TL25: KEY DOCUMENT
REQUIREMENT SPECIFICATIONS

Changelog

Date/Time	Updater	Description
2018-10-14T14:40:49Z	Sanket	Document creation and initial population
2018-10-14T14:54:06Z	Rowan 11986156	Added change log
2018-11-25T1:24:06Z	Sanket	Added Reliability Section
2018-11-25T15:04:15Z	Candice 16550155	Revised format and several sections
2018-11-25T17:27:14Z	Jimmy	Updated goals and functional specifications
2018-11-25T10:06:06Z	Rowan 11986156	Milestone 2 prep work
2018-11-25T10:16:02Z	Parth 45738135	Final content addition and edits
2019-2-5T15:34:00Z	Rowan 11986156	Update Citations, Add Executive Summary, Some Editing
2019-02-07T15:30:00Z	Candice 16550155	Revised executive summary Made suggested revisions to sections 1-3
2019-2-10T20:51:00Z	Parth 45738135	Edited executive summary, changed tenses and voice tone

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EXECUTIVE SUMMARY

Our product is a display made of reconfigurable “Tiles”. Each Tile has a Light Emitting Diode (LED) and Infrared (IR) sensor matrix that is sensitive to gestures directly above it. For instance, when an object moves within three inches of the display, the LEDs light up creating a reflection-like effect. The display can display text, and in the future, could be configured to show time, weather, bus information, etc. The Tiles can be rearranged at the user’s discretion to create larger displays and/or displays different shapes. Each Tile connects seamlessly with its neighbors via a magnetic pogo pin connector to avoid cables. The display is internet enabled and can be controlled through an app. Furthermore, the Tile is a visual work of art that you can show off to your friends and family, turning an otherwise mundane surface into a visually stimulating display. [Fig 1] depicts a two-Tile display with a third Tile being added to the display.

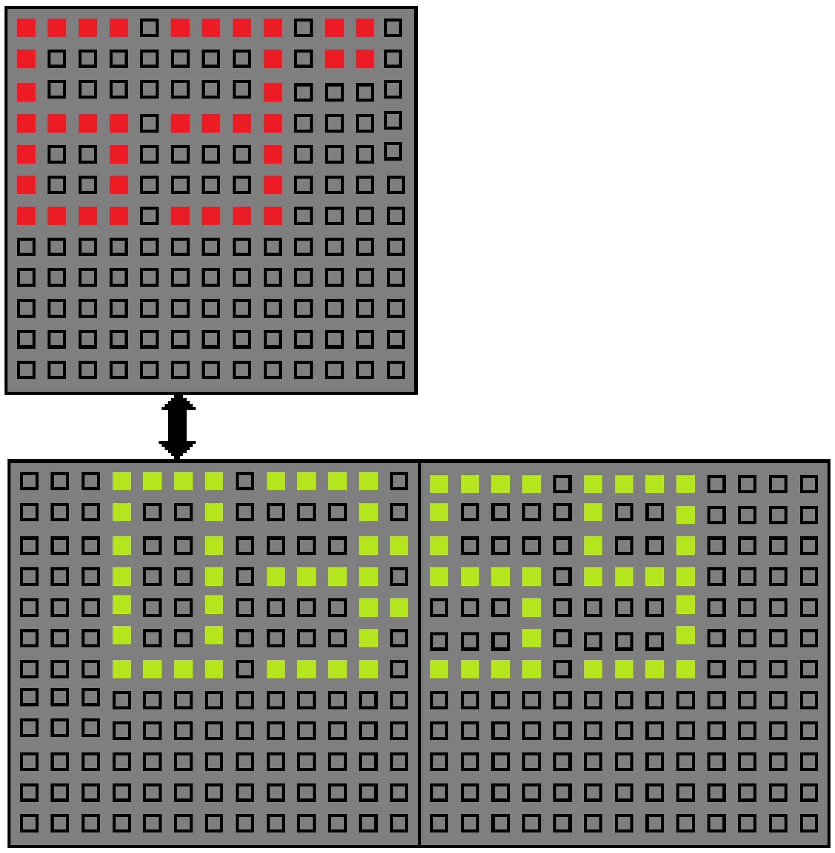

Figure 1: Artistic Depiction of a Three Tile Display

1 - CONTEXT AND BACKGROUND

With the advent of Internet of Things (IoT), the idea of smart homes is picking up traction with consumers. There is a demand for internet enabled entertainment lighting solutions, with the current market leaders being the NanoLeaf and the LIFX Tile [1]. The NanoLeaf Canvas has touch enabled panels but is only capable of displaying a single color per panel, while the LIFX Tile can display multiple colors per LIFX Tile but uses a cumbersome cable management system. Neither of these products are responsive to movement or capable of displaying text, though some avid engineers have attempted to hack their LIFX Tiles to do just that [2].

Our Client is Lab498, a local tech startup company that is hardware oriented and wants to change the way we interact with power at home. Their flagship product, VoltSafe, aims to magnetically connect wall plugs and control them wirelessly. Our product is an extension of their vision for smarter homes. They have asked our team to create a proof of concept modular display capable of gesture responsiveness, text display, on the fly reconfigurability, and internet connectivity.

2 - DOMAIN

Our project, the responsive modular LED display, falls under the smart home technology domain, an emerging market that is currently valued at $31 billion in the United States and is projected to reach an excess of $50 billion by 2022 [3]. The main competing products to our project are the NanoLeaf Canvas and the LIFX Tile.

3 - GOALS

3.1 - Cost

The product is intended to be competitive on the consumer market, so the cost must be comparable to the NanoLeaf Canvas retailing at 9 panels for $299.99 [4] and the LIFX Tile retailing at 5 Tiles for $249.99 [5].

3.2 - Wireless Connectivity

To be a smart home device, the product must incorporate wireless communication to allow users to connect a mobile phone. Users will be able to change the colour, brightness, and text displayed on the Tile over Wi-Fi. In the future, incorporating wireless connectivity as an open source Application Programming Interface (API) will allow integration with smart home controllers like Google Home and Alexa and let users create their own applications to control the responsive modular display.

4 - Functional Specification

4.1 - Real Time Feedback

The Tiles must mirror movements directly in front of them in real-time. They must also be able to interpret and change operating modes based on gestures. These features will provide a level of interactivity not present in comparable products such as the NanoLeaf Canvas.

4.2 - Modularity

4.2.1 - Dynamic Addition and Removal of Devices

One of the key features of this product must be the ability to add and remove devices dynamically. The devices must have a fast “plug-and-play” setup to allow users to adjust the size and shape of their display as needed. Additionally, this would add flexibility in powering up the whole display from any of the Tiles.

4.2.2 - Unified Display

Tiles must connect to each other to form a larger unified seamless display. For example, if four Tiles are connected in series, then a message must scroll across all 4 Tiles as if it was one long display.

5 - Non-Functional Specifications

5.1 - Reliability

5.1.1 - Electrical Components

Electrical components, if handled correctly, have a long operating life expectancy. Key factors for reliable preservation of the main components on the test Printed Circuit Board (PCB) are outlined below according to the manufacturer datasheets.

<u>IR Phototransistor (VEMT2020x01)</u>
Recommended operating temperature is (-40 - 100◌̊C) [6].

<u>LED (COM-14608)</u>
Recommended operating temperature is (-40 – 70◌̊C) [7]. We need to take caution against electrostatic discharge and heat generated from the LEDs when making the system design.

Furthermore, since the product uses IR Sensors for reliable operation, a robust heat dissipation system must be designed within our PCB to ensure that the heat generated from the LEDs does not affect the IR Sensor readings.

5.1.2 - Mechanical Components

The Tiles must connect using pogo pins and magnets like the Apple magsafe connectors. Pogo pins are typically rated for a minimum of 10,000 cycles, which must be enough for a multi-year lifetime expectancy. We may face reliability issues in the following areas:

- Pogo pins are not designed to transfer high speed data’.
- The female mating pad can get corroded and contaminated increasing the contact resistance through the connection making it more difficult for low voltage, high speed signals to be transmitted.
- The internal spring must make good contact with the pogo pins plunger and base. But this can get worn over time and lead to improper contact between the pin and the pad. A solution to this is mentioned in (section 5.2.1 - Connection, Key Documents Design).

5.2 - Aesthetics

The Tiles must be visually appealing on a wall or table during operation and when powered off. This means that connected Tiles must appear as one seamless display. LEDs must not be uncomfortably bright (< 10000 Lux) and the packaging must be slim and sleek.

6 - CONSTRAINTS

6.1 - Regulations and Safety

All components, especially the power distribution system, must be compliant with current regulations set by the Institute of Electrical and Electronics Engineers (IEEE) and other relevant regulatory bodies. Although creating our own AC/DC power converter will reduce costs, it will pose regulatory and safety constraints in the product design timeline [8].

6.2 - Power Management

In North America, 1800W is the typical maximum power an outlet can provide. Products must ideally not consume more than 600W. Thus, the total modular display must consume less than 600W.

6.3 - Size

Each module must be smaller than 20 cm by 20 cm as per client specification.

6.4 - Display Resolution

The Tiles must have a minimum display resolution to outline moving objects as well as display text. Text requires a minimum of 5x7 pixels per character.

6.5 - Object Detection

6.5.1 - Detection Resolution

The sensors must have a minimum resolution of 1.7 cm by 1.7 cm.

6.5.2 - Detection Distance

The Tiles must be able to detect an object up to 10 cm away.

GLOSSARY OF TERMS

API	An Application Programming Interface is a set of functions and procedures allowing the creation of applications that access the features or data of an operating system, application, or other service.
IR	Infrared is a spectrum of non-visible light spanning in wavelength from Red (700 nm) to Microwaves (1 mm)
PCB	A Printed Circuit Board is a sheet of layered copper and non-conductive substrate that mechanically supports and electrically connects electronic components via embedded copper tracks.
Phototransistor	A semiconductor junction that alters the level current flowing through it depending on the level of light the junction is exposed to.
Pogo Pin	A spring-loaded conducting device used to connect two PCBs
LED	A Light Emitting Diode is a semiconductor junction that emits light when current flows through it
Lux	The lux is a derived SI unit for measuring the luminous flux per unit area. It is equivalent to 1 lumen per square meter.

CITATIONS

[1] CNet, “CES smart lighting showdown: Lifx squares off with NanoLeaf”, CNet, 2019 [Online]. Available: https://www.cnet.com/news/color-changing-showdown-lifx-squares-off-with-
NanoLeaf-at-ces-2018/. [Accessed: 5-Feb-2019].

[2] K. Wildenradt, *My Custom LIFX Tile Modes and Effects Made with Devicebook.* 2018 Available: https://www.youtube.com/watch?v=nOfBqgVM0Bs [Accessed: 5-Feb-2019]

[3] "Global smart home market size 2016-2022 | Statistic", *Statista*, 2018. [Online]. Available: https://www.statista.com/statistics/682204/global-smart-home-market-size/. [Accessed: 14- Oct- 2018].

[4] N. Canada, "NANOLEAF CANVAS SMARTER KIT", NanoLeaf Shop Canada, 2019. [Online]. Available: https://ca-shop.NanoLeaf.me/products/NanoLeaf-canvas-smarter-kit. [Accessed: 5- Feb- 2019].

[5] Lifi Labs, "LIFX Tile Sets", *lifx.com*, 2019. [Online]. Available: https://www.lifx.com/products/lifx-Tile [Accessed: 5- Feb- 2019].

[6] Vishay Semiconductors., "Silicon NPN Phototransistor," VEMT2000X01, VEMT2020X01 datasheet, 2017.

[7] iPixel LED Light Co., Ltd, "SUPER LED", COM-14608 datasheet.

[8] "The AC-DC Power Supply: Make It or Buy It?", *Electronic Design*, 2018. [Online]. Available: https://www.electronicdesign.com/boards/ac-dc-power-supply-make-it-or-buy-it. [Accessed: 14- Oct- 2018].

TL25: KEY DOCUMENT

Design

Changelog

Date/Time	Updater	Description
2018-10-14T14:40:49Z	Sanket	
2018-10-14T14:51:31Z	Rowan	Document creation and initial population
2018-10-16T09:59:32Z	Rowan 11986156	● Add Design Overview ● Add LED Matrix Design
2018-11-23T13:51:20Z	Jimmy	Added Communication between Tiles Section
2018-11-24T11:28:15Z	Sanket	Added Challenges Section and underneath added ambient light subsection
2018-11-25T11:39:45Z	Rowan	● Added Updated IR Sensor Matrix Section ● Added Citations Section
2018-11-25T13:00:24Z	Jimmy	Update Communication Design (Formerly Communication between Tiles)
2018-11-25T14:00:00Z	Parth	Added section on Power systems design
2018-11-25T14:15:38Z	Candice 16550155	Added hardware calculations to IR sensor section Added to power system design section Major revisions of IR sensor and power system design sections

2018-11-25T19:32:10Z	Rowan 11986156	Milestone 2 prep
2019-02-05-6T5:03:00Z	Rowan 11986156	Add glossary of terms, update sections 1-3
2019-02-10T14:00:00Z	Jimmy 40243140	Added Section 4.3 Position Mapping
2019-02-10-6T17:16:00Z	Sanket	Added Section 6 Wi-Fi Connectivity
2019-02-10-6T18:36:00Z	Candice 16550155	Revised IR sensor resistor justification
2019-02-10-6T23:34:00Z	Parth 45738135	Updated section 5, grammar edits

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1 - Design Overview

The product is an interactive modular display composed of discrete square shaped Tiles that can be rearranged “on the fly” to change the shape and size of the display. Each Tile can respond to gestures directly in front of it and render text and imagery.

Each Tile has a matrix of Light Emitting Diodes (LED) and sensors mounted onto a Printed Circuit Board (PCB). The Tiles can sense movement and display it back onto their LED matrices. [Fig 1] is an artistic representation of a single display of nine Tiles mirroring a hand movement.

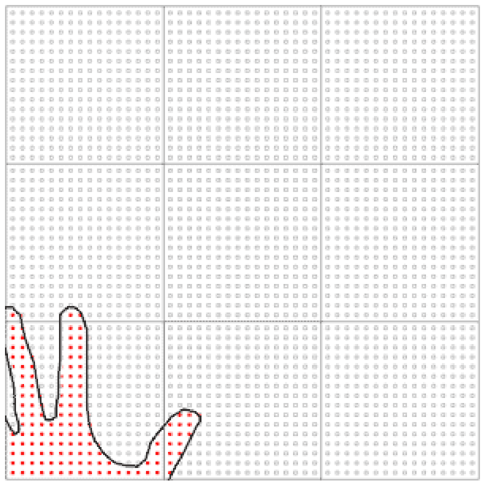
Figure 1: Nine Tile display mirroring a hand gesture

The Tiles connect to each other via a magnetic pogo pin connector. The LEDs matrices are positioned from the edges of the Tile to create a seamless display when multiple Tiles are connected. The display can be powered from any of its Tiles with a magnetic power plug.

The components are protected by a face plate, which is a 3D printed piece that gives the Tile a flat surface and shields the sensors from direct sunlight. An exploded view of the Tile assembly including the PCB, pogo pins, and faceplate can be seen in [Fig 2].

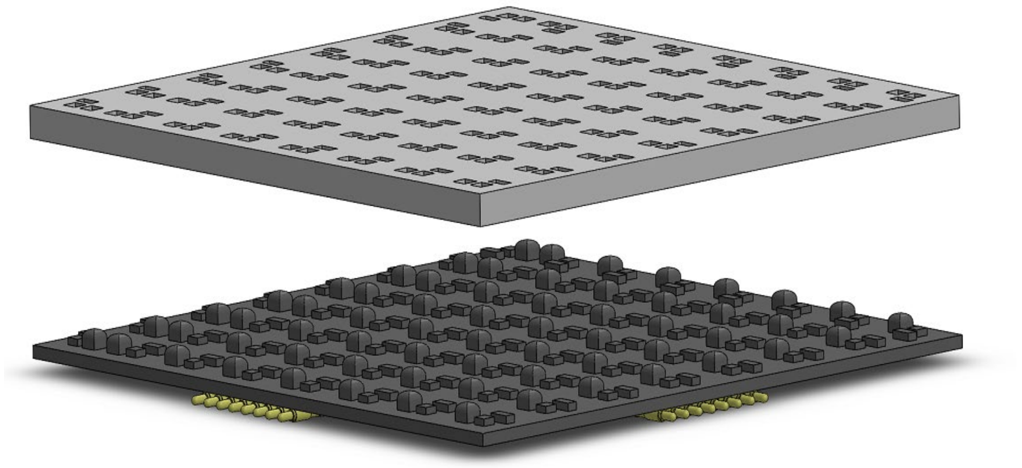
Figure 2: Exploded model view of Tile PCB and faceplate

2 - LED Matrix Design

Each Tile has an 8x8 LED matrix to display text and mirror gestures. This matrix can display at least one 5x7 pixel character of text at a time as per requirement [6.4,1]. The matrix is square with a pixel pitch of 12mm. This gives an overall Tile size of 96mm by 96mm, which satisfies the requirement [6.3, 1]. The LEDs used are an APA102 2020 addressable rgb LED. These LEDs are manufactured by the Adafruit company.

Each LED in the matrix is connected serially via a data line and clock line. Each LED is powered in parallel with 3.3V. See [Fig 3] for the LED connection schematic.

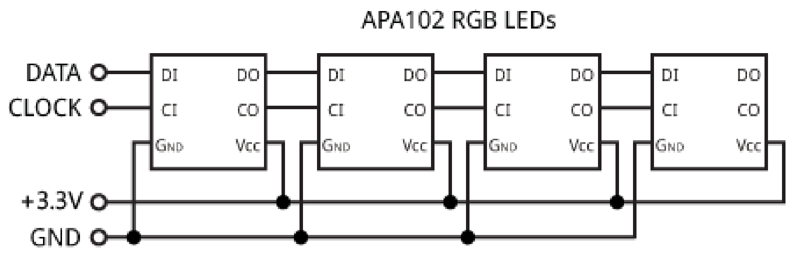

Figure 3: APA102 connection schematic

3 - Infrared Sensor Matrix Design

Each Tile has an 8x8 infrared (IR) sensor IR emitter pair matrix. The sensors are placed horizontally adjacent to the LEDs while the emitters are placed vertically adjacent to the LEDs. The sensor-emitter pairs are spaced by 12mm in a square grid between the LEDs except for the first row and column of the matrices. This ensures that all components fit within the edges of the PCB while maintaining a unique sensor for each LED, which is necessary to meet the sensor resolution requirement as per [6.4.2, 1]. A graphical representation of the LED, sensor, emitter matrix layout can be seen in [Fig 4].

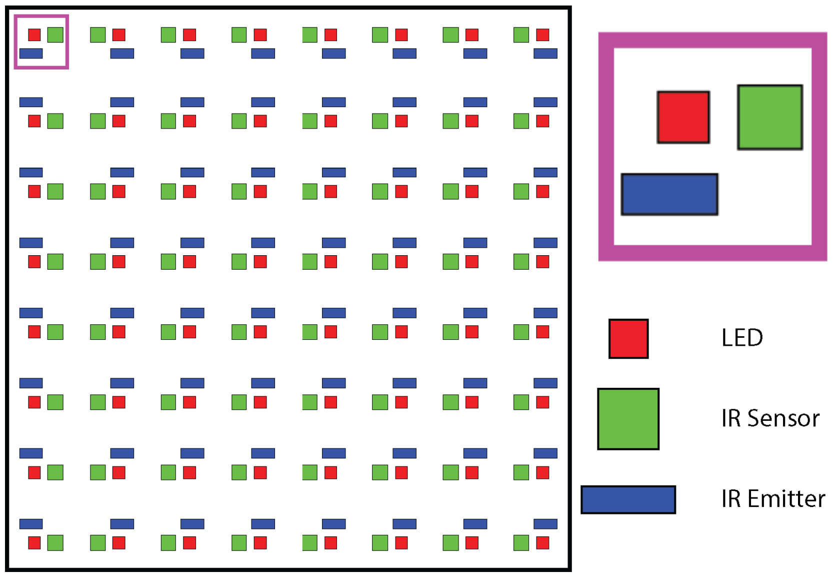

Figure 4: Tile LED and sensor matrix layout

The IR sensor selected is the VEMT2020x01. The IR sensor can be modelled as a BJT. To produce a readable voltage at the output, a resistive load is connected to the emitter of the sensor, as seen in the figure below [Fig 5]. The value of the resistive load is computed as follows with assumptions $I_C \approx I_E$ for $\beta \geq 100$ and $V_{CE(sat)} = .4V$.

$$R_L > \frac{V_{o(max)}}{I_{c(max)}} = \frac{3.3V - .4V}{9mA} = 322\Omega$$

In the interest of decreasing the rise time of the output signal, a smaller resistor is recommended, as it decreases the RC delay generated by the IR sensor circuit. However, there is also an interest in generating enough output voltage difference for a change in distance of the object detected, as this will allow the microcontroller's analog to digital converter (ADC) to detect changes in distance more easily. Thus, the next most common resistor value that satisfies the above requirement, 470Ω, was chosen.

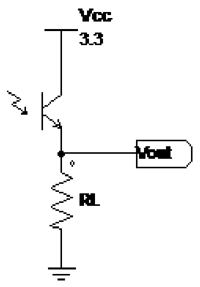

Figure 5: NPN IR phototransistor circuit schematic

For further justification of the IR sensor selection, the output voltage and power dissipation at several input conditions is displayed in the table below.

Table 1: IR sensor power consumption and output voltage

Base Current Condition	$I_{c(dark)} = 100nA$	$I_{c(min)} = 3mA$	$I_{c(max)} = 9mA$
$V_o\ (V)$	47µ	1.01	3.3
$P_{diss}\ (mW)$	.0005	3.03	3

Each IR sensor/emitter pair will be multiplexed. An interrupt subroutine will sequentially turn on emitters and read the sensors using the following logic:

```
if first sensor:
    Turn on current emitter
    Turn on next emitter
    Wait for sensor rise tim        e
    Read current sensor
    Store sensor data
else if not      last sensor:
    Turn on next emitter
    Turn off prev Emitter
    Read current sensor
    Store sensor data
```

```
else:
        Read current Sensor
        Turn off current emitter
        Store sensor data
```

Power consumption will be kept to a minimum, as only a couple of IR emitters will be on simultaneously. Furthermore, because only one IR sensor-emitter pair will be powered at once, the IR reflected will be local for each sensor. Thus, there is no need for blinding the IR sensor/emitter pair from each other.

The faceplate will create a physical barrier between the IR sensor and emitter so only light reflected from the object is detected. A graphic depicting this concept can be seen in [Fig 6].

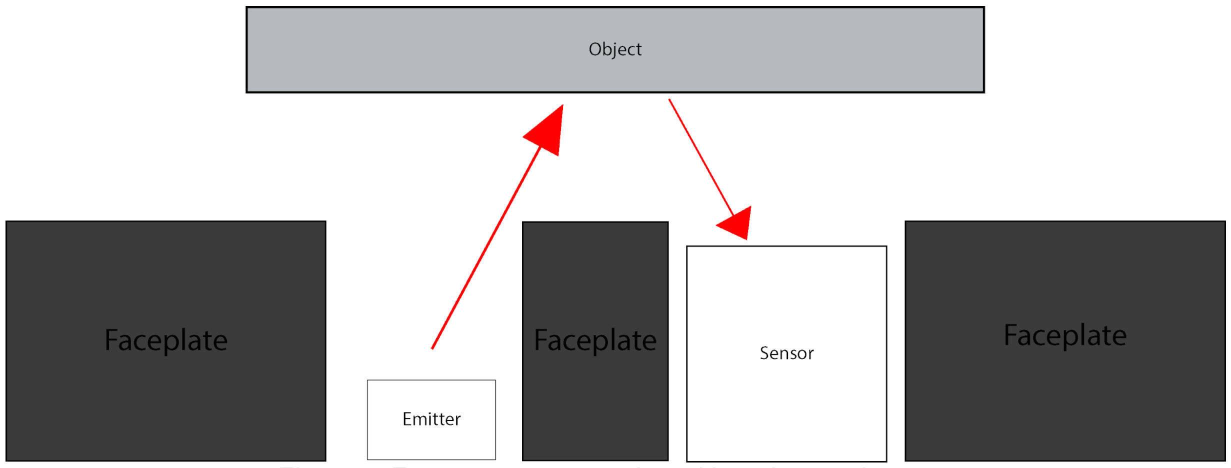

Figure 5: Faceplate cross section with emitter and sensor

The IR emitter selected is the SFH 4056. See [“IR Emitter and Sensor Selection Justification”, 2] for justification.

4 - Communication Design

The inter-Tile communication in a single display is implemented with a serial communication protocol. The Inter-Integrated Circuit (I^2C) serial communication protocol is the best choice for the project as it allows us to:

- Implement the functional requirement of being modular [4.2, 1]
- Satisfy the specification of being able to add and remove devices dynamically [4.2.1, 1]
- Satisfy the specification of creating a unified display by allowing devices to exchange data [4.2.2, 1]
- Satisfy the 8-month constraint of the project

During the planning phase we removed from consideration UART, SPI and CAN Bus for the following reasons:

- Number of total devices on the bus
- Pins required
- Data Transfer Limits

The limits of each serial communication protocol are summarized in the table below.

Table 2: Serial communication protocol comparison

I^2C	SPI	UART	CAN Bus
Up to 127 devices using 7 bit addressing	Up to number of unused GPIO pins	One-to-one device communication	Typically, 30 Nodes [4.12, 3]
1 SCLK (clock) and SDA (data) line	1 MOSI, 1 MISO, 1 SCLK, 1 Slave Select (per slave)	1 Tx, 1 Rx pin	1 Can Hi, 1 Can Lo,
400 Kbits/s	18 Mbits/s	4.5 Mbits/s	1 Mbits/s 8 bytes/message [Figure 3, 3]

4.1 - Modularity

A single master device controls the data flow between all the slave Tiles in the display. Each slave Tile only needs to synchronize with the master and not any other Tiles. UART only supports a one-to-one device communication which does not meet our constraint. Additionally, the SPI interface uses a physical slave select line for each individual slave removing the ability to add or remove slaves dynamically.

One concern with I^2C for this modular method is that devices are usually assigned a fixed address in the code. To address this, we will modify the I^2C software to dynamically allocate addresses as outlined below [Fig 6]. The blue and red boxes represent the slave and master Tiles respectively.

1. Slave device connects to the I^2C bus with default address
2. Master detects a device on default address and will check for the next available address.
3. Master marks the address as unavailable and then sends it to the slave device.
4. Slave receives this address on the I^2C bus
5. Slave re-initialize I^2C hardware with new address.

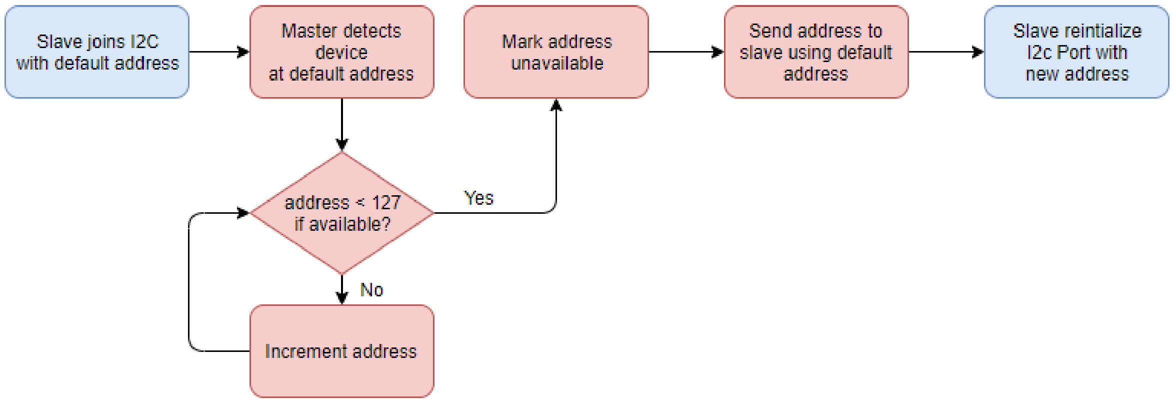
Slave joins I2C with default address
Master detects device at default address
Mark address unavailable
Send address to slave using default address
Slave reintialize I2c Port with new address
address < 127 if available?
Yes
No
Increment address

Figure 6: Dynamic Addressing Flowchart

With the use of dynamic addressing, we can have all slave devices run the same code, simplifying the process of configuring multiple devices. If the master assigns an address as each slave appears it minimizes the risk of having an address belonging to multiple devices.

4.2 - Data Transfer

The decision made between I^2C and Can Bus was based on the data transfer format we expect to use. To find our transfer rate, we used the following sample message to justify our decision.

Sample Data Packet

- 8 bits - position data (4 bits to select 16 horizontal or vertical lines)
- 8 bits - per character data
- 16 bits - RGB data (around 4 bits each for 16 levels of brightness for each colour)

Each character is about 5 by 8 pixels so on a 16 by 16 display we can fit 3 horizontally and 2 vertically. We also have the case where characters are partially on the screen so we can fit a total of 4 characters horizontally and 3 vertically for a total of 12 characters. This means our data packet can vary from 4 bytes to 15 bytes. The varying message length causes an issue on the CAN Bus since the maximum number of bytes contained in a single message is limited to 8 bytes. CAN Bus would require us to possibly send more than one message at a time complicating the communication protocol.

In I^{2}C, given that our maximum data length is 16 bytes (15 bytes + 1 additional byte for address data), we can then calculate the expected speed requirements. NanoLeaf light panels support a maximum of 30 panels [4] and be the number used for analysis. For scrolling text, we will use our targeted frame rate of 24 fps.

$$30\,Tiles\ \times 24\,fps\ \times 16\,bytes\ = 11520\,bytes\ or\ 92160\,bits/s$$

This value is much lower than the maximum data transfer rate of the STM32F103C8 I^{2}C bus of 400 Kbits/s [5]. Therefore, the master can transmit 16 bytes of data to any slave on the I^{2}C bus without concern for speed [Fig 7].

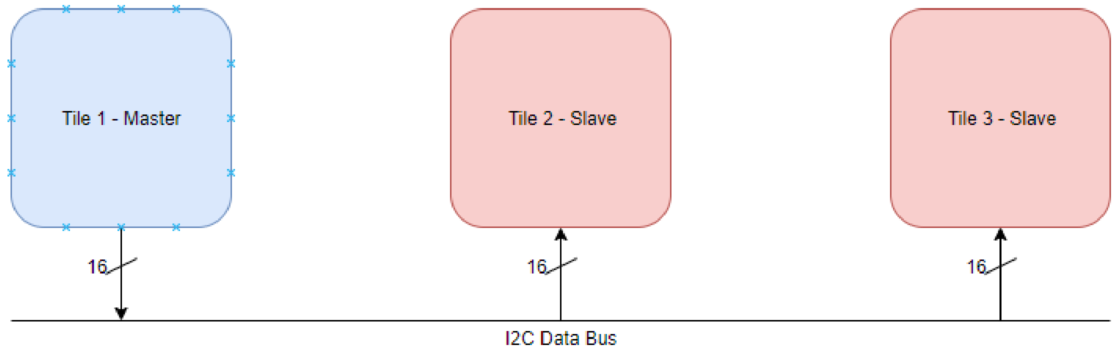

Figure 7: Visual Representation of I2C Bus

4.3 - Position Mapping

The master needs to know the position of each Tile in order to be able to determine what data a Tile gets based on the position the Tile is currently at. Thus, the master will need a method to correctly determine the position of each Tile. We are using a 2D integer array to achieve this functionality.

The master Tile is always located in the center of this 2D array. The array size will also depend on the maximum number of Tiles supported. If X represents the maximum number of Tiles, the array size will be (2X - 1) by (2X - 1). The reason for this size is that for X number of Tiles the maximum length it can extend is X in any one direction.

For example, if we have 4 Tiles our array size will be 7 by 7. The coordinates of the master Tile will then be the center at (4, 4). The 3 other Tiles, represented by T1, T2, and T3, will be located at (5, 4), (6, 4) and (7, 4) if we were only connecting them to the right of the master. All configurations possible with four adjacent Tiles are shown below as white boxes in the following figure [Fig 9].

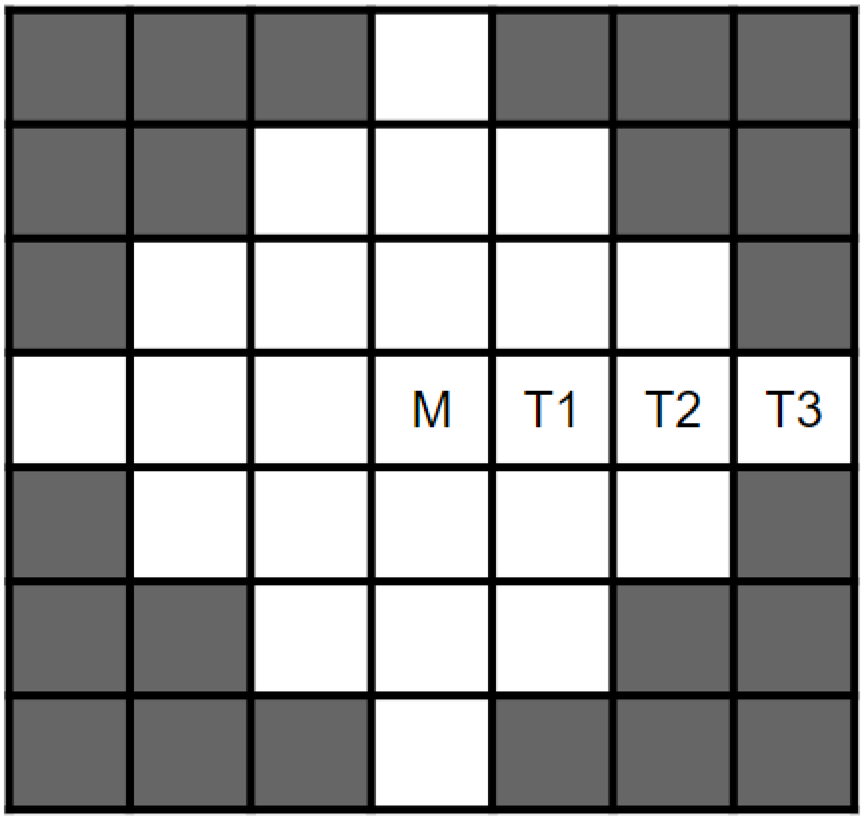

Figure 8: Master Tiles Internal Layout Map

The STM32F103C8 microcontroller we are using has a maximum of 20480 bytes available for variables. Thus, we have a maximum of 5120 four-byte integers for the array. This translates to a 71 x 71 matrix or a maximum of 36 Tiles constraint, which does not restrict our goal of 30 Tiles. The calculation for the maximum number of Tiles is shown below:

$$20480\ bytes \times \frac{1\ integer}{4\ bytes} = 5120\ integers \approx 71.55\ \times 71.55\ integers$$

$$\therefore (2X - 1) = 71.55 \Rightarrow X\ \approx 36.2\ Tiles$$

As mentioned in section 4.1, the slave Tiles will start with the default address and dynamically assign new addresses as they join the bus. Each address assigned also has an identification number associated with it. The master must place these identification numbers at the correct coordinates in the 2D array. To achieve this, each Tile has four directional input pins corresponding to up, down, left and right. This will help determine the relative location of a connected Tile. The algorithm we will use is summarized below.

1. Each Tile polls the status of its four directional pins.
2. Each Tile continuously monitors a change in the value of the pins raises a flag for that direction when it detects change.
3. The master polls every Tile to see if the flag has been raised. If there is, the new Tile's position can be determined using the coordinates of the currently polled Tile.
4. The master checks the I^2C bus for a slave using the default address. If detected, the master sends the next available address for use to that slave Tile.
5. The master fills the array using the coordinates determined in step 3 and the identification number of the assigned address in step 4 upon successful communication.

5 - Power System Design

5.1 - Power Requirements

The display consists of a variable number of Tiles, which, as of now we have restricted to 30 per display. An individual Tile requires a relatively small amount of continuous power (.875W - 1W). However, a whole display may have variable power requirements depending on number of Tiles and the content displayed. Hence, due to a maximum Tile configuration of 30 Tiles (30W), the maximum available power supply needs to be high and at the same time be able to regulate to lower power with minimum power loss as other forms of energy, such as heat.

The generally accepted rating when considering inrush current is approximately 20 times [6], but because our system is primarily low power and will not have many large reactive elements, in consideration of the lifetime of the LEDs 10 times the estimated maximum power consumption would be ideal. Although, in the scope of this capstone project, a power adapter rated 60W will be used.

5.2 - Power Design Features

5.2.1 - Connection

The display can be powered from any Tile. A Tile will consist of a connection port on each of the 4 sides with 2 male connection ports on the top and right, and 2 female ports on the bottom and left sides which also connect to the power cord [Fig 11]. They will be held together on each side by neodymium magnets.

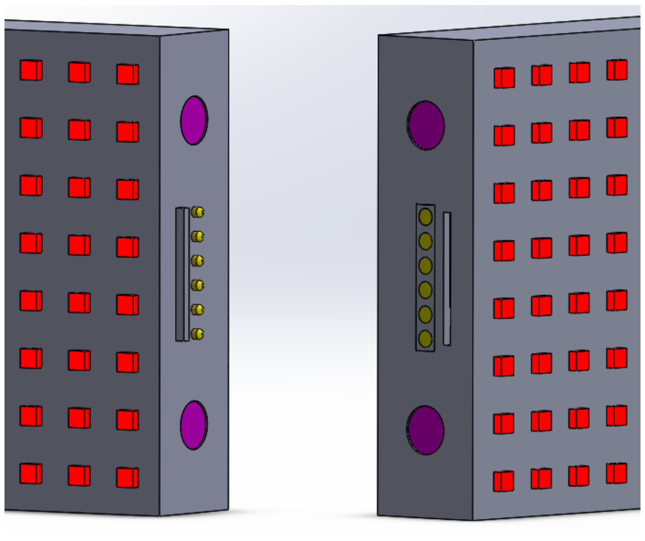

Figure 9: Pogo connectors on Tiles

Magnetic pogo pin connectors are used which have a current rating of 2 Amps(A). Besides the 2 data pins, each port will consist of 4 pogo pins for power flow as opposed to just 2 since that allows lowering the voltage supply to half, while supplying the same power. With 2 voltage pins we can supply maximum 4A. To extend the life of pogo pins if we pass half the current limit through each of them (=1A), to provide 30W of power, we would need:

$$V = \frac{P}{I} \Rightarrow V > \frac{30W}{1A} = 15V$$

The voltage pins in each connector will be installed symmetrically to allow for 2 connection configurations, as shown in [Fig 11].

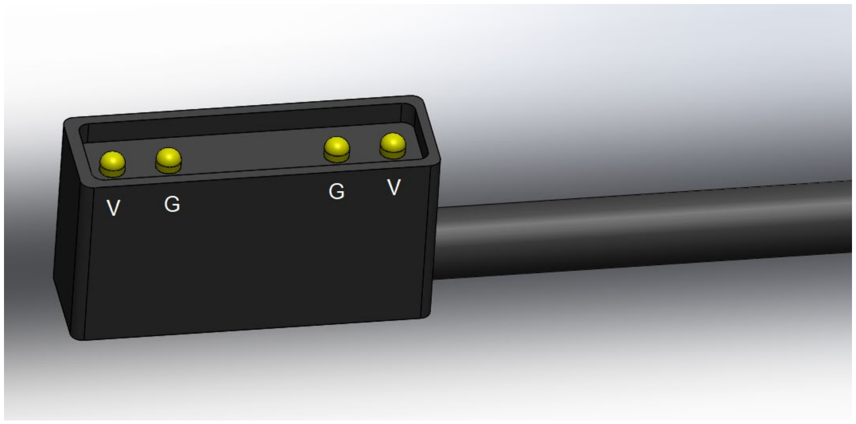

Figure 10: Power Cord Connector Model

A power adaptor of **18V/ 3.61A (65W power)** has been chosen to allow for enough room in power while considering current constraints on pins. This will consist of an AC/DC converter and will hence feed DC power into the connected Tile. This 65W DC power line will run across each Tile, allowing the Tile to use a small amount of power from the bus and remaining power to flow into the connected Tiles.

5.2.2 - Efficient Power conversion

Stepping down from high power supply a high voltage bus to a much smaller one for each module requires stepping voltage down while still being able to pull required current.

If each Tile's: $P = 1W$ at $V = 3.3V$,

Then, $I_{in} = \frac{1W}{3.3V} = 0.303A$ (input current per Tile)

DC/DC buck converter - The purpose of this device is to convert the 18V output of the AC/DC converter to 3.3V for use by the microcontroller, LEDs, IR sensors and emitters. Buck convertors operate at about 96% efficiency and can step up the input current to supply enough current to the Tiles' components. This allows us to pass more current in our Tiles' components than the AC/DC converter would provide.

The buck converter provides 1W using an 18V input and minimum required current:

$$P_{in} = I_{in}V_{in} \Rightarrow I_{in} = \frac{1W}{18V} = 55.56mA \text{ (input current per Tile)}$$

This is **1.667A** of total current draw for max configuration of 10 Tiles and hence the supply of 3.6A will be enough. The buck convertor will subsequently provide power (in parallel) to the components within the Tile as seen in [Fig 12].

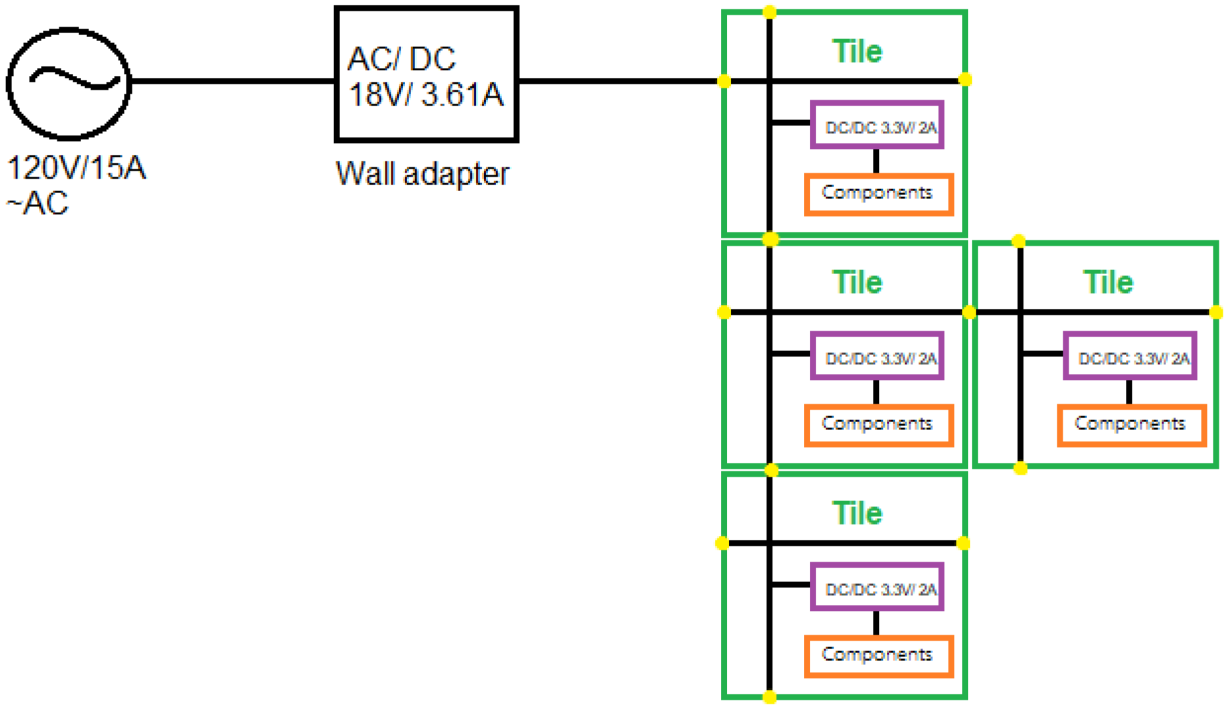

Figure 11: Visual of Power Distribution

6 - Wi-Fi Connectivity Design

A key aspect of the product is giving the user freedom to control the display wirelessly. This is achieved by using the Wi-Fi communication protocol connected to a basic Android application. The below figure [Fig 13] visualizes the communication pathway taken by the data from the app to the Tile.

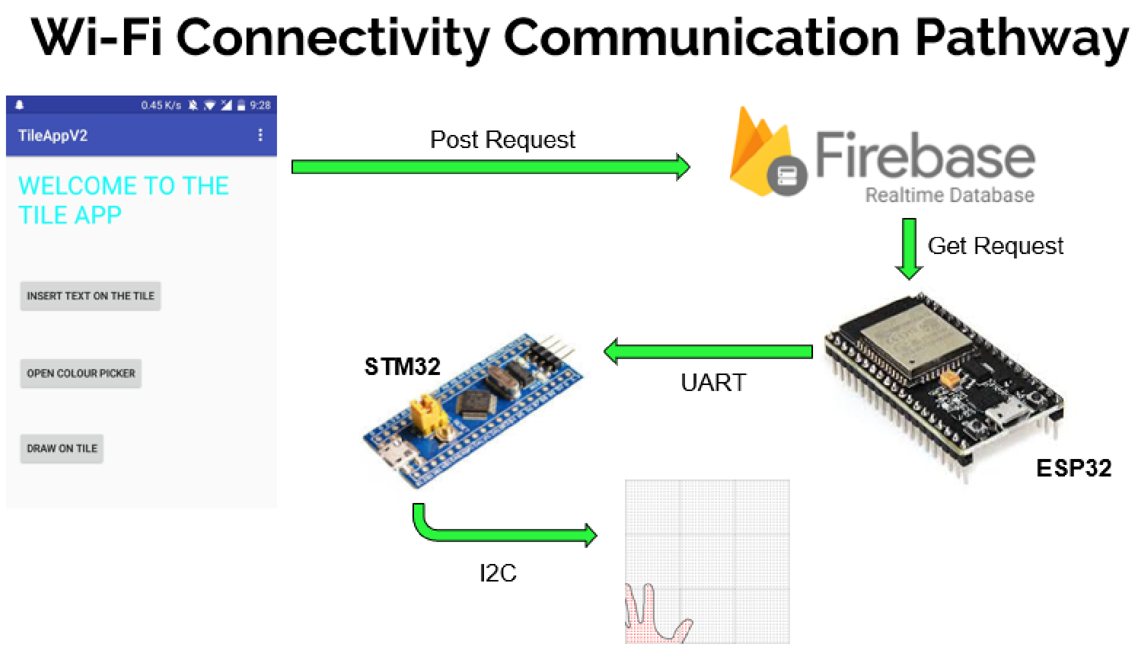

Figure 12: Wi-Fi Connectivity Communication Pathway

The communication starts from the app when performing any of the three following functions colour change, display text or draw on Tile. The app transfers data to the Firebase Database where the information is stored for future use and passed along to the ESP32. The ESP32 is a Wi-Fi enabled microcontroller that acts as a local access point allowing wireless data transfer to occur between the database and itself. Once the data has arrived at the ESP32, it transfers through the UART communication protocol to the STM32. The STM32 is directly wired to the LEDs and through I^{2}C protocol gives it the necessary commands to perform the functions asked of it.

Glossary of Terms

API	An Application Programming Interface is a set of functions and procedures allowing the creation of applications that access the features or data of an operating system, application, or other service.
BJT	A bipolar junction transistor (BJT) is a type of transistor that uses both electron and hole charge carriers, as opposed to field effect transistors which use only one type of charge carrier.
CAN bus	Controller Area Network (CAN bus) is a robust bus standard for microcontroller communication without a host computer.
SPI	Serial Peripheral Interface (SPI) is a synchronous serial communication interface specification for short distance communication in embedded systems.
IR	Infrared (IR) is a spectrum of non-visible light spanning in wavelength from Red (700nm) to Microwaves (1mm).
I^2C	I2C is a serial protocol for two-wire interface to connect low speed devices, such as microcontrollers, in embedded systems.
Master/slave	The Master/slave model of communication has a single master device with unidirectional control over one or more slave devices. Slave devices only send or receive data upon a request by the master.
PCB	A Printed Circuit Board (PCB) is a sheet of layered copper and non-conductive substrate that mechanically supports and electrically connects electronic components via embedded copper tracks.
Phototransistor	A semiconductor junction that alters the level current flowing through it depending on the level of light the junction is exposed to.
Pogo Pin	A spring-loaded conducting device used to connect two PCBs.
LED	A Light Emitting Diode is a semiconductor junction that emits light when current flows through it.
UART	Universal Asynchronous Receiver/Transmitter is a physical circuit in microcontrollers that uses two wires (TX and RX) for serial data transfer.

Citations

[1] Team 25, “TL25: KEY DOCUMENT Requirements”, Capstone Key Document, Team 25, November 2018

[2] Team 25, “TL25: KEY DOCUMENT Validation”, Capstone Key Document, November 2018

[3] Texas Instruments, "Controller Area Network Physical Layer Requirements", Application Report. SLLA270, Jan. 2008

[4] NanoLeaf, “LED Lighting Products: Technical Specifications”, 2018 [Online] Available: https://NanoLeaf.me/en-ca/consumer-led-lighting/for-owners/get-support/technical-specifications/. [Accessed Oct 16, 2018].

[5] STM32F103C8 datasheet, https://www.st.com/, Oct 10, 2018

[6] SunPower UK. (2018). What is Inrush Current? - SunPower UK. [online] Available at: https://www.sunpower-uk.com/glossary/what-is-inrush-current/ [Accessed 26 Nov. 2018].

[7] Renesas, “Linear vs. Switching Regulators”, 2018 [Online] Available: https://www.renesas.com. [Accessed: Nov 2, 2018]

TL25: KEY DOCUMENT

Validation

Changelog

Date/Time	Updater	Description
2018-10-14T14:40:56Z	Rowan 11986156	Document creation and initial population
2018-11-14T10:05:06Z	Rowan 11986156	Add LED Power Test
2018-11-24T08:12:06Z	Sanket	3.2.4 - Gesture Control Verification
2018-11-16T09:13:13Z	Rowan 11986156	LED Text Display Test
2018-11-20T12:29:13Z	Jimmy 40243140	Population of I2C Testing Section
2018-11-25T16:41:29Z	Jimmy 40243140	Small edits and formatting
2018-10-25T18:42:59Z	Rowan 11986156	● IR Emitter/Sensor Selection Verification test ● Add IR Sensor Object Detection test
2018-11-25T20:35:37Z	Parth	Added Linear regulator functionality test
2018-11-25T20:35:37Z	Candice 16550155	Section 4.2 - Power converter simulation Minor format revisions
2018-11-25T20:35:37Z	Rowan 11986156	Milestone 2 prep work
2019-02-10T19:19:04Z	Jimmy 40243140	Milestone 3 review, Update with Topology Test

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1 - I^{2}C Communication Tests

These tests demonstrate the data communication between multiple Tiles and verify features available within the protocol.

1.1 - Common Setup

Two STM32 devices are connected to the I^{2}C bus operating at 100kHz. 4.7 kHΩ resistors are used to pull the logic level high for SCL and SDA lines of the I^{2}C bus. The standard I^{2}C pins for the STM32F103C8 (SCL as PB6 and SDA as PB7) are connected to the microcontroller I^{2}C bus.

The 3.3V rail of the bootloader connects and powers the microcontrollers to simulate the devices being powered from a single power source. Functions from the I^{2}C “Wire” library initializes and configures the bus for use with the microcontroller.

1.2 - I^{2}C Scan Test

Purpose

- To verify that the master device acknowledges the presence of one a slave device on the bus.
- To transfer data from the master device to slave over the I^{2}C bus.

Setup

[Fig 1] shows the test setup as described in section 1.1. The slave device will have a hard coded of address 0x02.

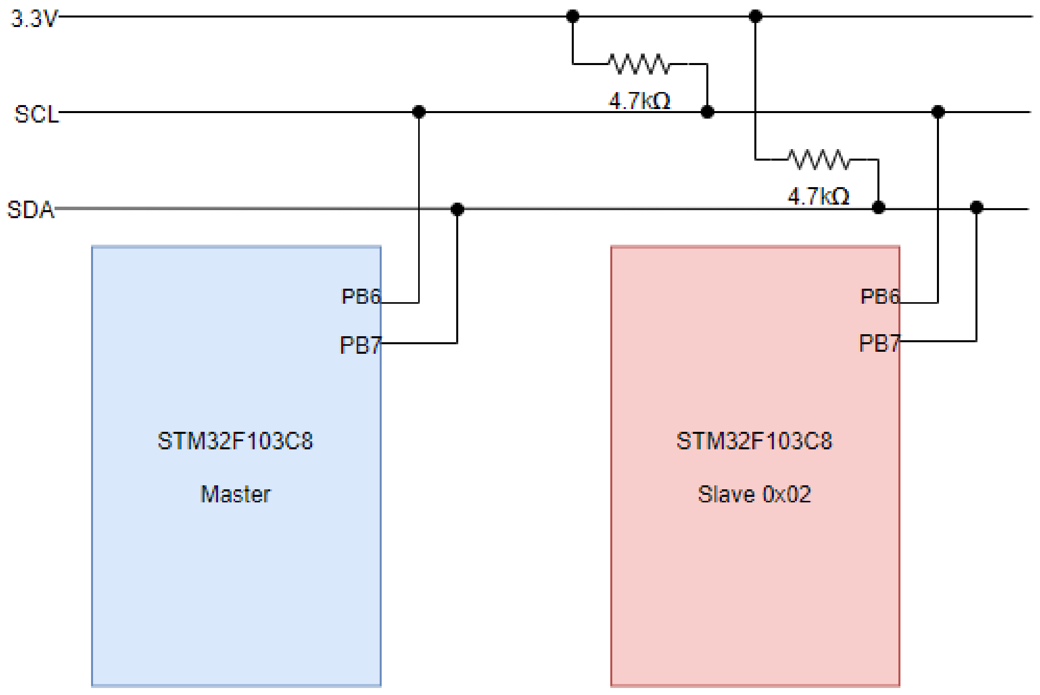


Figure 1: I2C Simple Data Transfer Test Schematic

Procedure

Master Code: [i2c_LED_Master.ino, Appendix I]

Slave Code: [i2c_LED_Slave.ino, Appendix I]

1. Initialize I^{2}C on master device.
2. Initialize I^{2}C on slave device with address 0x02
3. Master transfers 1 byte of data if the slave is available

    a. The transferred data is a counter modulo 2 (alternating between 0 and 1)

4. Slave turns the built-in LED on and off to reflect value based on the last value received.

Outcome

The master can successfully detect and communicate with the slave device. The slave successfully receives the byte and can blink the LED about 2 times a second. This confirms data transfer is successful on the I2C bus with one Tile. This can also be extended to three Tiles if we initialize another slave device with a different address.

1.3 - I²C Dynamic Addressing

Purpose

- To test dynamic allocation of the address of the slave devices.

Setup

[Fig 2] shows the test setup as described in section 1.1 with some additions. A push button connected to the slave device at pin PA5 resets the device address when pressed.

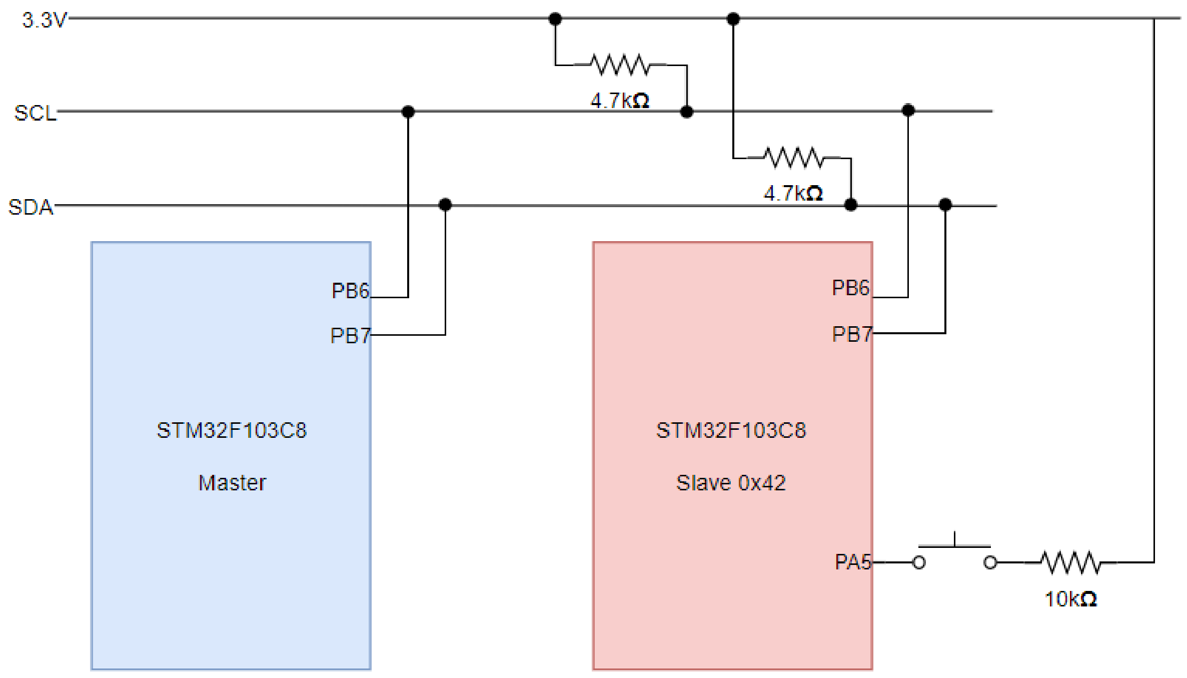


Figure 2: I2C Dynamic Addressing Test Schematic

Procedure

Master Code: [I2C_DynamicAddress_Master.ino, Appendix I]

Slave Code: [I2C_DynamicAddress_Slave.ino, Appendix I]

1. Initialize I²C on master device.
2. Initialize I²C on slave device using default address 0x42.
3. Master scans the bus for all addresses
    a. The master sends the slave device one-byte data containing new address if a device is detected at the default address. This test uses 0x6A as the new address.

4. Slave device holds this new address in a variable until a push button is pressed. Upon pressing the button, slave restarts the I^2C port with the new address.
5. Master device now sees only one device at address 0x6A.

Outcome

At the beginning of the test, only one device at address 0x42 (default address) on the I^2C bus. After pushing the button there is still only one device found on the I^2C bus by the master. However, the address is 0x6A which is the address that the master sent to the slave with the default address of 0x42 earlier. The results of this test prove we can re-initialize slave devices using dynamic address allocation.

1.4 - I²C Dynamic Display

Purpose

- To verify the ability to add and remove devices from the I²C bus dynamically

Setup

[Fig 3] shows the test setup as described in section 1.1 with some additions. This test also includes 4 LEDs connected to each Tile. The LEDs are connected to pins PA1-4.

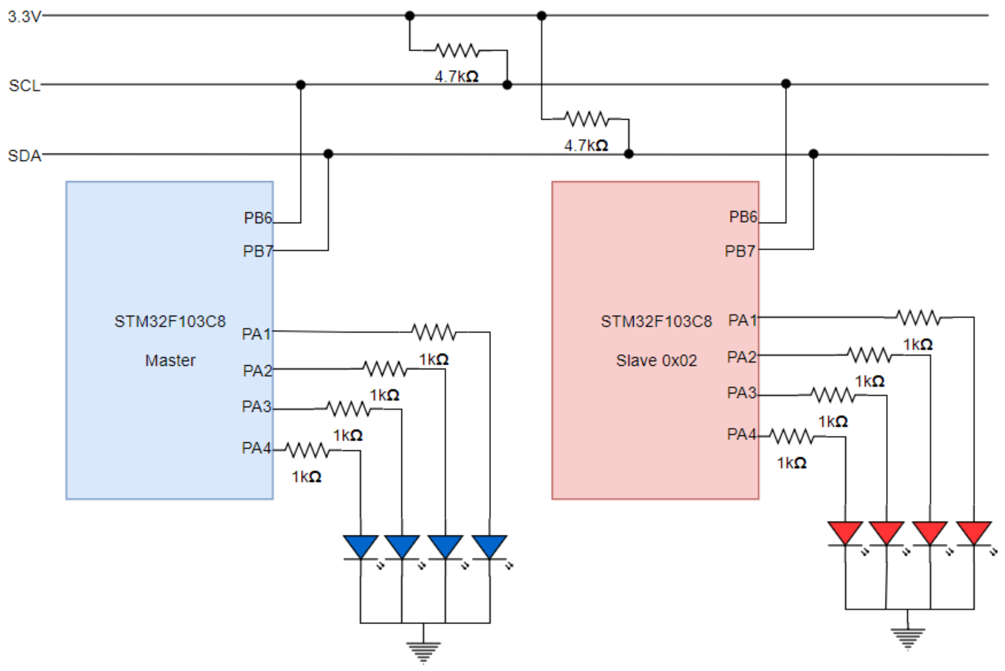


Figure 3: I2C Dynamic Display Test Setup

Procedure

Master Code: [I2C_DynamicDisplay_Master.ino, Appendix I]

Slave Code: [I2C_DynamicDisplay_Slave.ino, Appendix I]

1. Initialize I²C on master device with LEDs 1 to 4.
2. Initialize I²C on slave device using default address 0x02 and LEDs 5 to 8.
3. Master determines which LEDs to turn on depending on the number of devices on the bus.

    a. The master scrolls the LED across all LEDs currently connected to the display in an endless loop. Both the red and blue LEDs turn on if both devices are connected, otherwise only the blue LEDs turn on.

4. Slave listens on the bus to determine the output value of the red LEDs.
5. Occasionally, the reset button on the slave device is pressed to simulate removing it from the bus. Letting go of the reset button will simulate adding the device to the bus.

Outcome

Video of the test can be seen here:
https://drive.google.com/open?id=1nmlbj_mVQLO1qjlOnqgz28PdHdXJ0SXw

Operating at about 10 fps we are able observe the LEDs dynamically changing the length of the display when the slave is “added and removed”. This test verifies that we can add and remove devices from the bus dynamically.

1.5 - I2C Communication Testing Results

Slave device addresses can change after the device has already been turned on. This allows us to keep the slave source code the same and have the master device reassign an address instead of using a predetermined device address.

2 - LED Tests

2.1 - Common Setup

[Fig 4] shows the connection setup for the LED Tests. For detailed pin out diagrams of the STM32 dev board and test PCB please see [Fig 1, Appendix II] and [Fig 2, Appendix II] respectively.

1. Connect the PB10 and PB11 pins of the STM32 to the PCB's DATA INPUT and CLOCK INPUT pins respectively
2. Supply the PCB with 3.3V from a separate power supply
3. Ensure grounds of the PCB and STM32 are connected to minimize signal noise
4. Boot load the relevant testing code to the STM32

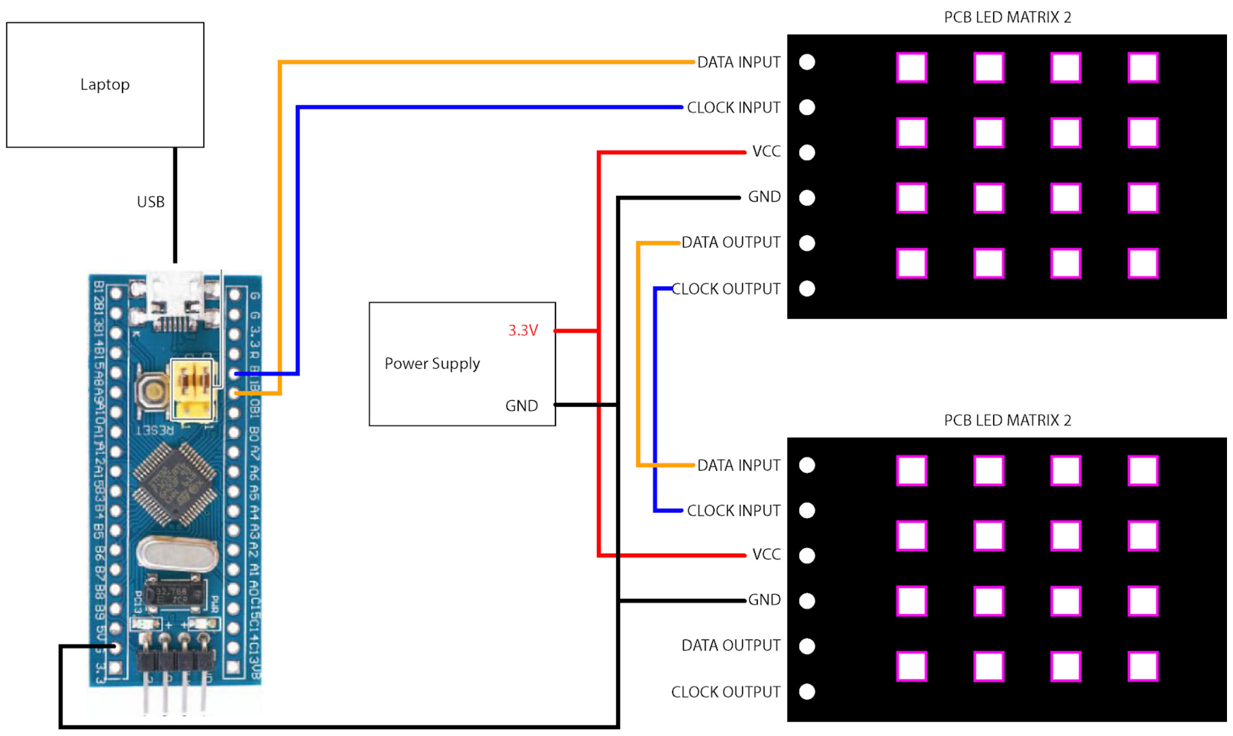


Figure 4: LED Test Connection Schematic

2.2 - PCB LED Functionality Verification

Purpose

- To check each LED on the test PCB for defects.

Setup

White light is an even combination of red, green, and blue light, and ideal for visual verification that all colors are functioning for a given LED. The white light is set with a maximum of ¼ brightness so as not to blind the tester.

Procedure

STM32 Code: [MatrixTestStm32.ino, Appendix I]

1. Cycle every LED with white light using testEachPixel()

Outcome

Three of the four PCBs have a fully functioning matrix of LEDs. The faulty PCB functions only for the first 7 serially connected LEDs. This is likely due to an error during the manual placement of parts on the PCB.

2.3 - LED Power Consumption

Purpose

- To determine the worst-case power consumption of a 8x8 LED matrix.

Setup

The PCB is powered with 3.3 Volts and the current draw is recorded for each color and maximum brightness cycle.

Procedure

STM32 Code: [MatrixTestStm32.ino, Appendix I]

1. The testAllPixel() turns on all 16 LEDs simultaneously and cycles them through white, blue, green, and red light at full, ½, ¼, ⅛, and $\frac{1}{16}$ maximum brightness settings.

A video of the test can be seen here:
https://drive.google.com/file/d/1RRLvuonGjAmrLjJZLJ2IU8eCijgDMBpZ/view?usp=sharing.

Outcome

[Table 1] lists the current draw of the PCB at varying brightness levels and colours.

Table 1: Current Draw of APA102 2020 LEDs at Different Brightness Levels

	Color				**Worst Case Power (4x4 Matrix)**	**Worst Case Power (8x8 Matrix)**
Max Brightness	White	Blue	Green	Red	3.3V*(White light Current)	4*(Worst Case Power (4x4 Matrix))
Full	135mA	50mA	54mA	90mA	.45W	1.8W
1/2	84 mA	34mA	36mA	55mA	.28W	1.12W
1/4	53mA	25mA	26mA	36mA	.17W	.68W
1/8	34mA	20mA	21mA	26mA	.11W	.44W
1/16	25mA	18mA	19mA	20mA	.083W	.332W

The LEDs are too bright to look at directly for max brightness settings of Full, ½, and ¼. This suggests the LEDs can operate with a maximum brightness of ⅛, which has a worst-case power consumption of .68W and current draw of 206mA for an 8x8 LED matrix.

Design Ramifications

During testing it was discovered that there are two different LEDs on three of the PCBs. One set of LEDs is significantly dimmer than the other at equivalent power consumptions. After confirming the LEDs had the same part and batch number, it was determined there is an issue with the current LED supplier. Further LEDs will be procured from the Adafruit manufacturer, as they provide the same LED part number at a similar price with top review ratings.

Further Testing

The LED light will also be diffused through a square piece of glass to provide a larger pixel display and more even lighting effect. Because of this and the manufacturing anomaly mentioned earlier, higher brightness, and therefore more power, may be required than currently assumed.

2.4 - Text Display

Purpose

- To demonstrate that text can be displayed and scrolled across the LED matrices.
- To verify the matrices can be linked together for larger displays.
- To profile the processing time required to display text on a LED matrix.

Setup

The 4x8 pixel display can only show the top half of characters so the string “” ^ ~” was chosen.

Configuration of a single display was achieved by setting the following variables:

- matrixWidth = 8;
- matrixHeight = 4;

Simulation of a full 8x8 Tile matrix was achieved by setting the following variables:

- matrixWidth = 8;
- matrixHeight = 8;

The STM32 MCU processing time is recorded by setting a pin HIGH at the beginning of the scrollText() function, and LOW upon function completion. An oscilloscope is used to measure the interval between the pins high and low output.

Procedure

STM32 Code: [MatrixTestStm32.ino, Appendix I]

1. The scrollText() function scrolls a string from left to right on three LED matrices connected to make a 4x8 pixel display.

A video of the test can be seen here:
https://drive.google.com/file/d/1BRqLP1Gf0W6TVumukrwBBzP3Aoo1r-3-/view?usp=sharing

Outcome

Text can be successfully scrolled across the matrixes. There is no reason to assume this cannot be scaled to a full 8x8 Tile matrix.

For an 8x4 LED Matrix, the scrollText() function required 1.25ms of MCU time per frame. For an 8x8 LED Matrix, the scrollText() function required 10ms of MCU time per frame. This gives a maximum frame rate of 100 fps assuming 100% of MCU time is spent updating the LED matrix. As our target frame rate is 24fps [1], this would require approximately 24% of MCU time be devoted to matrix updating.

3 - IR Sensor and IR Mask Tests

3.1 - Common Setup

Initial setup should be the same as the LED tests: Common setup, refer to [Fig 5] if needed. The STM32 dev board used for testing has only 10 analog pins capable of being read by the ADC. Thus 10 of the 16 sensors are read using the analog pins PA0-PA8, PB0, and PB1. Sensors S7-S8 are mapped to pins PB1 and PB0 respectively while sensors S9-S16 are mapped to pins PA8-PA0 respectively, see [Fig 2, Appendix II] and [Fig 1, Appendix II] for a detailed pin map of the STM32 dev board and test PCB. Each sensor value was processed using the ADC. All sensors were polled 10 times every second using an interrupt subroutine. The values are then printed to the serial monitor.

3.2 - PCB IR Sensor Functionality Verification

Purpose

- To determine IR sensor sensitivity to Background IR levels.
- To determine the effectiveness of the IR Mask.

Setup

An oscilloscope was connected to the output of several sensors not measured by the ADC. The IR mask used is 1cm thick, with a 1mm diameter hole centered above the IR sensor. Testing was conducted around noon on a sunny day.

Procedure

STM32 Code: [IRSensorsSTM32.ino, Appendix II]

1. Connect the oscilloscope probe to the output of the IR Phototransistor.
2. Begin the code
3. Measure the phototransistor voltage in normal room-light conditions without sunlight (curtains drawn)
4. Measure the voltage of the phototransistor with a heavily sun lit room (curtains opened)
5. Repeat steps 1 - 4 with the IR Mask.

Outcome

The sensors output less than 1mV in room light conditions with the currents drawn, which registers a raw analog to digital converter (ADC) value of 0. The sensors output roughly 50 mV in room light conditions with the currents up [Fig 6], which gives measurable A values around 60. This leads to a condition with insufficient IR to detect movement in normal room lighting conditions, and too much IR to detect movement in direct sunlight. With the IR mask attached to the sensor matrix, the sensors are unable to output more than 150 mV when facing direct sunlight [Fig 6].

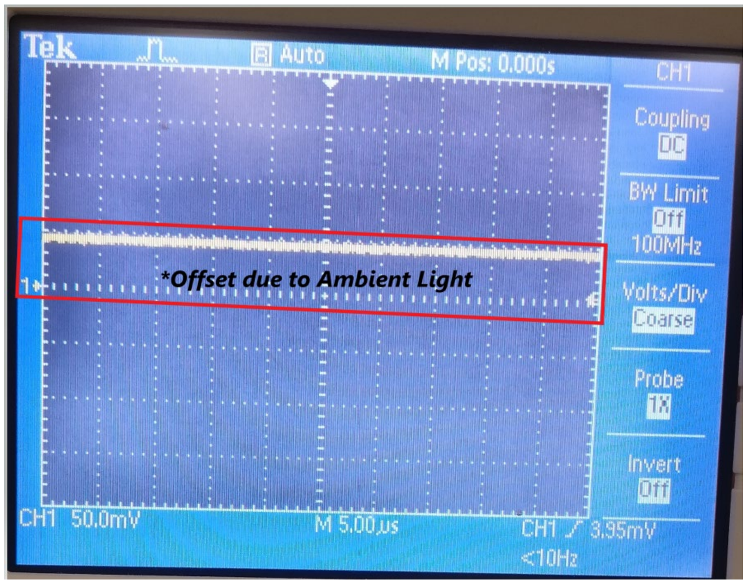


Figure: Steady State Sensor Output - Ambient Sunlight Condition

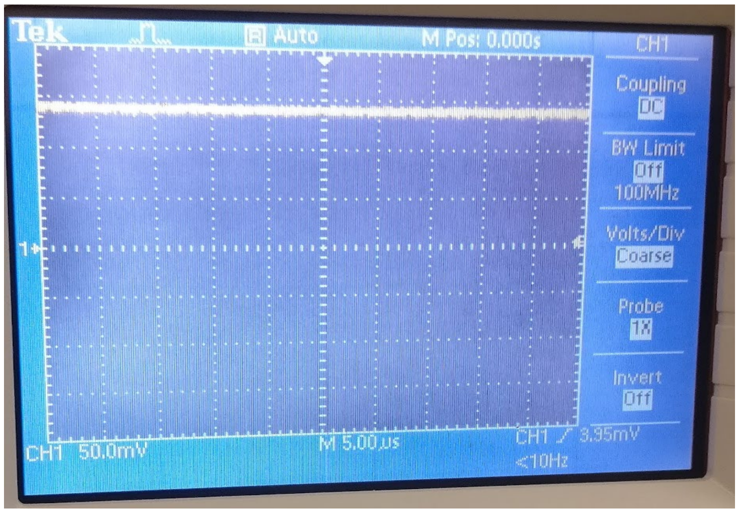


Figure 5: Steady State Sensor Output - Direct Sunlight

Design Ramifications

IR emitters will have to be added in order to generate IR that can be reflected off objects in front of the sensor matrix.

The IR mask will have to allow more light to reach the sensors or be removed entirely. Furthermore, the primary purpose of the IR mask will be to shield the sensors from direct sunlight.

Even when not in direct sunlight, the IR sensors still read non-zero values from ambient sunlight on sunny days.

Suggested Solution

IR sensors with daylight filtering lenses, such as the VEMT2020x01, should be used.

3.3 - IR Sensor Object Detection

Purpose

- Demonstrate that an object can be detected by measuring reflected IR
- Verify real-time LED matrix updating

Setup

STM32 Code: [IRSensorsSTM32.ino, Appendix II]

1. Set up an array of IR LEDs next to the IR sensor matrix.
2. Run the sensor polling code as described in the common setup.
3. Map each sensor value from 0 to 4096 to 0 to 255 and store it in an array.
4. Threshold the value to account for IR noise.
5. Pass the value as a brightness to the sensor's nearest LED.

Procedure

A tester moves an object near the sensor matrix to be detected.

A video of the test can be seen here:

https://drive.google.com/file/d/1QyKGC2f2Skh5RIxxfqVEEDQ5djhL_1oR/view?usp=sharing

Outcome

The sensors can see reflected IR. Furthermore, the LED matrix can be updated real time without issue. However, as the sensors are located off the PCB and there is no IR mask obscuring the sensors from each other, the sensors see a "blurry" object.

Design Ramifications

The IR emitters should be paired with and located as close as possible to the IR sensors to reduce IR noise and ensure strong but local IR levels. Furthermore, if the IR sensor/emitter pairs can be turned on and off during the sensor polling interrupt routine, the measured IR value will not be influenced by other IR sensor/emitters pairs. See the "Updated IR sensor Matrix Design" section in the design document for further details.

3.4 - IR Emitter and Sensor Selection Justification

Purpose

- Determine if the VEMT2020x01 NPN Phototransistor will meet project requirements
- Determine if the SFH 4056 Infrared Emitter will meet project requirements

Setup

The phototransistor detects objects by measuring the amount of IR reflected from them. To determine the range of detection we first estimate the irradiance at the sensor as a function of distance from the emitter. The following equation solves for irradiance at the sensor:

$$L_{sensor} = \frac{(RF_{object})\, L_{emitter}}{D^2}$$

For a more intuitive understanding of what these variables relate to, see [Fig 7].

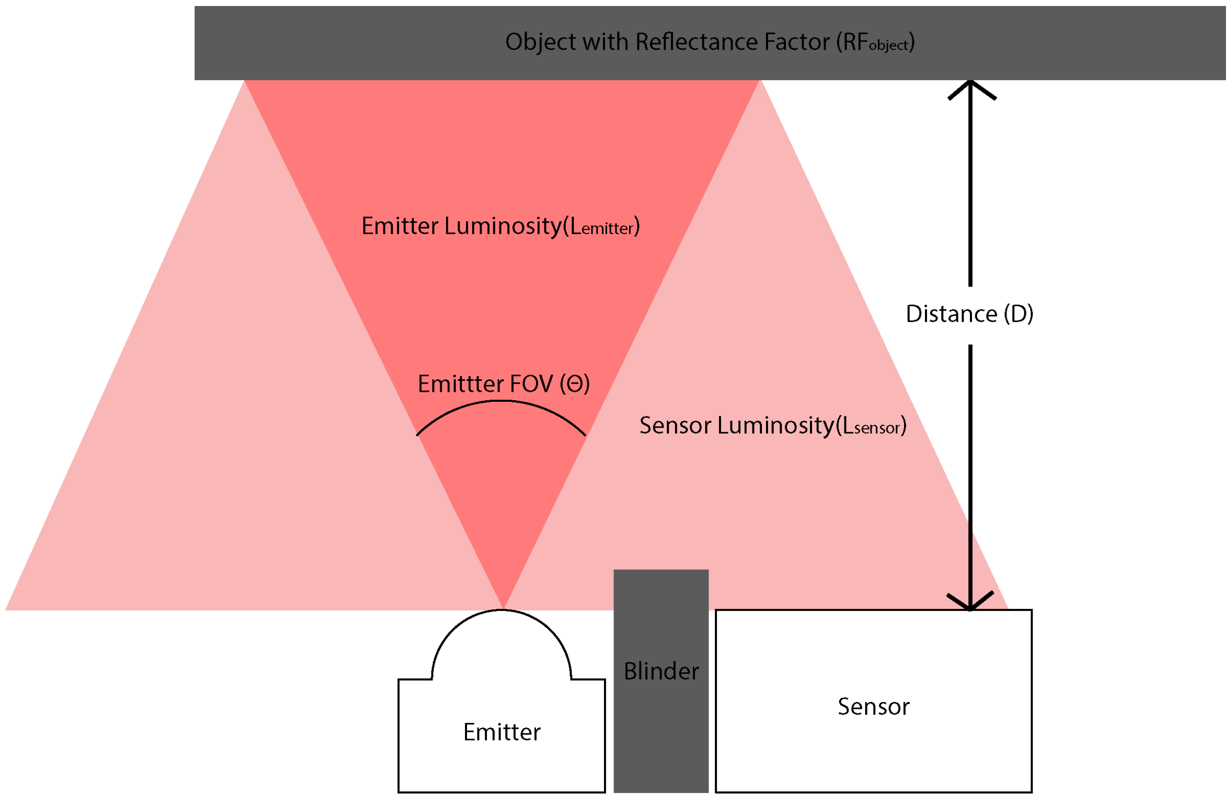

Object with Reflectance Factor (RF$_{object}$)
Emitter Luminosity(L$_{emitter}$)
Distance (D)
Emitter FOV (Θ)
Sensor Luminosity(L$_{sensor}$)
Blinder
Emitter
Sensor

Figure 6: IR Emitter and Sensor Pair Irradiance diagram

Procedure

The expected irradiance at the sensor as a function of distance is graphed using the following assumptions:

1. The IR emitter is the Osram SFH 4056 with a minimum irradiance @70mA is 2.5mW/cm^2 [1].
2. The reflectance factor of human skin (RF$_{object}$) is approximately 0.55 [2].

The graph is generated with a minimum irradiance of 2.5mW/cm^2,4.25mW/cm^2, and 6 mW/cm^2. These values can be achieved by supplying the IR emitter with a forward current of 70mA and are dependent on the binning of the device [1].

Outcome

[Fig 8] compares reflected IR irradiance at the sensor with object distance from the sensor.

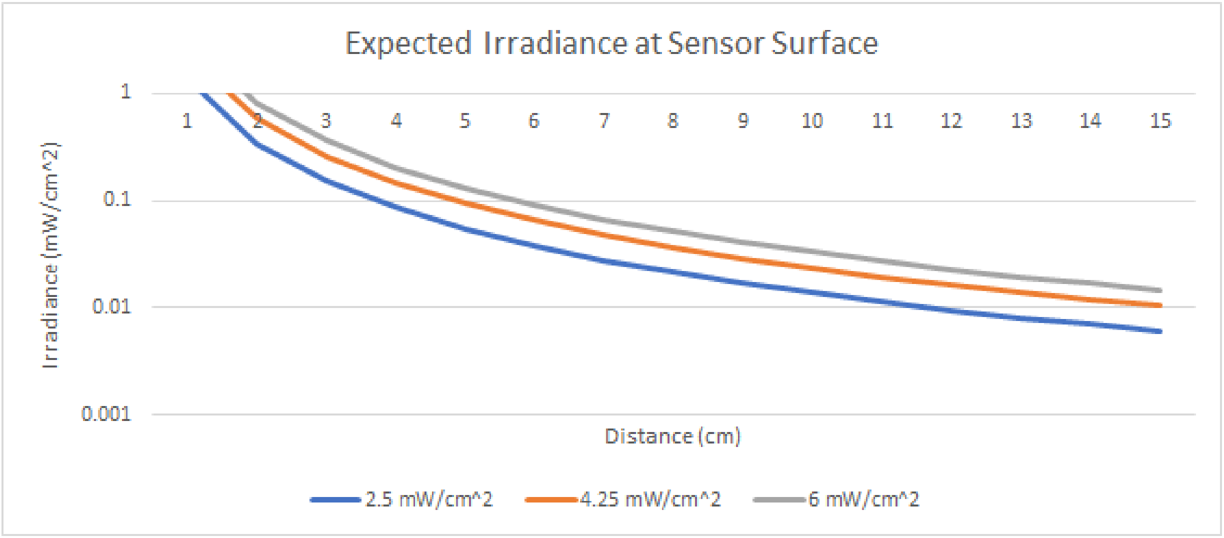


Figure 7: Expected Reflected Irradiance vs Distance

The above graph suggests there is enough IR reflected from a hand up to 11 cm away to read with the VEMT2020x01 IR phototransistor, as required in by requirement 6.5.2. This phototransistor can detect irradiances as low as .01 mW/cm^2 [3].

3.5 - Gesture Control Verification

Purpose

- To prove the gesture control abilities of the APDS 9960 module.

Setup

The 9960 module is a pre-packaged module, with a built in IC and 4 photodiodes, used to determine the direction of the user's hands movement.

STM32 Code: [*GestureControl_LED.ino* code, in Appendix I]

1. Connect the 9960 module via the I2C pins on board to the STM32.
2. Send sensor readings from the 9960 to the STM32.
3. Output sensor data from STM32 to turn the LEDs on.

Procedure

After the setup the test was conducted by a user maintaining a distance of 4 inches of the board (optimal reading range recommended by the 9960-module datasheet) and waving their hand arbitrarily in one of the four directions (Up, Down, Left, Right). The Serial Monitor on the Arduino IDE would output the direction the user waved their hand and a specific colour on the LEDs depending on direction.

Outcome

When the user waves their hand in one of the distinct directions, UP, DOWN, LEFT, RIGHT, it corresponds to a specific LED colour change (UP = Green; DOWN = RED; LEFT = Blue; RIGHT = WHITE). This is a starting point and a proof of concept to show the output of 9960 module is capable of the controlling the test PCB.

4 - Power Components Verifications

Purpose

To prove physical functionality of components selected, as well as feasibility of the designed power system from wall to each component.

4.1 - Linear regulator functionality test

Purpose

- To test an available linear voltage regulator that outputs the required 3.3V using variable higher voltage input to see how the input current varies based on input voltage.

Setup

For testing purposes, we used MCP1700- 3302E/TO linear regulator which gives our desired 3.3V along with a maximum current rating 250mA [9], which was enough for our test PCB (1/16th of a final Tile size). We connected the output to a 51Ω resistor and an adjustable DC power supply on the input. A voltmeter was connected across the resistor to observe the voltage.

Procedure

Current requirement for resistor used:

$$I = V / R = 3.3/51 = 65mA$$

We supplied the 1V- 5V voltage to the resistor via the regulator and observed steady voltage output across the resistor which varied with the Vin up to 3.3V and stayed at 3.3V at all Vin above that. The current drawn was recorded at multiple Vin's.

Outcome

The current drawn remained stable at 65mA at anything above Vin= 3.3V, therefore telling us that all the increase in power was being lost. The linear regulator is not able to regulate current when the supplied voltage is in excess hence all the excess power input (from increased voltage) is lost as heat. This way the regulator draws all its output current directly from source.

The heat level significantly increased at Vin > 6V and was too hot to even touch above 9V input, which can be calculated as: [(Vin - Vout) x Iout] Watts

Additionally, there was a dropout voltage (Vout - Vin for all Vin up to regulator limit) of 0.2V.

Design Ramifications

For our power supply of 18V, the heat dissipation would be very high and hence we needed to lower the difference between the Vin and Vout at the linear regulator. For that reason, we will be utilizing a DC-DC buck convertor set around 4V to compensate for dropout voltage while keeping heat dissipation minimum.

4.2 - Power Converter Design Simulation

Purpose

To demonstrate the feasibility of designing a 40-60W power converter in the interest of reducing cost. This is a consideration for the client for future iterations of the product.

Setup

The power converter design considers the wall outlet as the source, and thus, should have a rectifier, some form of isolation, and a step-down (buck) converter. The buck converters have specifications as outlined in [Table 2] below. Note that stepping down the voltage should be done in two stages because the total difference between the input and output voltage is very large.

Table 2: Specifications of the Designed Buck Converter for a Single Tile

Design Specifications	Input Voltage	Output Voltage	Input Power	Inductor Current Ripple	Voltage Ripple
Stage 1	120V_{rms}	30V	7.8W	---	±.01%
Stage 2	30V	h3.3V	7.8W	±8%	±.5%

Simulations were performed in PSIM using the circuit shown in [Fig 9]. Component values were chosen according to the calculations in the procedure section.

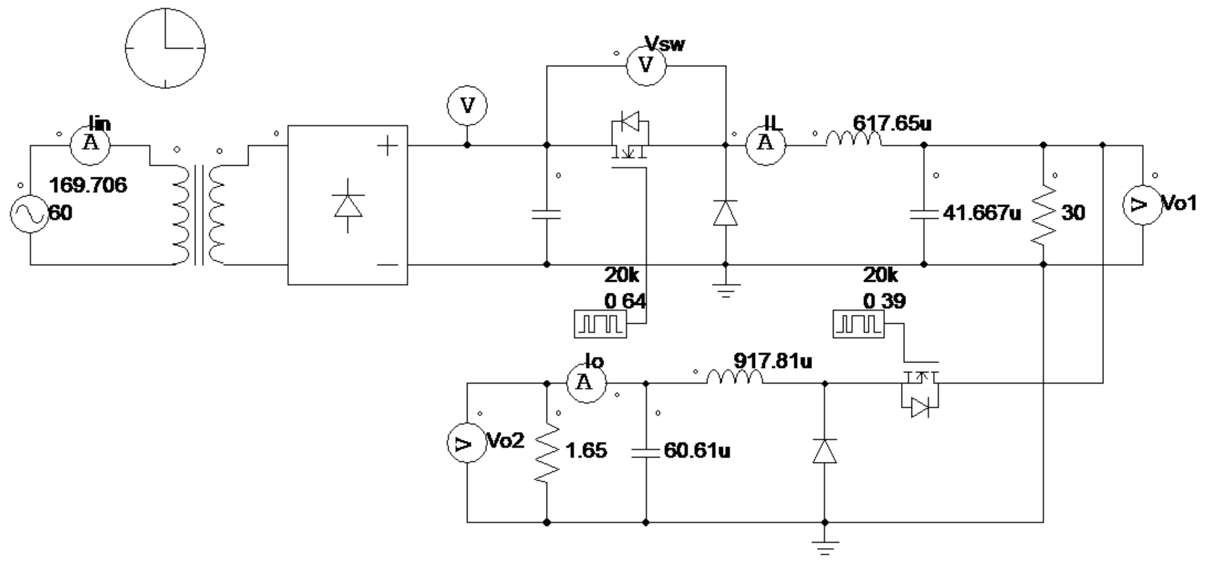


Figure 8: AC/DC and DC/DC Buck Converter Circuit Schematic

Procedure

1. Calculate duty cycle and component values for the first buck converter stage

$$D = \frac{V_o}{V_{in}} = \frac{30}{170} = 0.1765$$

$$L_1 = \frac{D(V_{in} - V_o)}{f_s \Delta i_L} = 617.65\mu H$$

$$C_1 = \frac{\Delta i_L}{8 \Delta V_o f_s} = 41.67\mu F$$

2. Repeat step 1 for the second stage

$$D = \frac{V_o}{V_{in}} = \frac{30}{170} = 0.11$$

$$L_1 = \frac{D(V_{in} - V_o)}{f_s \Delta i_L} = 60.61\mu H$$

$$C_1 = \frac{\Delta i_L}{8 \Delta V_o f_s} = 917.81\mu F$$

3. Create the AC/DC and DC/DC buck converter circuit [Fig 10]

4. Simulate the second stage voltage output, output current, first stage switch voltage, and inductor current to confirm that the larger components are necessary. Use an ideal transformer and rectifier, switching frequency of 20kHz, and buck converter input capacitor of 10mF

5. Select suitable components and estimate the cost of the full converter for a quantity of approximately 10,000 Tiles (1,000 converters)

Outcome

The simulation results in [Fig 11] confirm that all design specifications are met for one Tile.

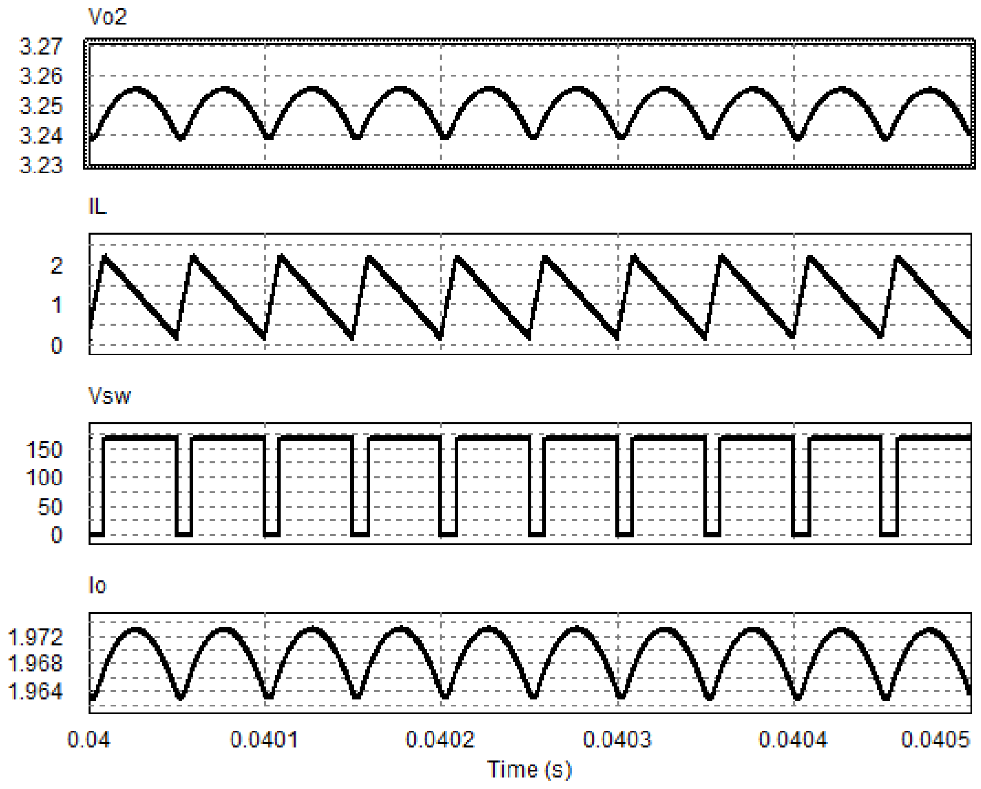
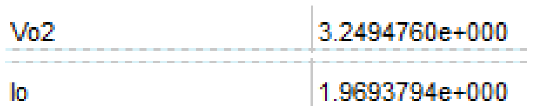


Figure 9: Power Converter Simulation Waveforms and Average Values



Vo2	3.2494760e+000
Io	1.9693794e+000

$$\Delta V_o = 16.5364mV < .16V_o$$

Implementing the buck converters in two stages allows us to transmit power between Tiles at a lower current, and thus, use fewer pogo pins because stage 1 will be part of the AC/DC converter on the master Tile and stage 2 will be on every Tile. To power a full display, each Tile's buck converter (stage 2) will be interleaved, which has the added benefit of being more efficient than a single buck converter [4]. By interleaving the buck converters, we are essentially performing a current step-up at the load, as the loads add in parallel to draw more current from stage 1 up until 10 Tiles are connected.

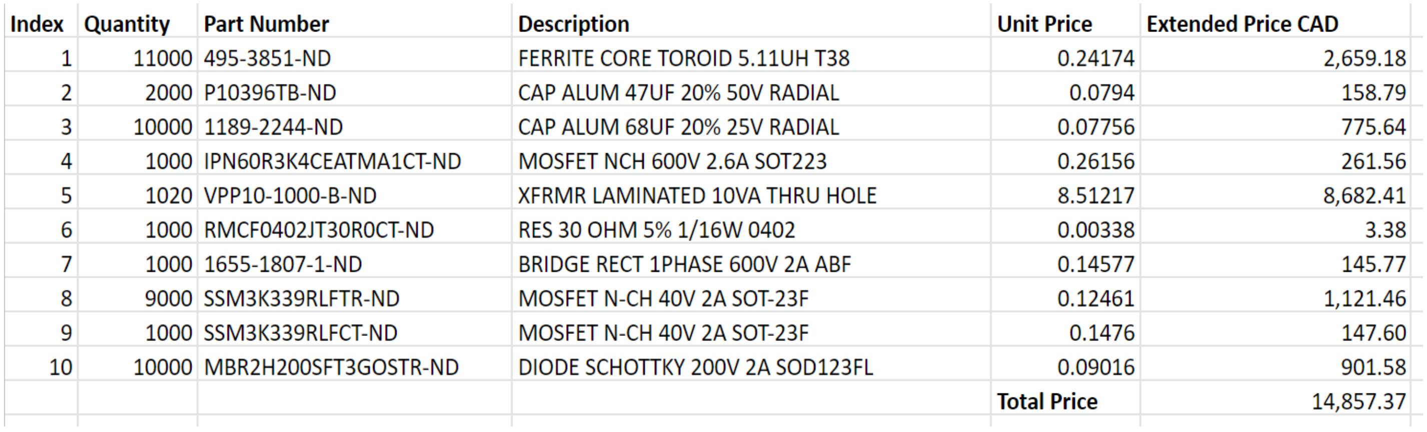
Note that with this configuration, boundary discontinuous conduction mode (DCM) for the first stage should be considered because a resistive load must be connected in parallel with the output capacitor. The resistive load at the output of the first stage dissipates minimal power when it has its maximum value [5]. This is computed below.

$$R_{L1} = \frac{2f_sL}{1-D} = 30\Omega$$

The simulation shows this value to be correct because in the inductor current waveform of the first stage, the trough reaches nearly zero, but does not reach DCM ($i_L(t) = 0A$).

While the cascaded buck converter configuration works, it is not the most efficient power converter design. Integrating the transformer into the converter is possible in more complex topologies such as the fly back or half-bridge converter and can reduce the number of components used in the design, but due to the scope of this capstone project, it will suffice to say that designing a power converter for use with the LED and IR matrices is possible.

In a sample parts order [Fig 12] the total cost of implementing self-designed power converters on 10,000 boards is CAD$14,857.37, or CAD$1.49 per Tile, and CAD$14.86 for every 10 Tiles. This price is comparable to a very cheap computer charger but has the benefits of being more efficient (i.e. the input to the voltage regulator will be designed to more closely match the voltage output of the regulator, reducing power losses in the voltage regulator, as described in section 4.1) and can be integrated into the packaging of each Tile. One major drawback is that this design would need to be approved by regulatory bodies before being made commercially available. This will consume a large amount of time, so we recommend that this design be used in a future iteration of the product.



Index	Quantity	Part Number	Description	Unit Price	Extended Price CAD
1	11000	495-3851-ND	FERRITE CORE TOROID 5.11UH T38	0.24174	2,659.18
2	2000	P10396TB-ND	CAP ALUM 47UF 20% 50V RADIAL	0.0794	158.79
3	10000	1189-2244-ND	CAP ALUM 68UF 20% 25V RADIAL	0.07756	775.64
4	1000	IPN60R3K4CEATMA1CT-ND	MOSFET NCH 600V 2.6A SOT223	0.26156	261.56
5	1020	VPP10-1000-B-ND	XFRMR LAMINATED 10VA THRU HOLE	8.51217	8,682.41
6	1000	RMCF0402JT30R0CT-ND	RES 30 OHM 5% 1/16W 0402	0.00338	3.38
7	1000	1655-1807-1-ND	BRIDGE RECT 1PHASE 600V 2A ABF	0.14577	145.77
8	9000	SSM3K339RLFTR-ND	MOSFET N-CH 40V 2A SOT-23F	0.12461	1,121.46
9	1000	SSM3K339RLFCT-ND	MOSFET N-CH 40V 2A SOT-23F	0.1476	147.60
10	10000	MBR2H200SFT3GOSTR-ND	DIODE SCHOTTKY 200V 2A SOD123FL	0.09016	901.58
				Total Price	14,857.37

Figure 10: Sample Digikey BOM for Power Converter Components for 10,000 Tiles

5 - Topology Tests

5.1 - Position Mapping

Purpose

- To verify that the master can map out the Tiles using the four directional pins
- To verify that the master can reorder the Tiles based their relative locations.
- To verify that the master can send different data to different Tiles.

Setup

The setup [Fig 12] builds the common setup described in section 1.1. The 4 x 4 Test PCB is connected to each microcontroller on pins PB11 and PB10 to transmit serial data. Not shown are four arbitrary pins used to determine topology. The pins used in the source code to represent the four directions are PA3, PA4, PA5 and PA6. [TopologyTest_Master.ino, Appendix I]

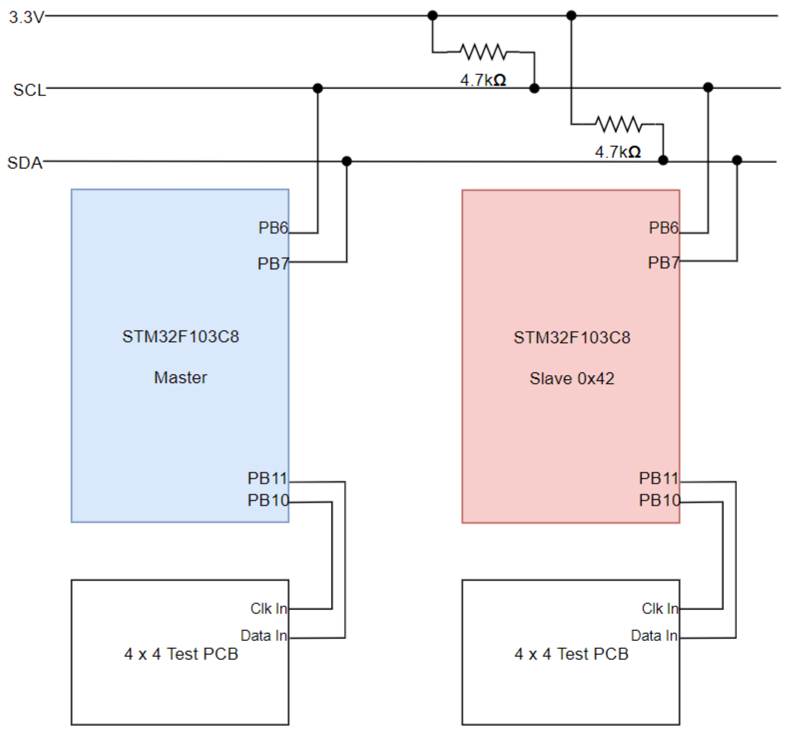


Figure 11: Topology Test Schematic

Procedure

Master Code: [TopologyTest_Master.ino, Appendix I]

Slave Code: [TopologyTest_Slave.ino, Appendix I]

1. Power up the master device and connect the I^{2}C pins of a second device.
2. Connect the directional pin corresponding to the down direction to 3.3V on the master. Then power up the slave using 3.3V
3. The 4 x 4 test PCB connected to the master should display a 2x2 green box while the test PCB connected to the slave displays blue.
4. Verify on the serial output that the displayed array shows the master Tile at the center and the slave Tile (#4) is directly below.
5. Turn off the slave device and change the powered directional pin corresponding to the up direction instead of down. Power the slave device again.
6. The 4 x 4 test PCB connected to the master should now display a 2x2 blue box while the test PCB connected to the slave displays green.
7. Verify on the serial output that the displayed arrow shows the master Tile at the center and the slave Tile (#4) is directly above.
8. Repeat with another slave using the Left and Right directional pins.
9. Verify the serial output displays the correct order. The uppermost Tile takes priority with a preference for the Tile closest to the left.
10. Check the colours displayed by the test PCB connected to each Tile.

Outcome

The master can correctly map out the devices in the internal array and is able to reorder them when a device is added or removed. The master is then able to send data according to the order to each of the slave devices. The test PCB connected to each Tile also reflects this change. The order of the Tiles determines the colour displayed with the first Tile showing green, the second showing blue, and the third showing red.

Appendix I: Testing Source Code

The following source code was used in the test procedures outlined in this document.

A1.1 - GestureControl_LED.ino

```
#include <A     dafruit_GFX.h>
#include <Adafruit_DotStarMatrix.h>
#include <Adafruit_DotStar.h>
#include "Adafruit_APDS9960.h"
Adafruit_APDS9960       apds;

// Pin setup
const uint8_t MATRIX_DATA_PIN = 4;
const uint8_t MATRIX_CLK_PIN = 7;

// Size of each Tile matrix
const ui     nt8_t matrixWi       dth = 4;
const uint8_t matrixHeight = 4;

// Number of Tile matrices
const uint8_t TilesX = 1;
const uint8_t TilesY             = 1;


Adafruit_DotStarMatrix matrix = Adafruit_DotStarMatrix(
    matrixWidth,
    matrixHeight,
    TilesX,
    TilesY,
    MATRIX_DATA_PIN,
    MATRIX_CLK_PIN,
    DS_MATRIX_TOP     + DS_MATRIX_LEFT +
    DS_MATRIX_COLUMNS + DS_MATRIX_ZIGZAG + DS_TILE_PROGRESSIVE,
    DOTSTAR_RGB
);

const uint16_t colors[] = {
    matrix.Color(255, 0, 0), matrix.Color(0, 255, 0), matrix.Color(0, 0, 255), ma                                        trix.Color(255        ,
255, 255), matrix.Color(0,0,0)
};

void setup() {
    #if defined(__AVR_ATtiny85__) && (F_CPU == 16000000L)
    clock_prescale_set(clock_div_1); // Enable 16 MHz on Trinket
    #endif

    matrix.begin(); // Initialize pins for output
    matrix.setB      rightness(45);          // Set max brightness (out of 255)

    matrix.setTex       tWrap(false);
    matrix.setTextColor(colors[0]);
    matrix.show();  // Turn all LEDs off ASAP
    Serial.begin(115200);

  if(!apds.begin()){
        Serial.println("failed to initialize device! Plea                              se check your        wiring.");
    }
    else Serial.println("Device initialized!");

    //gesture mode will be entered once proximity mode senses something close
    apds.enableProximity(true);
    apds.enableGesture(        true);

}

void testAllPixels(uint8_t index) {
          matrix.setCurs       or(0, 0);
          matrix.fillRect(0, 0, matrixWidth, 4*matrixHeight, colors[index]);
          matrix.show();

}

void loop() {

    //read a gesture from the device
        uint8_t gesture = apds           .readGesture();

        switch (gesture){

            case(AP  DS9960_DOWN):
                    testAllPixels(2);
                    Serial.println("DOWN");
                    delay(1000);
            break;

          case(APDS9960_UP):
                testAllPixels(1);
                Serial.println("UP");
                delay(1000);
            break;

            case(APDS9960_LEFT):
                testAll      Pixels(0);
                Serial.println("LEFT");
                delay(1000);
            break;

            case(APDS9960_RIGHT):
                testAllPixels(3);
                Serial.println("RIGHT");
                delay(1000);
            break;

            default:
                  testAllPixel        s(4);
            br eak;

        }

}
```

A1.2 - I2C_DynamicAddress_Master.ino

```
/****************************************************************************************
*              Title: I2C_DynamicAddress_Slave
*            Description: Modification of i2c_scanner example for STM32
*            Author: Jim     my Wong
*            Date: Nov 18, 2018
*            Code version: 0.0.1
********     ********************************************************************************/

#include <Wire.h>
#define I2C_DEFAULT 0x42

void setup() {

  Serial.begin(9600);
  Wire.begin();
  Serial.println(          " \ nI2C Scanner");

}

void loop() {
  byte error, address;
  int nDevices;

  Serial.println("Scanning...");

  nDevices = 0;
  for(address = 1; address < 127; address++) {
    // The i2c_scanner uses the return value of
    // the Write.endT          ransmisstion t        o see if
    // a device did acknowledge to the address.
    Wire.beginTransmission(address);
    error = Wire.endTransmission();

    if (error == 0) {
      Serial.print("I2C device found at address 0x");
      if (address < 16)
        Serial.print         ("0");
      Serial.println(address, HEX);
      if (addres       s == I2C_DEFAULT){
        Wire.beginTransmission(address);
        Wire.write(0x6A);
        int data_t = Wire.endTransmission();
        Serial.print("sending data ");
        Seria  l.print(addres         s);
        Serial.print(" result: ");
        Serial.print         ln(data_t);
      }

      nDevices++;
    }
    else if (error == 4) {
      Serial.print("Unknown error at address 0x");
      if (address < 16)
        Serial.print("0");
      Serial.println(a           ddress, HEX);
    }
  }
  if (nDevices == 0)
    Serial    .println("No I2C devices found");
  else
    Serial.println("done");
    delay(5000);           // wait 5 seconds for next scan
}
```

A1.3 - I2C_DynamicAddress_Slave.ino

```
/*****************              **************           *******************************************************
*              Title: I2C_DynamicAddress_Slave
*              Author: Jimmy Wong
*              Date: Nov 18, 2018
*              Code version: 0.0.1
*****************************************************************************************                                              /

#include <W    ire.h>

// Pin setup
#define BTN_PIN          PA5

int butt       onState;
int lastButtonState = 0;
unsigned long lastDebounceTime = 0;
unsigned long debounceDelay = 50;

// Size of each Tile matrix
const uint8_t matrixWidth = 4;
const uint8_t matri            xHeight = 4;


// Number of Tile matrices
const uint8_t TilesX = 1;
const    uint8_t TilesY = 1;

// I2C
uint8_t I2C_ADDR = 0x21; //Initalize I2C_ADDR
#define I2C_DEFAULT 0x42

void setup()
{
    //I2C Setup
    Wire.begin(I2C_DEFAULT);         // join i2c bus w                          ith the defaul          t address
    Wire.onRequest(requestEvent); // register event
    Wire.onReceive(receiveEvent); // register event

    //Button Setup
    pinMode(BTN_PIN, INPUT);

    Serial.begin(9600);           // start serial for output
}

uint8_t column = 0;

void loop()
{
      int reading = digitalRead(BTN_PIN);
    //buttonEvent
    i f (reading != lastButtonState) {
            lastDebounceTime = millis();
    }
    if ((millis()            - lastDebounceTime)> debounceDelay) {
        if (reading != buttonState){
            buttonState = readin           g;
            //Ser   ial.print("button pressed but don't know value: ");
            / /Serial.println(buttonState);
            if (buttonState == 1){
                //Turn off I2C and reinitialize
                Wire.end();
                delay(100); //slight delay before trying to reintiali                                   ze
                Wire.begin(I2C_ADDR); //join the i2c bus with a different add                              ress
                Wire.onRequest(requestEvent);
                Wire.onReceive(receiveEvent);
                Serial.print("Attempted Address Change");
                Serial.print(I2C_ADDR);
            }
        }
    }
    lastBu   ttonState = reading;
}

// function that executes whenever                    data is received from master
// this function is registered as an event, see setup()
void receiveEvent(int howMany)
{
    if (Wire.available()) //loop through all but the last
    {
        I2C_ADDR = Wir   e.read(); //receive byte as a int
    }
    Serial.println("rea             d value");
}

// function that executes whenever data is requested by master
// this function is registered as an event, see setup()
void requestEvent()
{
    Wire.write("hello          \ n");  //         respond with        message of 6 bytes
                                                // as expected          by master
}
```

A1.4 - I2C_DynamicDisplay_Master.ino

```
/******************************************************************************************
*              Title: I2C_DynamicDisplay_Master
*              Author:      Jimmy Wong
*              Date: Nov 18, 2018
*              Code version: 0.0.1
******************              **********************************************************************/

#include <Wire.h>

#define I2C_ADDR  2

int x = 0;
byte LED_state = 0;
// Size of each Tile matrix
const uint8_       t MATRIX_WIDTH   = 4;
const uint8_t MATRIX_HEIGHT = 4;

#define LED1_PIN PA      1
#define LED2_PIN PA2
#define LED3_PIN PA3
#define LED4_PIN PA4
int LED_array [4] = {LED1_PIN, LED2_PIN, LED3_PIN, LED4_PIN};
```

```
unsigned int TilesX = 1;
void setup()
{
    Wire.begin();                        // joi      n i2c bus (address optional for master)
    pinMode(LED1_PIN,      OUTPUT);
    pinMode(LED2_PIN, OUTPUT);
    pinMode(LED3_PIN, OUTPUT);
    pinMode(LED4_PIN, OUTPUT);
    Serial.begin(9600);  // start serial for output
}

    uint8_t column_max = 8;
    uint8   _t column = 0;
    uint8_t Tile = 0;
    uint8_t Tile_column;

void loop()
{
    //Check if the slave device exists on the bus
    Wire.beginTransmission(2);
    int error = Wire.endTransmission();
    if(error == 0) {
        Serial.print("Device connected at address 2                         -   ");
        Tiles   X = 2;
    }else{
        TilesX = 1;
    }
    column_max = MATR  IX_WIDTH * TilesX;
    column++;
    if(column >= column_max){
        column = 0;
    }
    Serial.print(" column: ");
    Serial.print(column);
    Tile_column = column % MATRIX_WIDTH;
    Tile = (co       lumn   -   Tile_co    lumn) / MATRIX_WIDTH;
    digitalWrite(LED1_PIN,LOW);
    digit    alWrite(LED2_PIN,LOW);
    digitalWrite(LED3_PIN,LOW);
    digitalWrite(LED4_PIN,LOW);
    Serial.print(" Tile #: ");
    Serial.print(Tile);
    Serial.print(" Tile_column: ");
    Serial.printl          n(Tile_column)       ;
    switch(Tile){
        case 0:
            digitalWrite(LED_array[            Tile_column],HIGH);
            if(TilesX == 2){
                Wire.beginTransmission(2);
                Wire.write(MATRIX_WIDTH+1);
                Wire.endTransmission();
            }
            break;
        case 1:
            Wire.beginTr      ansmission(2);
            Wire.write(Tile_column);
            Wire.en   dTransmission();
            Serial.println("Data Sent");
            break;
        default:
            break;
    }

    delay(100);
}
```

A1.5 - I2C_DynamicDisplay_Slave.ino

```
/********************************                    **************          *****************************************
*             Title: I2C_Dyna       micDisplay_Slave
*             Author: Jimmy Wong
*             Date: Nov 18, 2018
*             Code version: 0.0.1
****************************************************************************************/

#include <Wi     re.h>


// Pin       setup
const uint8_t MATRIX_DATA_PIN = 4;
const uint8_t MAT        RIX_CLK_PIN = 7;
#define LED1_PIN PA1
#define LED2_PIN PA2
#define LED3_PIN PA3
#define LED4_PIN PA4
int LED_array [4] = {LED1_PIN, LED2_PIN, LED3_PIN, LED4_PIN};

// Size of each Til             e matrix
const    uint8_t MATRIX_WIDTH = 4;
const uint8_t MATRIX_HEIGHT = 4;

// Number of Tile matrices
const uint8_t TilesX = 1;
const uint8_t TilesY = 1;

#define I2C_ADDR  2
void setup()
{
    Wire.begin(I2C_ADDR);         // join i2c bus with address #2
    Wire.onRequest    (requestEvent); // register event
    Wire.onReceive(receiveE         vent); // register event

    pinMode(LED1_PIN, OUTPUT);
    pinMode(LED2_PIN, OUTPUT);
    pinMode(LED3_PIN, OUTPUT);
    pinMode(LED4_PIN, OUTPUT);

    Serial.begin(9600);          // sta                          rt serial for            output
}

uint8_t column = MATRIX_WIDTH + 1;

void loop()
{
    digitalWrite(LED1_PIN,LOW);
    digitalWrite(LED2_PIN,LOW);
    digitalWrite(LED3_PIN,LOW);
    digitalWrite(LED4_PIN,LOW);
    if (column < MATRIX_WIDTH){
        digitalWrite(LED_array[colum             n],HIGH);
    }
}

// function that executes whenever data is received from                                master
// this function is registered as an event, see setup()
void receiveEvent(int howMany)
{
    Serial.println("receiving data: ");
    if(Wire.available()){
        column = Wire.read()          ; //receive by          te as a int
        Serial.println(column);
    }
}
```

A1.6 - I2C_LED_Master.ino

```
/*****************************************************************************************
*              Title: I2C_LED_Master
*              Author: Jimmy Wong
*              Date: Nov 8, 2018
*              Code version:        0.0.1
********      ***********************************************************                                       ********************/
  #include <Wire.h>
  #define I2C_ADDR  2
  byte x = 0;
byte LED_state = 0;
void setup()
{
    Wire.begin();        // join i2c bus (address optional for master)
    Serial.begin(960        0);  // start serial for output
}
  void loop()
{
    Wire.req    uestFrom(I2C_ADDR, 6);  // request 6 bytes from slave device
      while(Wire.available())         // slave may send less than requested
    {
        char c = Wire.read();         // receive                              a byte as char       acter
        Serial.print(c);             // print the charac                                      ter
    }
    delay(10);
    LED_state = x % 2;
    Wire.beginTransmission(I2C_ADDR); // transmit to device
    Wire.write(LED_state);           // sends one byte
    Wire.endTransmission();                              // stop       transmitting
    x++;
      delay(500);
}
```

A1.7 - I2C_LED_Slave.ino

```
/*****************************************************************************************
*              Title: I2C_LED_Slave
*              Author: Jimmy Wong
*              Date: Nov 8, 2018
*              Code version: 0.0.1
****    **************          ***********************************************************                                **********/

#include <Wire.h>
#define I2C_ADDR  4
const int ledPin = PC13;
```

```
  void setup()
{
    Wire.begin(I2C_ADDR);         // join i2c bus with address #2
    Wire.onRequest(requestEven         t); // registe            r event
    Wire.onReceive(receiveEvent); // register event
    pinMode(ledPin, OUTPUT);
    Serial.begin(9600);           // start serial for output
}
  void loop()
{
}
  // function that executes whenever data is received from master
// this functi            on is register          ed as an event, see setup()
void receiveEvent(int howMany)
{
    int x = Wire.read();        // receive byte as an integer
    if(x == 1){
        digitalWrite(ledPin,HIGH);          // print the integer
    }else{
        digitalWrite(ledPin, LOW);
    }
}
  // function t          hat executes whenever data is requested by master
// this f         unction is registered as an event, see setup()
void requestEvent()
{
    Wire.write("hello          \ n");  // respond with message of 6 bytes
                                         // as expected by master
}
```

A1.8 - IR_MATRIX_POLL.ino

```
/**********************************************                              *****************************************
*           Title: MatrixTestStm32
*           Author: Rowan Baker       - French, Sanket Mittal
*           Date: Nov 22, 2018
*           Code version: 0.0.1
*           Availability:
https://githu         b.com/Rowansda   bomb/T25ELEC491/blob/master/IRSensorsSTM32/IR_MATRIX_POLL.i             no
****************************************************************************************/

#include <Adafruit_GFX.h>
#include <Adafruit_DotStarMatrix.h>
#include <Adafruit_DotStar.h>

// Pin setup
const uint8_t MATRIX_DATA_PIN = PB10;
const uint8_t MATRIX         _CLK_PIN = PB11;

// Size of each Tile matrix
const uint8_t matrixWidth = 4;
const uint8_t matrixHeight = 4;

// Number of Tile matrices
const uint8_t TilesX = 1;
const uint8_t TilesY             = 1;

Adafrui    t_DotStarMatrix matrix = Adafruit_DotStarMatrix(
    matrixWi    dth,
    matrixHeight,
    TilesX,
    TilesY,
    MATRIX_DATA_PIN,
    MATRIX_CLK_PIN,
    DS_MATRIX_TOP     + DS_MATRIX_LEFT +
    DS_MATRIX_COLUMNS + DS_MATRIX_ZIGZAG + DS_TILE_PROGRESSIVE,
    DOTSTAR_BGR
);

const uint16_t colors[] = {
    matrix.Color(255, 0, 0),                 matrix.Color(0, 255, 0), matrix.Color(0, 0, 255), matrix.Color(255,
255, 255), matrix.Color(0,0,0)
};

const uint8_t sensorDataSize = 16;
volaTile int sensorData[sensorDataSize] = {0                       };

const uint      8_t led = PC13;
const uint8_t testPin = PB12;

volaTile boo      l interruptFlag = false;

HardwareTimer timer(2);

void setup() {

    #if defined(__AVR_ATtiny85__) && (F_CPU == 16000000L)
    clock_prescale_set(clock_div_1); // Enable 16 MHz on Tri                              nket
    #endif

    matrix.begin(); // Initialize pins for output
    matrix   .setBrightness(64); // Set max brightness (out of 255)

    pinMode(led, OUTPUT);
    pinMode(testPin, OUTPUT);


    Serial.begin(38400);

    // set sensor polling interupt routine
    // Pa   use the timer         while we're configuring it
    timer.pause();

    // Set up pe        riod
    timer.setPeriod(SENSOR_POLL_PERIOD*1000); // in microseconds

    // Set up an interrupt on channel 1
    timer.setChannel1Mode(TIMER_OUTPUT_COMPARE);
    timer.setCompare(TIMER_CH1,         1);  // Inter           rupt 1 count after each update
    timer.attachCompare1Interr            upt(sensorRead);

    // Refresh the timer's count, prescale, and overflow
    timer.refresh();

    // Start the timer counting
    timer.resume();
}

void sensorRead() {
    uint8_t si = 0;
    uint8_t pin =           0;
    gpio_write_bit(GPIOB, 12, HIGH);
```

```
  for(uint8_t i = (s          ensorDataSize     -   1); i > 5;        --  i) {
    pin = (sensorDataSize         -   1)   -   i;
    if(pin < 8){
      sensorData[i] = analogRead(pin)/16;
    }
    else {
      sensorData[i] = analogRead(pin             + 10)/16;
    }
  }

  gpio_write_bit(GPIOB, 12, LOW);
  interruptFlag =          true;
}

void printSensorData() {
  uint16_t color;
  matrix.setCursor(0, 0);

  for (uint8_t i = 0; i < matrixWidth; i++) {
    for(uint8_t j = 0; j < matrixHeight; j++) {
        Serial.print(        sensorData[i + j*(matrixHeight)]);

        if(j < matrixHe         ight     -   1)
          Serial.print(" | ");
        else
          Serial.println();
      }
  }
  Serial.println();
}
int Color_Brightness(int sensorData){
  uint16_t color = matrix.Col              or(sensorData,       0, 0);
  return color;
}

void  LEDControl() {
    uint1   6_t color;
    int adjusted;
     for (uint8_t i = 0; i < matrixWidth; i++) {
      for(uint8_t j = 0; j < matrixHeight; j++) {
        adjusted = sensorData[i + j*(matrixHeight)];
        if(adjus      ted > 20)
          adjusted *= 8;
        if (adjusted > 2          55)
          adjusted = 255;
        color = Color_Brightness(adjusted);
        matrix.drawPixel(i, j, color);
        matrix.show();
        }
     }
}

//Simply a while loop that                 gets the senso      r poll data and prints it on update
void loop() {
    if (i      nterruptFlag){


      //print the sensor data
      printSensorData();

      LEDControl();
```

```
        //reset flag
        interruptFlag = false;
      }
    }
```

A1.9 - IRSensorsSTM32.ino

```
/****    ************************************************************                                  ************************
*             Title: IRSensorsSTM32
*             Author: Rowan Baker       - French
*             Date: Nov 22, 2018
*             Code version: 0.0.1
*             Availability:
http://raw.githubusercontent.com/Rowansdabomb/                  T25ELEC491/mas ter/IRSensorsSTM32/IRSensorsSTM32.ino
*********************                ******************************************************************/

#define SENSOR_POLL_PERIOD 100

const uint8_t sensorDataSize = 16;
volaTile int sensorData[sensorDataSize] = {0};

const uint8_t          led = PC13;
const uint8_t testPin = PB12;

const uint8_t ma        trixWidth = 4;
const uint8_t matrixHeight = 4;

volaTile bool interruptFlag = false;
volaTile unsigned long interruptTime = 0;

HardwareTimer timer(2);

void setup() {
  // put your s          etup code here       , to run once:
  pinMode(led, OUTPUT);
  pinMode(testPin, O        UTPUT);
  Serial.begin(38400);
  // set sensor polling interupt routine
  // Pause the timer while we're configuring it
  timer.pause();

  // Set up period
  timer.setPeriod(SENSOR_P       OLL_PERIOD*1000); // in microseconds

  // Set up an interrupt on channel                      1
  timer.setChannel1Mode(TIMER_OUTPUT_COMPARE);
  timer.setCompare(TIMER_CH1, 1);  // Interrupt 1 count after each update
  timer.attachCompare1Interrupt(sensorRead);

  // Refresh         the timer's co         unt, prescale, and overflow
  timer.refresh();

  // Start         the timer counting
  timer.resume();
}

void sensorRead() {
  uint8_t si = 0;
  uint8_t pin = 0;
  gpio_write_bit(GPIOB, 12, HIGH);
```

```
    for(uint8_t i = (sensorDataSize                    -   1); i > 5;           --  i)    {
        pin = (     sensorDataSize       -   1)   -   i;
        if(pin < 8){
            sensorData[     i] = analogRead(pin)/16; //convert to 255
//      sensorData[i] = pin;
        }
        else {
            sensorData[i] = analogRead(pin + 10)/16;
//      sensorData[i] = pin + 10;
        }
    }
    gpio_write_bit        (GPIOB, 12, LOW);
    interruptFlag = true;
}

void printSens        orData() {
    Serial.write(27);       // ESC command
    Serial.print("[2J");    // clear screen command
    Serial.write(27);
    Serial.print("[H");     // cursor to home command

    for (u     int8_t i = 0;             i < matrixWidth; i++) {
        for(uint8_t j = 0; j < matrixHe                     ight; j++) {
            Serial.print(sensorData[i + j*(matrixHeight)]);
            if(j < matrixHeight               -   1)
                Serial.print(" | ");
            else
                Serial.println();
        }
    }
    Serial.     println();
}

//Simply a while loop that gets the sensor poll data and pr                                  ints it on update
void loop() {
    // put your main code here, to run repeatedly:

    Serial.println("Let's begin!");
    while(true){
//    digitalWrite(led, HIGH);
//    delay(200);
//          digitalWrit        e(led, LOW);
//    delay(200);

        if (interruptFlag){
            if (digitalRead(led) == HIGH) {
                digitalWrite(led, LOW);
            } else {
                digitalWrite(led, HIGH);
            }

            //print the sensor data
            printSensorD     ata();

            //reset flag
            interruptFlag = false;
        }
    }
}
```

A1.10 - MatrixTestStm32.ino

```
/*****************************************************************************************
*              Title: MatrixTestStm32
*              Author: Rowan Baker       - French, Jimmy Wong
*              Date: Nov 1     0, 2018
*              Code version: 0.0.1
*              Availability:
https://githu          b.com/Rowansdabomb/T25ELEC491/edit/master/MatrixTestStm32/MatrixTestStm32.ino
*****************************************************************************************/


#include <Adaf      ruit_GFX.h>
#i nclude <Adafruit_DotStarMatrix.h>
#include <Adafruit_DotSta            r.h>

// Pin setup
const uint8_t MATRIX_DATA_PIN = PB10;
const uint8_t MATRIX_CLK_PIN = PB11;
const uint8_t TEST_PIN = PA7;

const uint8_t CHAR_WIDTH = 5;
const uint8_t CHAR_HEIGHT =          8;

// Size o      f each Tile matrix
const uint8_t matrixWidth = 4;
const uin     t8_t matrixHeight = 4;

// Number of Tile matrices
const uint8_t TilesX = 1;
const uint8_t TilesY = 1;

// Last argument: line 30 in Adafruit_DotStar.h for mappings
Adafruit_DotStarMa       trix matrix =           Adafruit_DotStarMatrix(
   matrixWidth,
   matrixHeight,
   TilesX,
   TilesY,
   MATRIX_DATA_PIN,
   MATRIX_CLK_PIN,
   DS_MATRIX_TOP     + DS_MATRIX_LEFT +
   DS_MATRIX_COLUMNS + DS_MATRIX_ZIGZAG + DS_TILE_PROGRESSIVE,
   DOTSTAR_RGB
);

// See      https://l
cons t uint16_t colors[] = {
   matrix.Color(255, 0, 0), matrix.C                    olor(0, 255, 0), matrix.Color(0, 0, 255), matrix.Color(255,
255, 255)
};

void setup() {
   pinMode(TEST_PIN, OUTPUT);

   matrix.begin(); // Initialize pins for output

   matrix.set      Brightness(64)       ; // Set max brightness (out of 255)

   matrix.setTextWra       p(false);
   matrix.setTextColor(colors[0]);
   matrix.show();  // Turn all LEDs off ASAP
```

```
    Serial.begin(9600);
}

int x    = matrix.width();
int pass = 0;
uint8_t p_x = 0;
uint8_t p_y        = 0;
uint8_t c      olorIndex = 0;

void scrollText(uint8_t fps, char* text, in                              t textLength) {
    // Test Conditions:
    //  variables: matrixWidth, matrixHeight,
    //  No delay

    // Results: (same for text = "3 2 1" and text = "6 5 4 3 2 1")
    //  Max frame ra          te
    //    16x        16 = 57fps
    //    4x4 = 96fps
    //  SetupPeriod
    //    16       x16 = 17.5ms
    //    4x4 < 1.25ms


    // Takes in an fps and text to scroll
    gpio_write_bit(GPIOA, 7, HIGH);
    matrix.fillScreen(0);
    matrix.setCursor(x, 0);
    matrix.print(F(text             ));
    if(   --  x <    - textLength*CHAR_WIDTH) {
        x = matrix.width();
    }
    matrix.show();
    gpio_write_bit(GPIOA, 7, LOW);
    delay(1000/fps);
}

void testEachPixel(uint8_t fps) {
    matrix.fillScreen(0);
    matrix.setCursor(x, 0);
    uint16_t color = colors[3];
    Serial.printl          n(color);
    matrix.drawPixel(p_x, p_y, color);
    p_x++;
    i f (p_x >= matrixWidth) {
        p_x = 0;
        p_y++;
    }
    if (p_y >= matrixHeight) {
        p_y = 0;
    }
    matrix.show();
    delay(1000/fps);
}

uint8_t i = 16;

void testAllPixels(uint8_t f                    ps) {
    matrix   .setCursor(0, 0);
    matrix.fillRect(0, 0, matrixWidth, 4*ma                        trixHeight, colors[1]);

    Serial.println(colorIndex);
    colorIndex++;
    if (colorIndex >= 4){
          colorIndex = 0;
          matrix.setBrightness(255/(i*2));
          Serial.print("Color Br              ightness ");
          Serial.println(256/i);
          i*=2;
          if(i > 16)
              i = 1;
    }

    matrix.show();
    delay(1000/fps);
}

void testDigital() {
    // produces 672.4kHz square wave
    // risetime (3V) < 42ns
    // falltime (.3V) < 47ns
    digitalWrite(PA7         , HIGH);
    dig  italWrite(PA7, LOW);
}

void testGPIO() {
    // produces 1.8         93MHz pulse wave
    // risetime (2.5V) < 18ns (rises only to 2.7V)
    // falltime (.32V) < 52ns

    gpio_write_bit(GPIOA, 7, HIGH);
    gpio_write_bit(GPIOA, 7, LOW);
}

void loop() {
    char text[] =           "~ * ^";

    scrollText(10, text, sizeof(text)/sizeof(text[0                              ]));

//   testDigital();
//   testGPIO();

//   testEachPixel(8);
//   testAllPixels(1);
}
```

A1.11 - TopologyTest_Master.ino

```
/**********************************************************                                  **************           ***************
*  Title: Topology Test Master
* Author: Jimmy Wong
* Date: February 10, 2019
* Code version: 0.0.3
****************************************************************************************/

#include <Wire.h>
#include <Adafruit          _GFX.h>
#inclu    de <Adafruit_Dot       StarMatrix.h>
#include <Adafruit_DotStar.h>

#define I2C_DEFAULT 0x42
```

```
#define CNCT_U B0001
#define CNCT_D B0010
#define CNCT_L B0100
#define CNCT_R B1000

#define PIN_DIR_U PA4
#define PIN_DIR_D PA6
#define PIN_DIR_L PA3
#def  ine PIN_DIR_R      PA5

#define TIL      E_MAX 5

#define DEBUG 0

int print_flag = 0;
#define PRINT_EN 1

#define ARRAY_SIZE 7

//Use layout to store the addresses of the devices 7 by 7
int layout[7][7]= {{  0,  0,  0,  0,  0,  0,  0},
                                   {  0,  0,  0           ,  0,  0,  0,                 0},
                                   {  0,  0,  0,  0,  0,  0,  0},
                                   {  0,  0,  0,  9,  0,  0,  0},
                                   {  0,  0,  0,  0,  0,  0,  0},
                                   {  0,  0,  0,  0,  0,  0,  0},
                                   {  0,  0,  0,  0,  0,                        0,  0},
};

in  t Tile_order[4]            = {0, 0, 0, 0};

struct POS {
    int x;
    int y;
};

/* Tile structure
  * active = is this Tile currently active
  * addr   = address of the current Tile
  * posX   = position of Tile in the X direction
  * posY   = position of Ti                 le in the Y di           rection
  * ports         = state of the directional pins
  * ports_pre = state of the directional pins in the previous instance
*/
struct TILE {
    byte  active;
    int   addr;
    POS   ;
    int   ports;
    int   ports_pre;
};



TILE Tile[TILE_MAX];

//l    ast set as         default
int ad     dr_lst[TILE_MAX] = {0x08, 0x10, 0x18, 0x20, 0x28};

//int error;
int i;
int TileID;
int x_free;
int y_free;
int dirChange;
int dirChange_f;
int Tile_count;
int Tile_order_f = 0;
//int Tile_count_pre;
int show_Tile;
int show_x;
int     show_y;

int pinDir = B00          00;

//DotStar Setup
const uint8_t MATRIX_DATA_PIN = PB11;
const uint8_t MATRIX_CLK_PIN = PB10;
const uint8_t CHAR_WIDTH = 5;
const uint8_t CHAR_HEIGHT = 8;

// Size of each Tile matrix
const uint8_t matrixWidth = 4;
const uint8_      t matrixHe     ight = 4;

// Nu   mber of Tile matrices
const uint8_t TilesX = 1;
const uint8_t TilesY = 1;

Adafruit_DotStarMatrix matrix = Adafruit_DotStarMatrix(
    matrixWidth,
    matrixHeight,
    TilesX,
    TilesY,
    MATRIX_DATA_PIN,
    MATRIX_CLK_PIN,
    DS_MATRIX_TOP          + DS_MATRIX_LEFT +
    DS_MATRIX_COLUMNS + DS_MATRIX_ZIGZAG + DS_TILE_PROGRESSIVE,
    DOTSTAR_RGB
);

const uint16_t colors[] = {
    matrix.Color(255, 0, 0), matrix.Color(0, 255, 0), matrix.Color(0, 0, 255), matrix.Color(255,
255, 255)
};

void    handler_ti      m(void);

void s   how_Tile_info(int TileID);

void setup() {
    // Directional Pin Setup

    pinMode(PIN_DIR_U, INPUT_PULLDOWN);
    pinMode(PIN_DIR_D, INPUT_PULLDOWN);
    pinMode(PIN_DIR_L, INPUT_PULLDOWN);
    pinMode(PIN_DIR_R, INPUT_PULLDOWN);

    // Interna       l Device Map       -   I nitial Population
    for(i = 0; i < TILE_MAX; i++){
        Tile[i].active  = 0;
        Tile[i].addr    = addr_lst[i];
        Tile[i].pos.x    = 0;
        Tile[i].pos.y    = 0;
        Tile[i].ports   = B00000000;
    }

    Tile[0].active = 1;
    Tile[    0].addr =       0xFF;
    Tile[0].       pos.x = 3;
    Tile[0].pos.y = 3;


    //Timer for testing purposes
    Timer2.setMode(TIMER_CH1, TIMER_OUTPUTCOMPARE);
    Timer2.setPeriod(1000000);
    Timer2.setCompare(TIMER_CH1, 1);
    Timer2.attachInterrupt(TIMER_CH1, handler_tim);

    // I     2C Master Setup
    Wire.begin();

    // DotStar Setup
    matrix.begin(); // Initialize pins for output
    matrix.setBrightness(64); // Set max brightness (out of 255)
    matrix.setTextWrap(false);
    matrix.setTextColor(colors[0]);
    matrix.show();  /           / Turn all          LEDs off ASAP

    // Serial Setup            -   for output
    Serial.begin(9600);

    Tile_order_f = 1;
}

int x    = matrix.width();
int pass = 0;
uint8_t colorIndex = 0;

void loop() {

    if(print_flag == PRINT_EN){

        Serial.print("x free: ");
        Serial    .print(x_f        ree);
        Serial    .print(",y_free: ");
        Serial.println(y_free);

        show_Tile_info(0);
        show_Tile_info(1);
        show_Tile_info(2);
        show_Tile_info(3);
        show_Tile_info(4);

        Serial.print("# Tiles: ");
        Serial.print(Tile_count)                ;
        Seri   al.print(" Order              : ");
        for(int j = 0; j < 4; j++){
            Serial.print(Tile_order[j]);
            Serial.print(" ");
        }
        Serial.println();
        //Disable the flag
        //print_flag = 0;
    }

    int array_x_max = 3;
    int array_y_max = 3;
    i nt array_x      _min = 3;
    int     array_y_min = 3;

    //Serial.println("Determining Directions");

    //Determine occupied directions
    Tile[0].ports_pre = Tile[0].ports;
    Tile[0].ports = B0000;
    if(digitalRead(PIN_DIR_U)){
        Tile[0].ports = Tile[0].ports |                         CNCT_U;
    }
    if(digitalR         ead(PIN_DIR_D)){
        Tile[0].ports = Tile[0].ports | CNCT_D;
    }
    if(digitalRead(PIN_DIR_L)){
        Tile[0].ports = Tile[0].ports | CNCT_L;
    }
    if(digitalRead(PIN_DIR_R)){
        Tile[0].ports = Tile[0].ports | CNCT_R;
    }

    // Loo    p to check       if the currentl            y existing Tiles
    // still exist, if not clear and erase from layout
    // Tile[0] will be reserved for the master
    //Tile_count_pre = Tile_count;
    Tile_count = 1;

    //Serial.println("First I2C Check");
    Wire.beginTransmission         (I2C_DEFAU LT);
    int chk_e     rror = Wire.endTransmission();
    if (chk_error == 0){
        Serial.println("Default Address still detected");
    }


    for(i = 0; i < TILE_MAX; i++){
        int error;
        //Serial.print("Currently Checking Tile ");
        //Serial.print           ln(i);
        if( i != 0 ){//               Check if dealing with master Tile
            if( Tile[i].active == 1 ){
                Wire.beginTransmission(Tile[i].addr);
                error = Wire.endTransmission();
            }else{
                TileID = i;
            }

            if (error == SUCCESS) {
                i f(DEBUG){
                    Serial.print("I2C device found at address 0x");
                    Serial.println(Tile[i].addr, HEX);
                }//END DEBUG PRINT
                Tile[i].ports_pre = Tile[i].ports;
                //If available request current port status from slave d                                 evices
                Wire.reques    tFrom(Tile[i].addr, 1);
                Tile[i].ports = Wire.read();
                Tile_count++;
                if( Tile[i].pos.x < array_x_min ){
                    array_x_min = Tile[i].pos.x;
                }
                if( Tile[i].pos.x > array_x_max ){
                    ar ray_x_max    = Tile[i].pos.x;
                }
                if( Tile[i].pos.y > array_y_max  ){
                    array_y_max = Tile[i].pos.y;
                }
                if( Tile[i].pos.y < array_y_min ){
                    array_y_min = Tile[i].pos.y;
                }
            }else{
                if(DEBUG){
                    Serial.print("No I            2C device found at address 0x");
                    Serial.println(Tile[i].addr, HEX);
                }// END DEBUG PRINT
                layout[Tile[i].pos.y][Tile[i].pos.x] = 0;
                Tile[i].pos.x = 0;
                Tile[i].pos.y = 0;
                Tile[i].acti          ve = 0;
                //Tile Rem     oved
                Tile_order_f = 1;
            }// END Address Successfully found

        }

        //Check if the directional ports has changed
        if(Tile[i].ports != Tile[i].ports_pre){
            dirChange_f = 1;
            dirChange = Tile[i].ports                 ^ Tile[i].         ports_pre;
            switch(dirChange){
              case CNCT_U:
                    x_free = Tile[i].pos.x;
                    y_free = Tile[i].pos.y                 -   1;
                    break;
                case CNCT_D:
                    x_free = Tile[i].pos.x;
                    y_free = Tile[i].pos.y + 1;
                    break;
                case CNCT _L:
                    x_free = Tile[i].pos.x                 -   1;
                    y_free = Tile[i].pos.y;
                    break;
                case CNCT_R:
                    x_free = Tile[i].pos.x + 1;
                    y_free = Tile[i].pos.y;
                    break;
                default:
                    //will not          happen
                    break;

            }// END SWITCH
        }//End of Directional ports changing
    }// End FOR loop

    if(dirChange_f == 1 ){

        // Check if the default address exist
```

```
        Wire.beginTransmission(I2C_DEFAULT);
        int def_e      rror = Wir      e.endTransmissio      n();
        //Serial.println(def_error);
        if (def_error == SUCCESS){
            Serial.println("Device found at default address");
            Wire.beginTransmission(I2C_DEFAULT);
            Wire.write('A');
            Wire.write(Tile[TileID].addr); /                    /Assign th      e next available           address from
            Wire.endTransmission();
            //Maybe insert something here during the connection process?
            Serial.print("Sent address: ");
            Serial.println(Tile[TileID].addr, HEX);
        }

        delay(500); //Half se            cond delay      before checking         that the Tile is now in place
        //Determine the location of the Tile
        Wire.beginTransmission(Tile[TileID].addr);
        int addr_error = Wire.endTransmission();
        if (addr_error == 0){
            Tile[TileID].active = 1;
            Til   e[TileID].       pos.x = x_free;
            Tile[TileID].pos.y = y_free;
            layout[y_free][x_free] = TileID;
            x_free = 0;
            y_free = 0;
            dirChange_f = 0;// reset the direction changed flag
            Tile_order_f = 1;// raise the flag for to redo the                                  Tile order
        }

    }
    if   (print_flag == PRINT_EN){
        Serial.println("Current Internal Array");
        for(int j = 0; j < ARRAY_SIZE; j++){
            for(int k = 0; k < ARRAY_SIZE; k++){
                Serial.print(layout[j][k]);
                Serial.print(" ");
            }
            Serial.     println();
        }
        print_flag = 0;
    }
    if(print_flag == 5){
        Serial.print("Array X Values: ");
        Serial.print(array_x_min);
        Serial.print(" ");
        Serial.println(array_x_max);
        Serial.print("Array Y Values: ");
        Serial.print(ar          ray_y_min)    ;
        Serial.pri       nt(" ");
        Serial.println(array_y_max);
        print_flag = 0;
    }


    //TODO: Sending data dynamically
    if(Tile_order_f == 1){ // only needs to be done if number of Tiles changes
        int cnt_x;
        int cnt_y;
        int cnt_order          = 0;
        f or(cnt_order = 0         ; cnt_order < 4; cnt_order++){
                    Tile_order[cnt_order] = 0;  //reset the order
        }
        cnt_order = 0;
        for(cnt_y = array_y_min; cnt_y <= array_y_max; cnt_y++){
            for(cnt_x = array_x_min; cnt_x <= array_x_max; cnt_            x++){
                /*Serial.pri     nt("At position ");
                Serial.print(cnt_x);
                Serial.print(" ");
                Serial.println(cnt_y);
                */
                int temp_id = layout[cnt_y][cnt_x];
                if (temp_id == 9){
                    Tile_order[cnt_order] = temp_id        ;
                    cnt_order++;
                }else if (temp_id != 0){
                    if( Tile[temp_id].active == 1){
                        Tile_order[cnt_order] = temp_id;
                        cnt_order++;
                    }
                }
            }
            Tile_order_f = 0;
        }// End looping throu      gh array
    }// END if

    //Tile_order[x] is the index of the Tile
    for(show_Tile = 0; show_Tile < Tile_count; show_Tile++){

        if(Tile_order[show_Tile] == 9){
            matrix.fillScreen(0);
            if((Tile[0].ports & CNCT_U) == CNCT_U){
                matri  x.fillRect     (1, 3, 2, 1, col      ors[show_Tile]);
            }
            if((Tile[0].ports & CNCT_D) == CNCT_D){
                matrix.fillRect(1, 0, 2, 1, colors[show_Tile]);
            }
            if((Tile[0].ports & CNCT_L) == CNCT_L){
                matrix.fillRect(0, 1, 1, 2, colors[show_T            ile]);
            }
            if((T  ile[0].ports & CNCT_R) == CNCT_R){
                matrix.fillRect(3, 1, 1, 2, colors[show_Tile]);
            }
            matrix.fillRect(1,1, 2, 2, colors[3]);
            matrix.show();
        }else{
            Wire.beginTransmission(Tile[Tile_order[show_Tile          ]].addr);
            Wire.write    ('B');
            Wire.write(show_Tile);
            Wire.endTransmission();
        }
    }
    Serial.println("Reached the end");

    delay(100);

}

void handler_tim(void) {
    print_flag = 1;
}

void show_Tile_info(int TileID){
    Serial.print(          "Tile ID:         ");
    Serial.pri       nt(TileID);
    Serial.print(" x: ");
    Serial.print(Tile[TileID].pos.x);
    Serial.print(",y: ");
    Serial.print(Tile[TileID].pos.y);
    Serial.print(",active: ");
    Serial.print(Tile[TileID].active);
    Serial.print(", ports: ");
    Serial.prin       tln(Tile[TileID]           .ports, BIN);
}
```

A1.12 - TopologyTest_Slave.ino

```
/**************************************************************************************
*  Title: Topology Test Slave
* Author: Jimmy Wong
* Date: February 10, 2019
* Code version:          0.0.3
****    ****************            *******************************************************************/

#include <Wire_slave.h>
#include <Adafruit_GFX.h>
#include <Adafruit_DotStarMatrix.h>
#include <Adafruit_DotStar.h>

// Pin setup

#define CNCT_U B0001
#define      CNCT_D B0010
#define CNCT_   L B0100
#define CNCT_R B1000

#define PIN_DIR_U PA4
#define PIN_DIR_D PA6
#define PIN_DIR_L PA3
#define PIN_DIR_R PA5

#define LED_U PA3
#define LED_D PA4
#define LED_L PA5
#define LED_R PA2

//DotStar Setup
const uint8_t MATRIX_D        ATA_PIN =    PB11;
const uin      t8_t MATRIX_CLK_PIN = PB10;
const uint8_t CHAR_WIDTH = 5;
const uint8_t CHAR_HEIGHT = 8;

// Size of each Tile matrix
const uint8_t matrixWidth = 4;
const uint8_t matrixHeight = 4;

const uint8_t TilesX = 1;
const uint8_t TilesY =              1;

Adafr  uit_DotStarMatri         x matrix = Adafruit_DotStarMatrix(
    matrixWidth,
    matrixHeight,
    TilesX,
    TilesY,
    MATRIX_DATA_PIN,
    MATRIX_CLK_PIN,
    DS_MATRIX_TOP     + DS_MATRIX_LEFT +
    DS_MATRIX_COLUMNS + DS_MATRIX_ZIGZAG + DS_TILE_PROGRESSIVE,
    DOTSTAR_RGB
);

const uin     t16_t colors[] = {
    matrix.Color(255, 0, 0), matrix.Color(0, 255, 0), matrix.Color(0, 0, 255), matrix.Color(255,
255, 255)
};

int buttonState = 0;
// I2C
uint8_t I2C_ADDR = 0x42; //Initalize I2C_ADDR
#define I2C_DEFAULT 0x42

int pos_x       = 0;
int pos_y =        0;

int dspy_en = 0;
int mtrx_en = 0;
int brightness = 0;

int led_out[2][2] = { {LED_L, LED_U},
                                             {LED_D, LED_R}};

void handler_tim(void);

void setup()
{
    //I2C Setup
    Wire.begin(I2C       _DEFAULT);                    // join         i2c bus with the default address
    Wire.onRequest(requestEvent); // register event
    Wire.onReceive(receiveEvent); // register event

    // Directional Pin Setup
    pinMode(PIN_DIR_U, INPUT_PULLDOWN);
    pinMode(PIN_DIR_D, INPUT_P     ULLDOWN);
    pinMode(PIN_DI    R_L, INPUT_PULLDOWN);
    pinMode(PIN_DIR_R, INPUT_PULLDOWN);
    /*
    // Directional LED setup **Replace with DotStar**
    pinMode(LED_U, OUTPUT);
    pinMode(LED_D, OUTPUT);
    pinMode(LED_L, OUTPUT);
    pinMode(LED_R, OUTPUT);*/

    //     Timer Setu    p
    Timer2.setMo    de(TIMER_CH1, TIMER_OUTPUTCOMPARE);
    Timer2.setPeriod(1000000);
    Timer2.setCompare(TIMER_CH1, 1);
    Timer2.attachInterrupt(TIMER_CH1, handler_tim);

    // DotStar Setup           -   BEGIN
    matrix.begin();
    matrix.setBrightness(64); // Se                   t max brig      htness
    matrix   .setTextWrap(false);
    matrix.setTextColor(colors[0]);
    matrix.show();  // Turn all LEDs off ASAP

    //  Serial Setup            -   for output
    Serial.begin(9600);
}

int ports = B0000;
int temp_ports = B0000;
uint8_t column = 0;
char msg_   buf[6] = {0, 0,             0, 0, 0, 0};



void loop()
{
    //Serial.println(buttonState);
    if (buttonState == 1){
        //Turn off I2C and reinitialize
        Wire.begin(I2C_ADDR); //join the i2c bus with a different address
        Wire.onRequest(requestEvent);
        Wire.onR  eceive(receiveEv       ent);
        Serial.print("Attempted Address Change");
        Serial.println(I2C_ADDR, HEX);
        buttonState = 2;
    }
    //Determine occupied directions
    temp_ports = B0000;
    if(digitalRead(PIN_DIR_U)){
        temp_ports = temp_ports           | CNCT_U;
    }
    if(digital         Read(PIN_DIR_D)){
        temp_ports = temp_ports | CNCT_D;
    }
    if(digitalRead(PIN_DIR_L)){
        temp_ports = temp_ports | CNCT_L;
    }
    if(digitalRead(PIN_DIR_R)){
        temp_ports = temp_ports | CNCT_R;
    }
    ports = temp_ports;

    //Display
    //x position

    if(dspy_en){
        pos_x = (int) msg_buf[0]              -   48;
        pos_y = (int) msg_buf[1]              -   48;
        brightness = (int) msg_buf[2] * 25;
        digitalWrite(led_out[pos_x][pos_y], HIGH);
    }
    if(mtrx_en){
        Serial.print("Received: ");
        Serial.println(msg_buf[0]);
        matrix.fillScreen(0);
        if((ports & CNCT_U) == CNCT_U){
            matrix.fillRect(1, 3, 2, 1, colors[msg_buf[0]]);
        }
        if((ports & CNCT_D) == CNCT_D){
            matrix.fillRect(1, 0, 2, 1, colors[msg_buf[0]]);
        }
        if((ports & CNCT_L) == CNCT_L){
            matrix.fillRect(0, 1, 1, 2, colors[msg_buf[0]]);
        }
        if((ports & CNCT_R) == CNCT_R){
            matrix.fillRect(3, 1, 1, 2, colors[msg_buf[0]]);
        }
        matrix.fillRect( 1, 1, 2, 2, colors[2]);
        matrix.show();
    }


    delay(100);
    //Ser   ial.println("continuing");
}

// function that executes whenever data is received from master
// this function is registered as an event, see setup()
void receiveEvent(int howMany)
{
    char c;
    Serial.println("Event Received");
    if(Wire.available()){
        c = Wire.read();      // receive first byte as a character
        Serial.println(c);         // print the character
    }
    if(c == 'A'){
        I2C_ADDR = Wire.read();    // receive byte as an integer
        Serial.println(I2C_ADDR, HEX);         // print the integ                                    er h
        if(buttonState != 2){
            Wire.end();
            buttonState = 1;
        }
    }else if (c == 'E'){
        dspy_en = 1;
        int i = 0;
        while(Wire.available()){
            msg_buf[i] = Wire.read();
            Serial.print(msg_buf[i]);
            i++;
        }
        Seri  al.println();
    }else if (c == 'D'){
        dspy_en = 0;
        mtrx_en = 0;
    }else if (c == 'B'){
        mtrx_en = 1;
                int i = 0;
        while(Wire.available()){
            msg_buf[i] = Wire.read();
            Serial.print(msg_buf[i]);
            i++;
        }
    }
}

// f     unction that executes whenever data is requested by master
// this function is registered as an event, see setup()
void requestEvent()
{
    Wire.write(ports);  // respond with message of 1 byte
                                        // as expected by master
```

```
}
void handler_t        im(void){
    digitalWrite(led_out[0][0], LOW);
    digitalWrite(led_out[1][0], LOW);
    digitalWrite(led_out[0][1], LOW);
    digitalWrite(led_out[1][1], LOW);
}
```

Appendix II: Pinout Diagrams

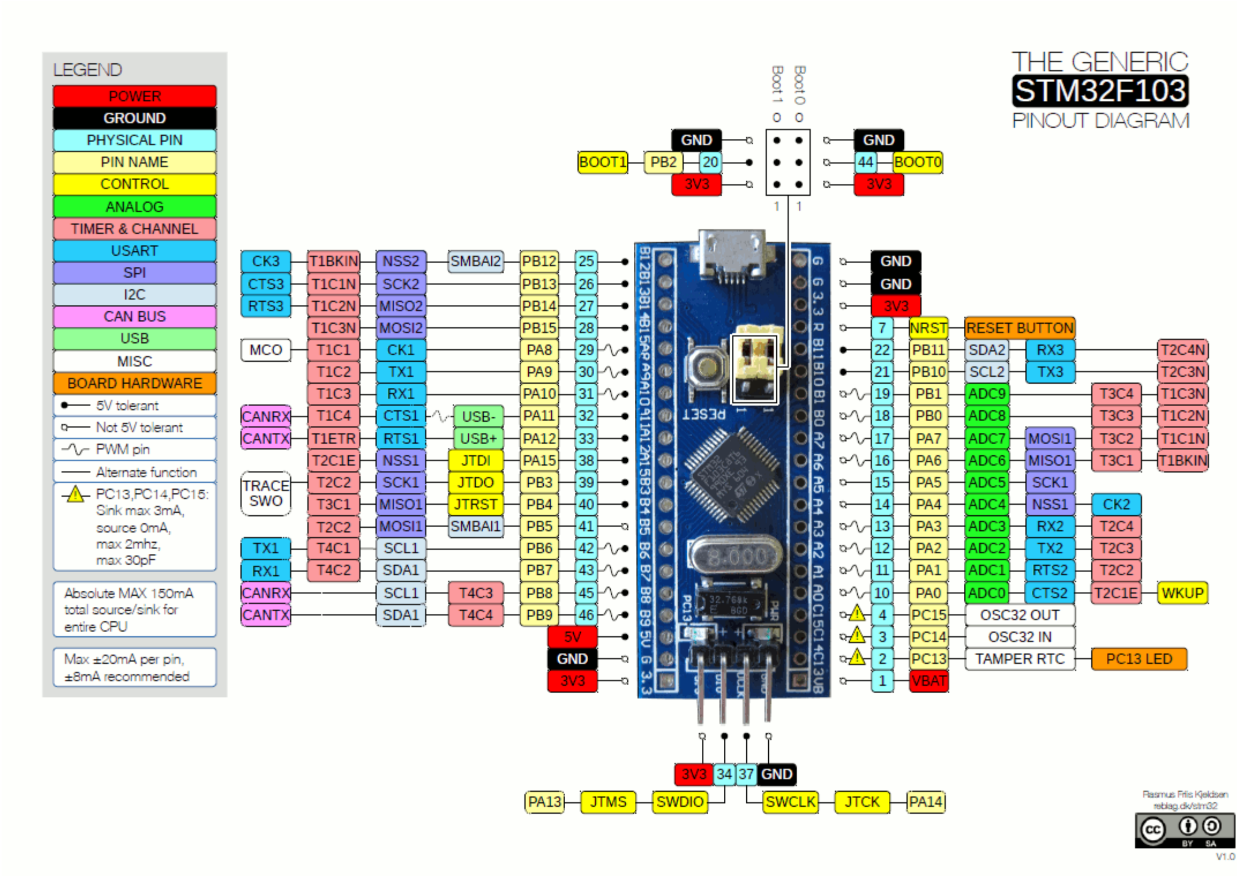


Fig 1: STM32F103 "Blue Pill" PinOut Diagram [4]

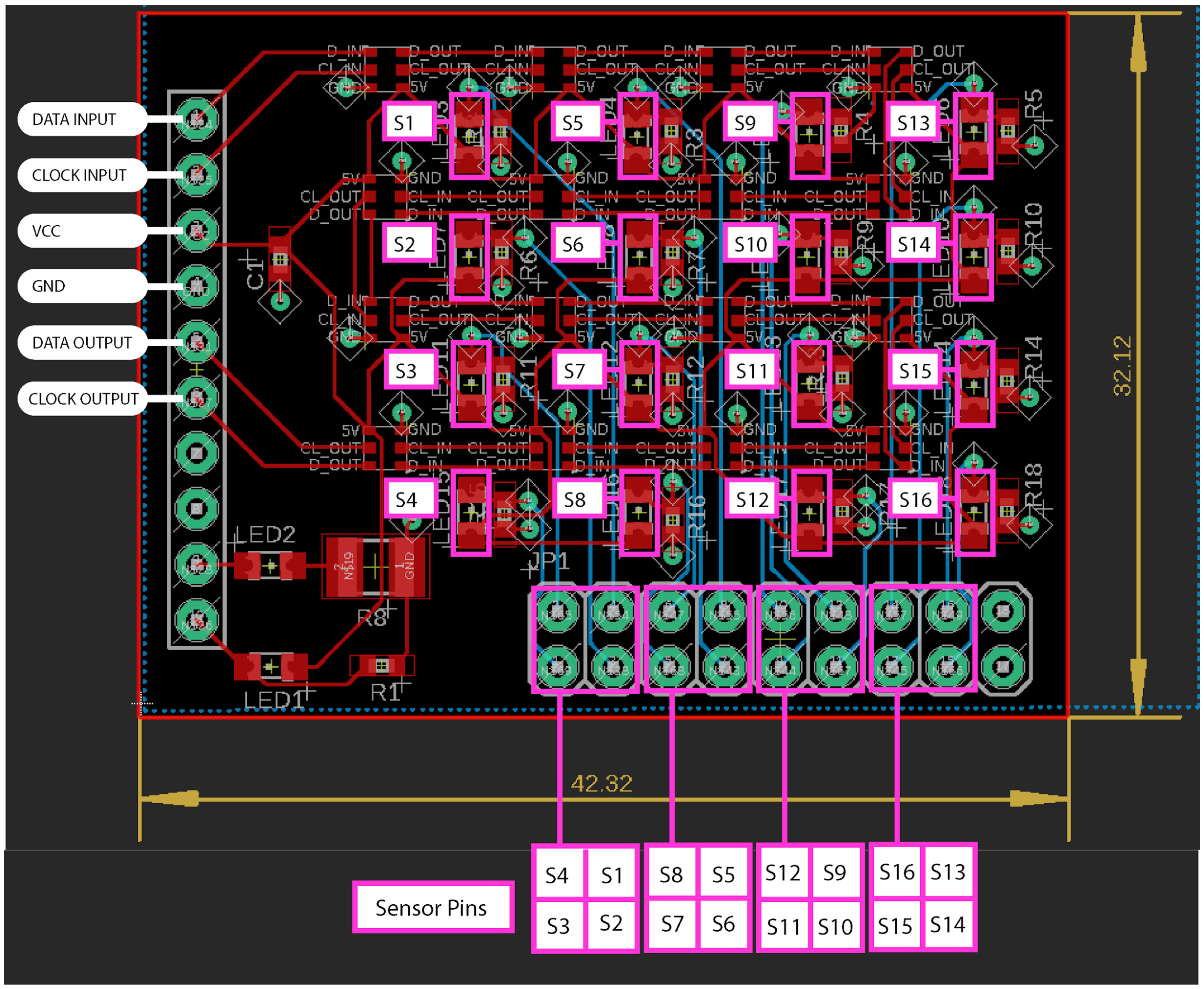


Fig 2: Pinout PCB Schematic

Citations

[1] OSRAM, “High Power Infrared Emitter (850 nm) Version 1.6”, SFH 4056 datasheet, August. 2016

[2] NIST, “Reflectance Measurements of Human Skin”, National Institute of Standards and Technology, 2015 [Online] Available: https://www.nist.gov. [Accessed: Nov 21, 2018].

[3] Vishay Semiconductors, “Silicon NPN Phototransistor”, VEMT2000X01, VEMT2020X01 datasheet, August. 2011

[4] I. Lee, S. Cho and G. Moon, "Interleaved Buck Converter Having Low Switching Losses and Improved Step-Down Conversion Ratio", IEEE Transactions on Power Electronics, vol. 27, no. 8, pp. 3664-3675, 2012.

[5] "Chapter 5. The Discontinuous Conduction Mode", Ecee.colorado.edu, 2018. [Online]. Available: http://ecee.colorado.edu/~ecen5797/course_material/Ch5slides.pdf. [Accessed: 26- Nov- 2018].