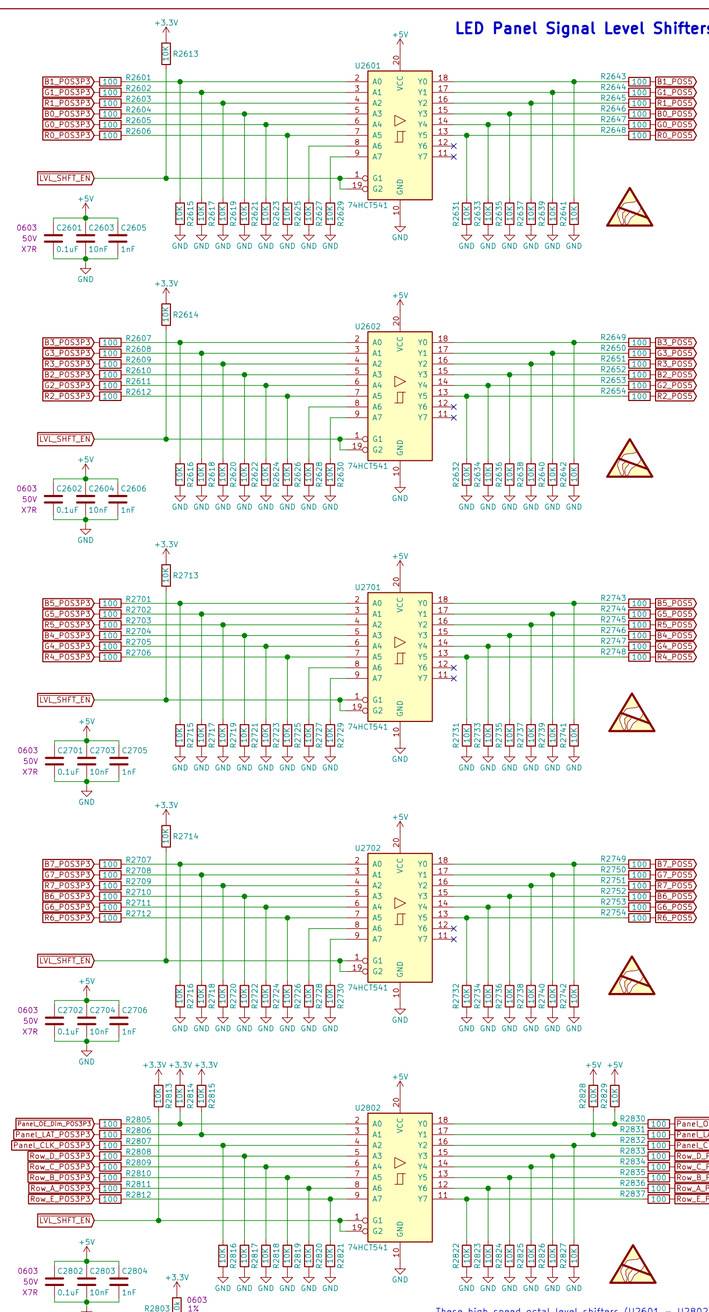
Voltage dividers and filters allow the microcontroller's analog to digital converter to measure all voltage rails on the logic board, as well as the LED panel drive voltage +5VP. This is helpful for debugging and fault detection. The ADC is only used when debugging to save microcontroller CPU bandwidth for more important tasks like driving the LED panels.

Stitching Capacitors



High frequency stitching capacitors placed across breaks in the printed circuit board power planes keep signal return currents from travelling long distances. Allowing a high frequency capacitive return path across breaks in reference planes ensures that PCB traces respond as better transmission lines, minimizes radiated electromagnetic interference, and minimizes signal cross talk. This helps keep PCB traces as close to ideal as possible. A number of capacitors are scattered across the plane breaks on the logic board.

LED Panel Signal Level Shifters



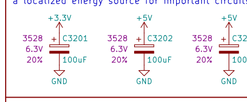
These high speed octal level shifters (U2601 – U2802) are needed because while the microcontroller operates at a 3.3V logic level, the LED panels require incoming data to be at a 5V logic level. By shifting the panel control logic signals, signal integrity is maintained when driving the LED panels, even at high speeds of around 6 MHz. These level shifters ensure that the LED panels interpret logic low's and logic high's correctly, and at the right times. There are level shifters for the RGB signals for each string of panels, and a fifth level shifter for the panel row select and control signals (CLK, LAT and OE). A single OR gate (U2801) allows the microcontroller to adjust the brightness of the LED panels with a pulse width modulated (PWM) square wave. The OR gate allows the microcontroller to force the LED panels to be disabled while loading data into them, but allows the PWM signal to dim the display while data is not being shifted.

Power Supply Interface Circuits

These digital buffers allow the MCU to interface with an external power supply which powers the actual LED panels. Signals travelling between the two boards include the output voltage of the external supply (+5VP), a PGOOD signal, a RUN signal, and a THWN signal, which signals if the power supply's temperature rises too high. The power supply is a quad-phase +12V to +5V buck converter based on the LTC7851 from Linear Technology. It switches at 1 MHz and has a maximum output current of 45 Amps. This satisfies the power requirements of all the LEDs in the display set to maximum brightness with a white color.

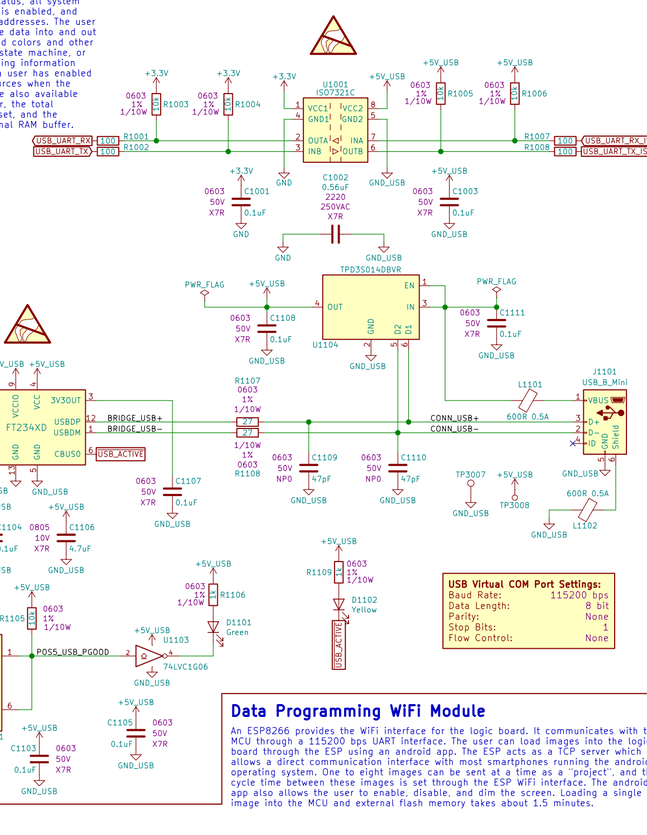
Tank Capacitors

These tank capacitors supply a strong DC source to circuits located a long physical distance from the DC/DC power supplies on the PCB. This helps keep the +3.3V and +5V rails stable across a variety of load conditions, and provides a localized energy source for important circuits across the PCB.



USB Serial Debug Virtual COM Port

A UART to USB bridge provides the USB debugging hardware features. This circuit is incredibly ruggedized, with U1001 providing digital isolation and U1104 acting as a USB circuit breaker and ESD protection. This 115.2 kbs virtual COM port allows users to communicate with the logic board through a USB serial program such as PuTTY or Tera Term. This provides tremendous flexibility for debugging issues with the system and providing the user with data. Serial commands allow the user to see which MCU peripherals are enabled or disabled, see all information about MCU interrupt status, all system voltage measurements when the MCU ADC is enabled, and WiFi information such as the IP and MAC addresses. The user can also directly control the flow of image data into and out of the MCU, directly set the screen to solid colors and other patterns, or allow the standard operation state machine, or "autopilot", to control the display. Debugging information is only printed over the serial port when a user has enabled the feature, in order to free up MCU resources when the feature is not in use. Serial commands are also available to print the MCU's Microchip serial number, the total device on time since the MCU was last reset, and the contents of the EBI SRAM cache and internal RAM buffer.



Data Programming WiFi Module

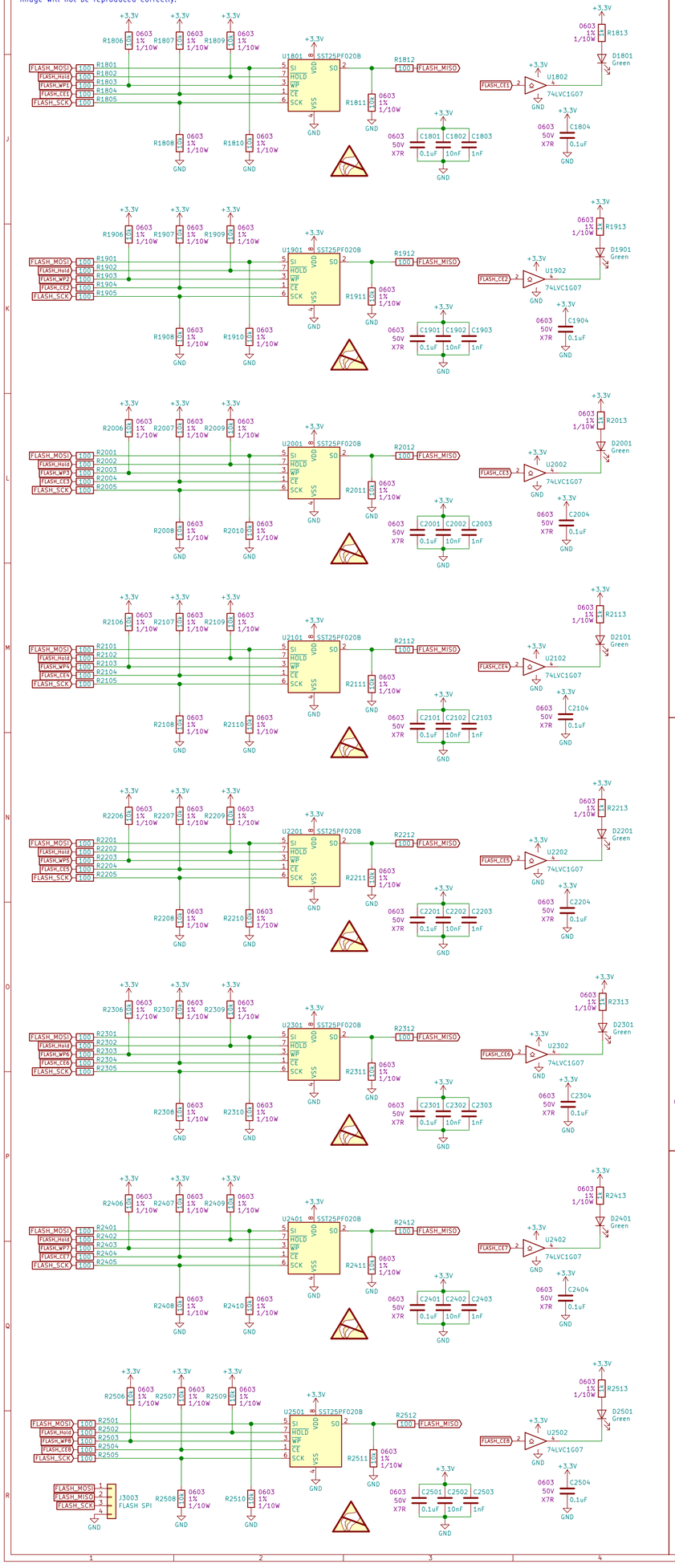
An ESP8266 provides the WiFi interface for the logic board. It communicates with the MCU through a 115200 bps UART interface. The user can load images into the logic board through the ESP using an android app. The ESP acts as a TCP server which allows a direct communication interface with most smartphones running the android operating system. One to eight images can be sent at a time as a "project", and the cycle time between these images is set through the ESP WiFi interface. The android app also allows the user to enable, disable, and dim the screen. Loading a single image into the MCU and external flash memory takes about 1.5 minutes.

USB Virtual COM Port Settings:

Baud Rate:	115200 bps
Data Length:	8 bit
Parity:	None
Stop Bits:	1
Flow Control:	None

External Non-Volatile Serial Peripheral Interface Flash Memory

Eight images worth of data can be stored in serial flash memory, which is non-volatile (NVM). This means that images can be loaded into NVM and will remain there until erased and reprogrammed, even after a power cycle. Writing to and reading from serial NVM is slower than access times to parallel SRAM because the microcontroller communicates with NVM through a serial interface. The parallel SRAM Cache (U1701) is used as an auxillary memory space that NVM data is moved to. This allows data for the next image to be displayed to be read from NVM into parallel SRAM while the currently displayed image remains in the microcontroller's internal RAM. This allows for seamless image transitions. There are a total of 8 serial flash chips, each holding data to display a single image. The memory size of each serial flash chip matches the size of parallel SRAM memory exactly, which means that there is a one to one match of memory address locations of data in both serial flash and parallel SRAM. This helps ensure that data is copied to and from serial flash in the correct memory locations, which is key to properly reproducing an image. If a single byte is copied into the wrong location, the image will not be reproduced correctly.



External SRAM Image Data Cache

Data for the next image to be displayed on the screen is moved from external serial Flash memory (U1801 – U2501) into external parallel SRAM cache (U1701). This allows the image transistion time to be minimized, since moving the 240kB image from parallel SRAM cache into internal RAM is faster than moving it from serial Flash into internal RAM directly. Data in external SRAM is accessible through virtual memory by the microcontroller (U601) through the external bus interface (EBI).

32 bit, 252MHz, 144 pin Microcontroller with 2MB Flash Program Memory, 512kB SRAM Data Memory, and MIPS32 Processor

At the time of writing, the PIC32MZ EF family of microcontrollers was Microchip's newest 32 bit MCU offered. This specific part has the highest memory option, highest pin count, and highest clock speed offered from the family. All of these features were needed to fulfill the extremely demanding requirements for driving the display and controlling the rest of the system. An internal frame buffer in SRAM holds the data to be drawn to the screen. The MCU's ADC is used as a debug feature to measure all voltage rails within the system. Most of the I/O pins were used, and almost all of data memory and program memory was utilized. Firmware was written in C and built with Microchip's XC32 compiler. The speed requirements to draw an image on the screen without flickering were so demanding that the pro license for the compiler was used to highly optimize the MCU firmware. Even with a clock speed of 252 MHz and a prefetch CPU instruction cache, the MCU was just barely fast enough to draw images on the screen without flicker. This just goes to show how much computing horsepower is required for computer graphics.

LED Panel Data Output Connectors

Data is shifted by the microcontroller through the level shifters and the panel data output connectors into the LED panels which make up the screen. Each "half string" of panels has three 320 bit long shift registers, representing colors red, green, and blue. Each half string has a width of 320 pixels and a height of 32 pixels. There are 8 "half strings" stacked on top of eachother that make up the screen, giving a resolution of 320 pixels by 256 pixels. Data is shifted through these connectors at around 6 MHz, which gives the screen a refresh rate of around 60 Hz.

Hardware/Embedded Firmware: Drew Maatman, Logan Wedel, and Caroline Gilger
Android App Software/Mechanical: Kevin Etta and Tuoxuan Ren
Passive Components with hidden attributes have 0603 package size, 1% resistor tolerance, 1/10W power dissipation, 50V voltage rating, X7R dielectric

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