SONOS COM.

CE Presentation

UCSB Capstone Team

Our Team

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SONOS

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Laritech

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Sponsored by: SONOS, Laritech

Our Task

To design and build a convenient communication device that works seamlessly with your existing Sonos systems.


SONOS

Overview

COM. is an intercom device that can connect and control all SONOS devices in a home network.

Communication & Music Control

Capacitive Touch

Modes

- Music
- Intercom

Music Control

Intercom

User Setup Procedure

1. Power on COM.

2. Connect to WiFi network "SONOS COM."

3. Use app to send SSID and Password.

Design and Size Constraints

Competitor Analysis

Amazon Echo Dot

- Advantages
  - Multiple functions
  - Smart Controls
  - Low price ($49.99)

- Disadvantages
  - Does not have a screen
  - Too many buttons
  - Does not have an intercom function

Weight	5.7 oz (163 grams)
Size	1.3” x 3.3” x 3.3” (32 mm x 84 mm x 84 mm)
Connectivity	Wifi
Power Source	Micro USB

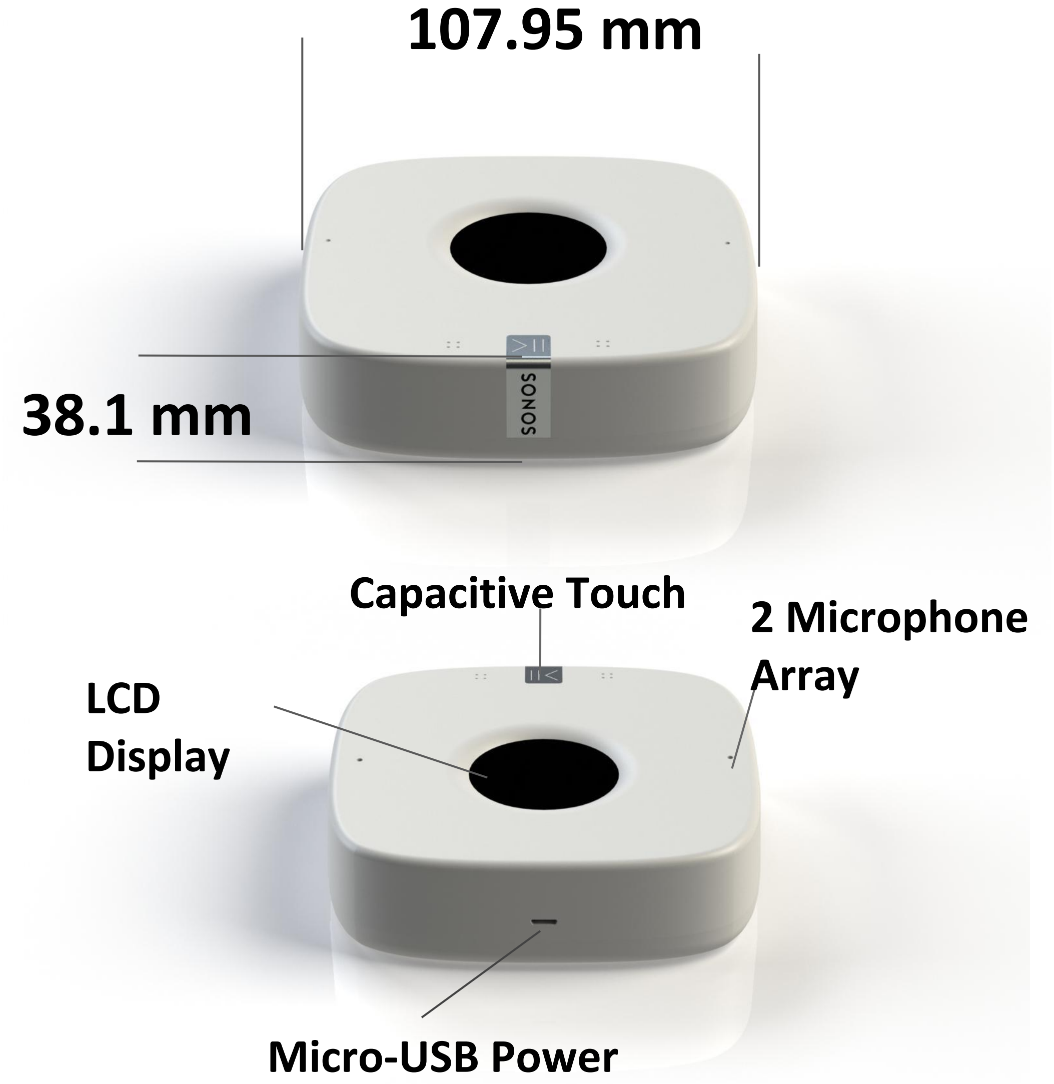
Competitor Analysis

Senic Nuimo

- Advantages
  - Premium design
  - Rotation controls
  - Dot display
  - Can be wall mounted
- Disadvantages
  - Only controls music
  - Only controls single device
  - Expensive ($199.99)

Weight	8.9 oz (254.5 grams)
Size	2.75” (70 mm) Diameter, 0.6” (15 mm) Height
Connectivity	Bluetooth LE
Power Source	Rechargeable Battery (4 months of charge)

Original Expected Design Specifications

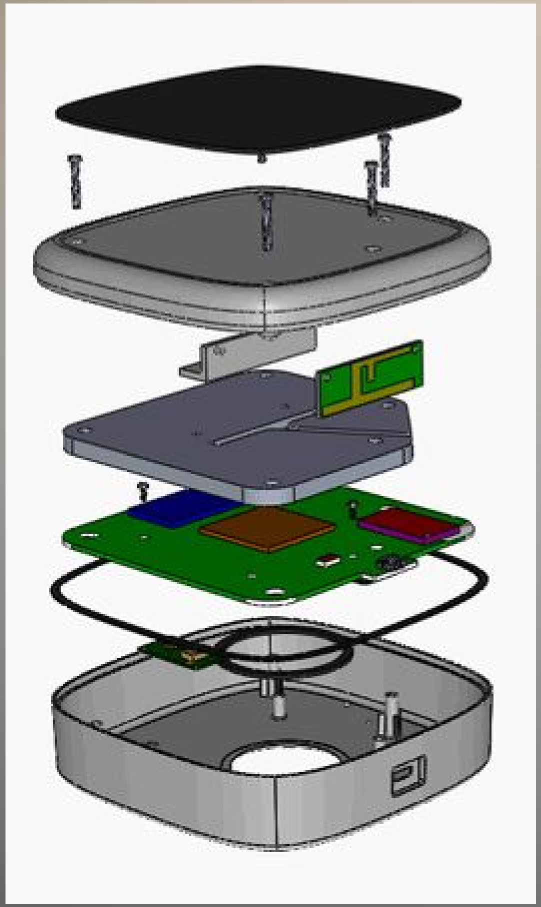


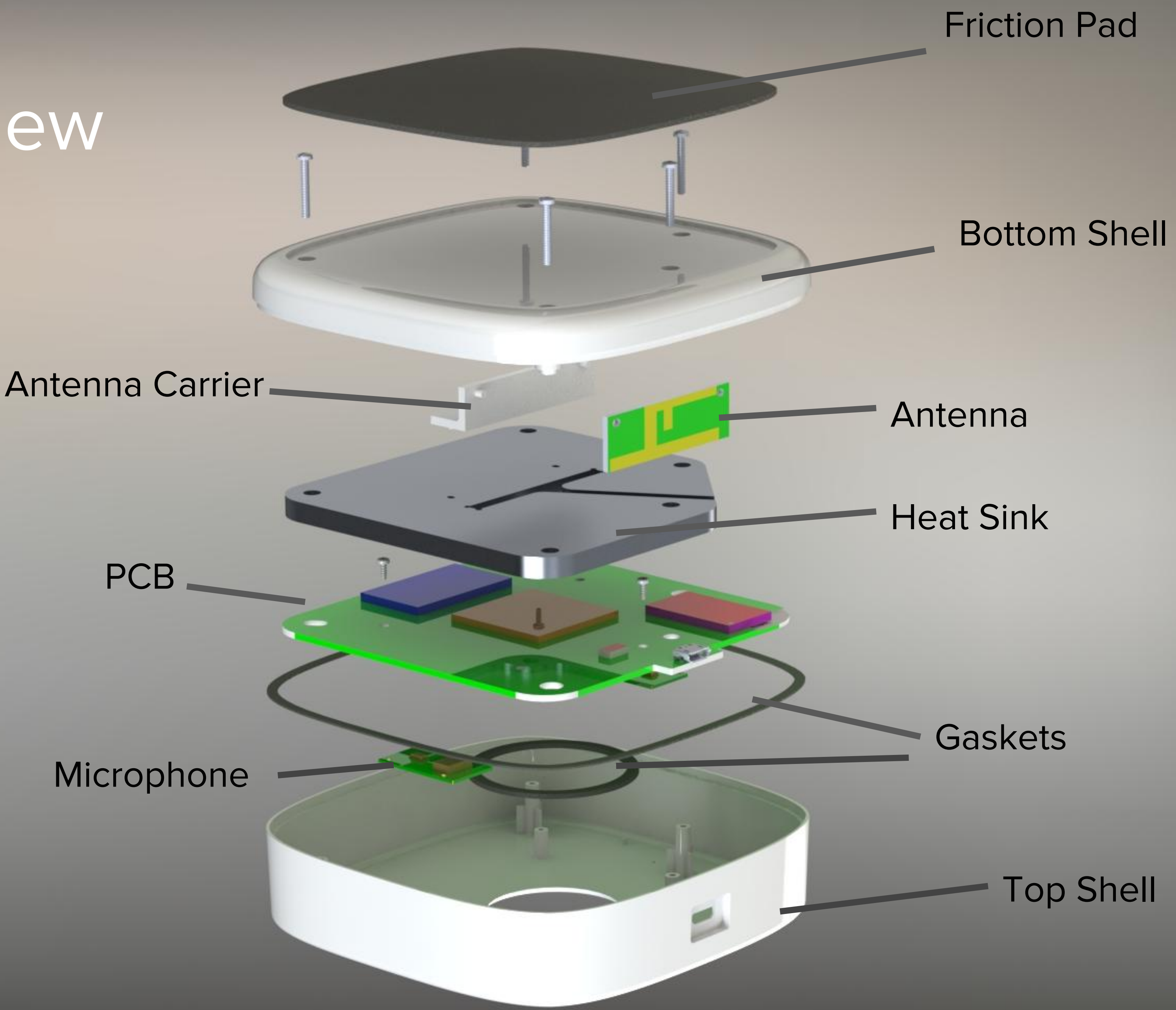
Design Requirements:
Must Design for Manufacturing, Assembly, Mass Production(Injection Molding), and for Experimentation.

Size	1.5” x 4.25” x 4.25” (38.1mm x 108mm x 108mm)
Weight	184 grams
Screen	2.2” (38 mm) Color TFT LCD Display
Material	ABS Plastic
Operating Temperature	Heat sink temperature about 55°C Shell temperature about 28~45°C
Water Protection	IP 62 (Dust tight and protection against dripping water)

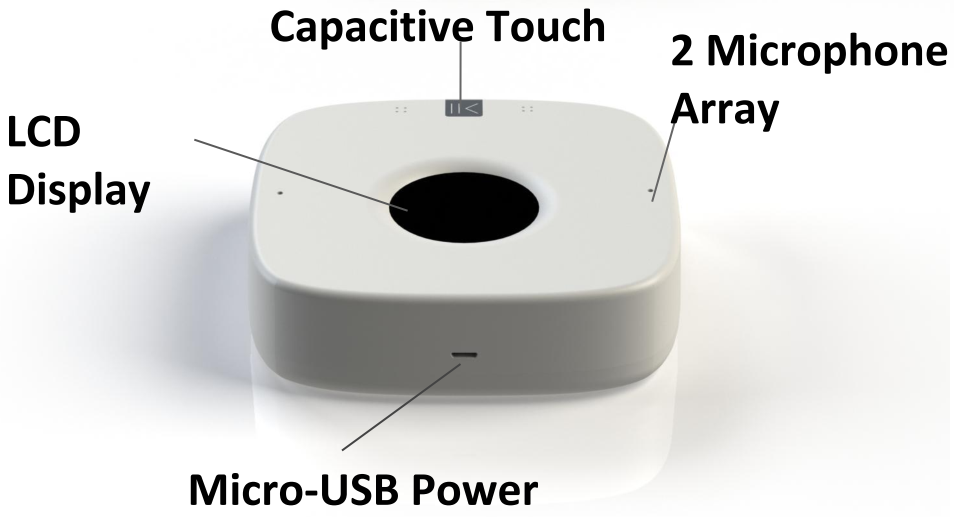
Final Design

Exploded View





Final Design Specification

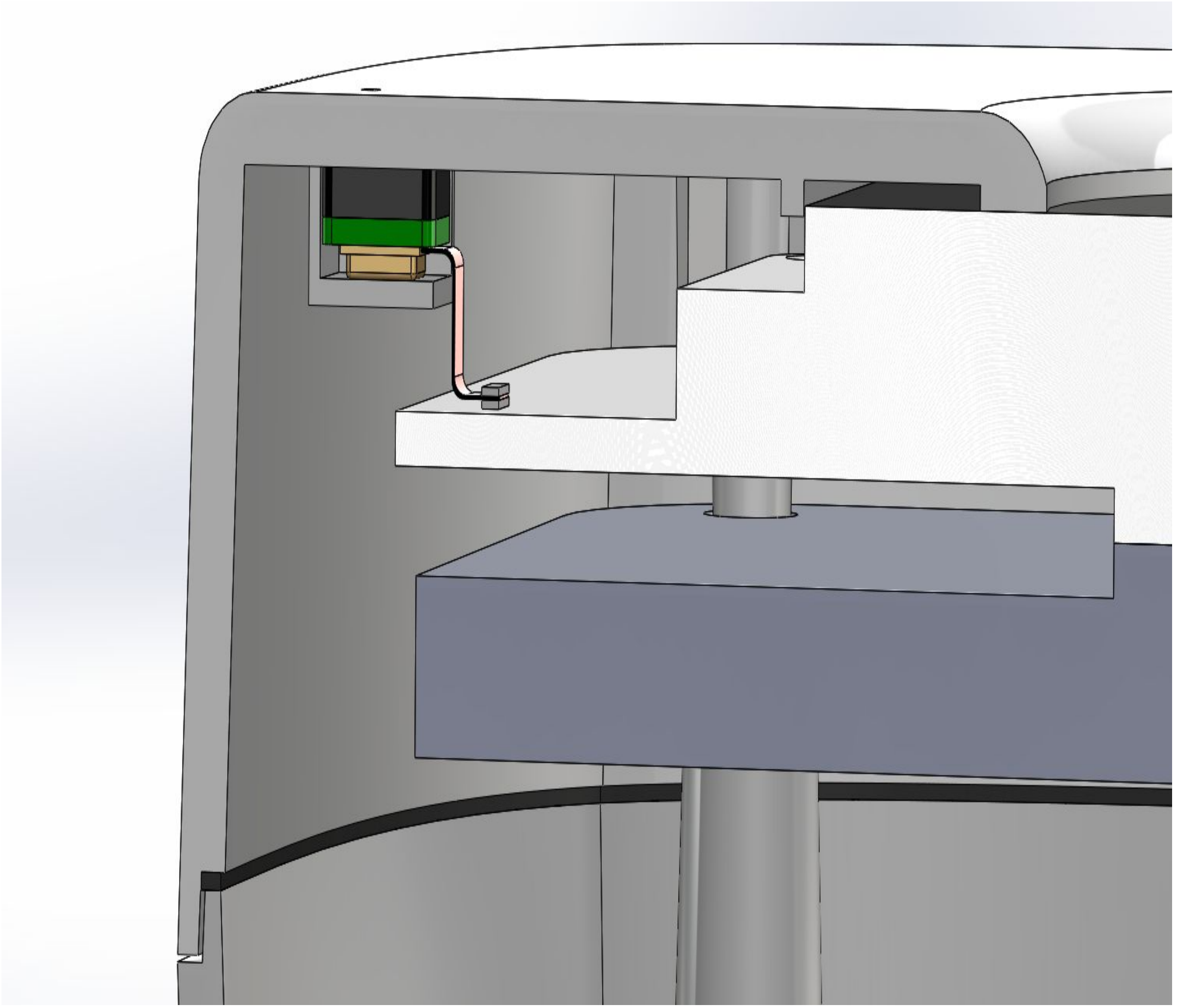


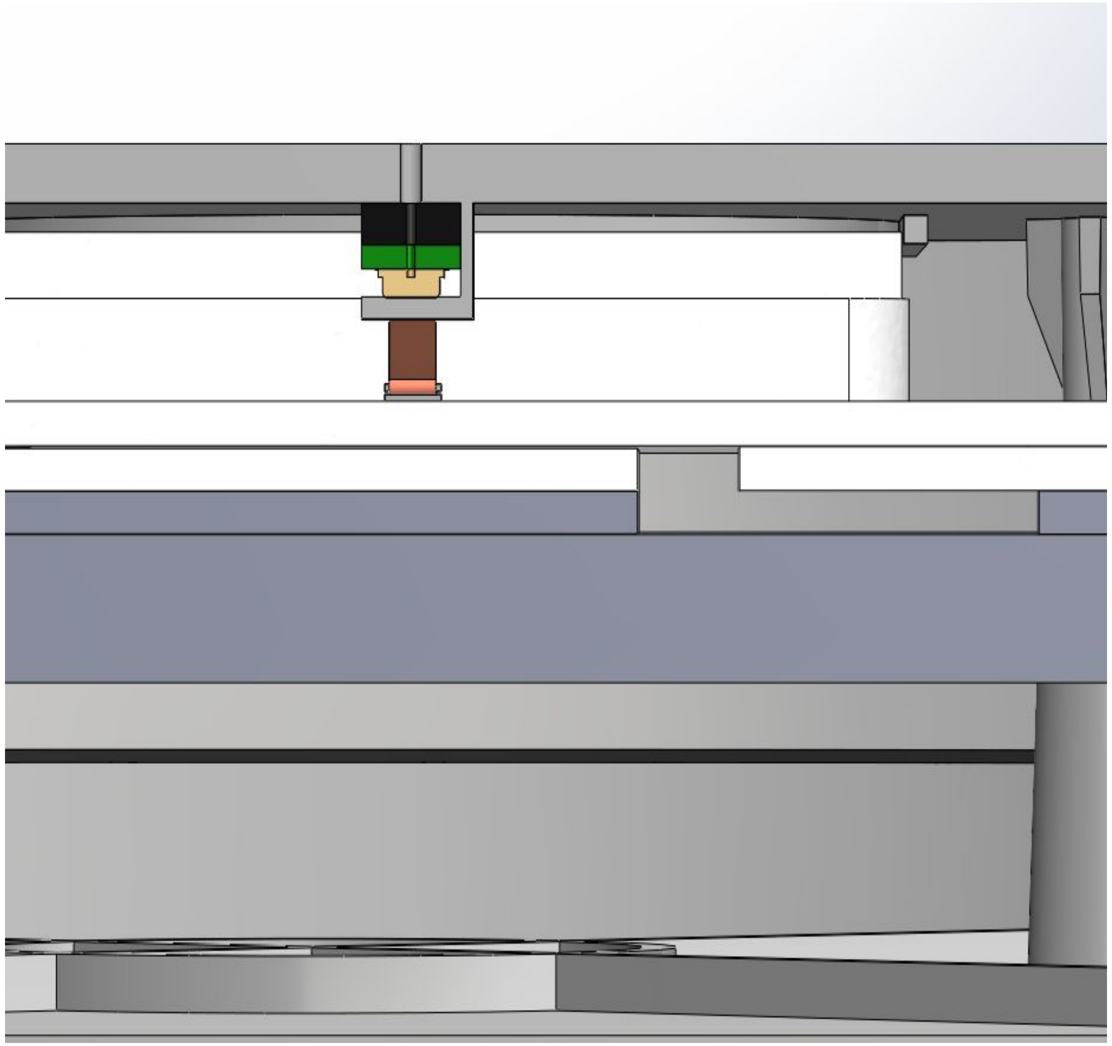
Size	1.5” x 4.25” x 4.25” (38mm x 108mm x 108mm)
Weight	248.5 grams
Screen	1.3” (33 mm) Diameter Color TFT LCD Display
Material	PC Plastic
Wi-Fi Connectivity	Wi-Fi module providing fully integrated 2.4 GHz 802.11 b/g/n radio, TCP/IP stack and a 32-bit microcontroller (MCU)
Audio	Able to seamlessly connect and control your existing SONOS home network

System Requirements	COM. comes ready to connect to your Wi-Fi. Requires an iOS or Android device compatible with the SONOS app.
Power	5V Supply via wall wart adapter to micro USB
Operating Temperature	CPU temperature ~43°C Shell temperature 26 °C
Water Protection	IP 62 (Dust tight and protection against dripping water)

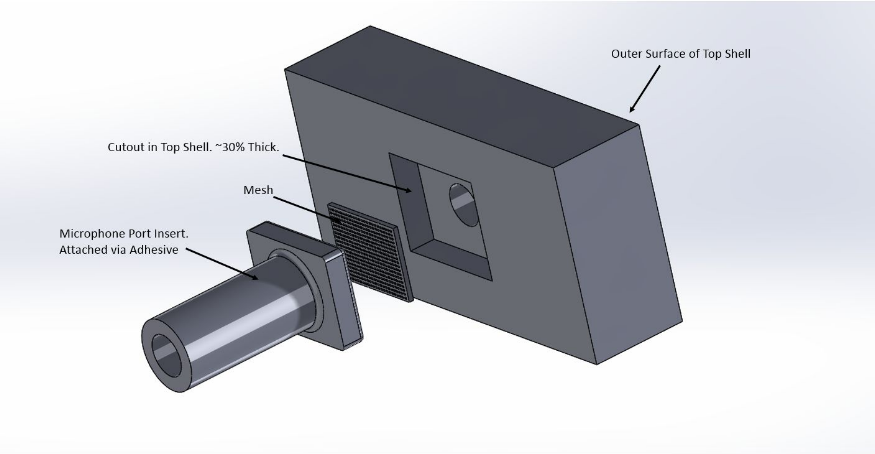
Microphone Placement Evolutions

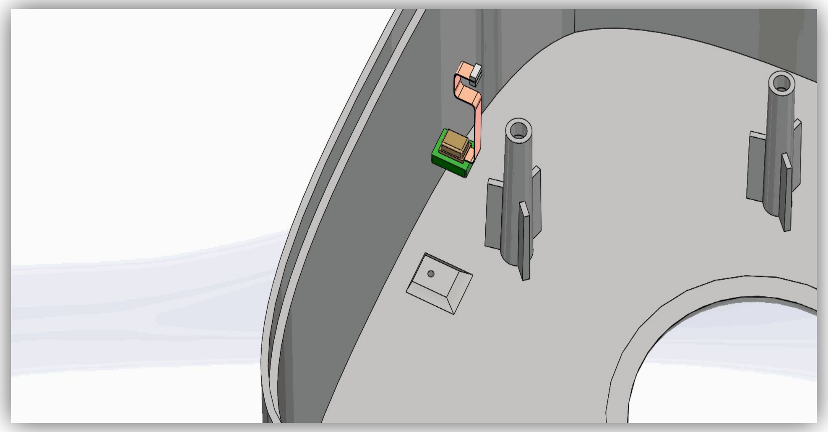
Initial Placements

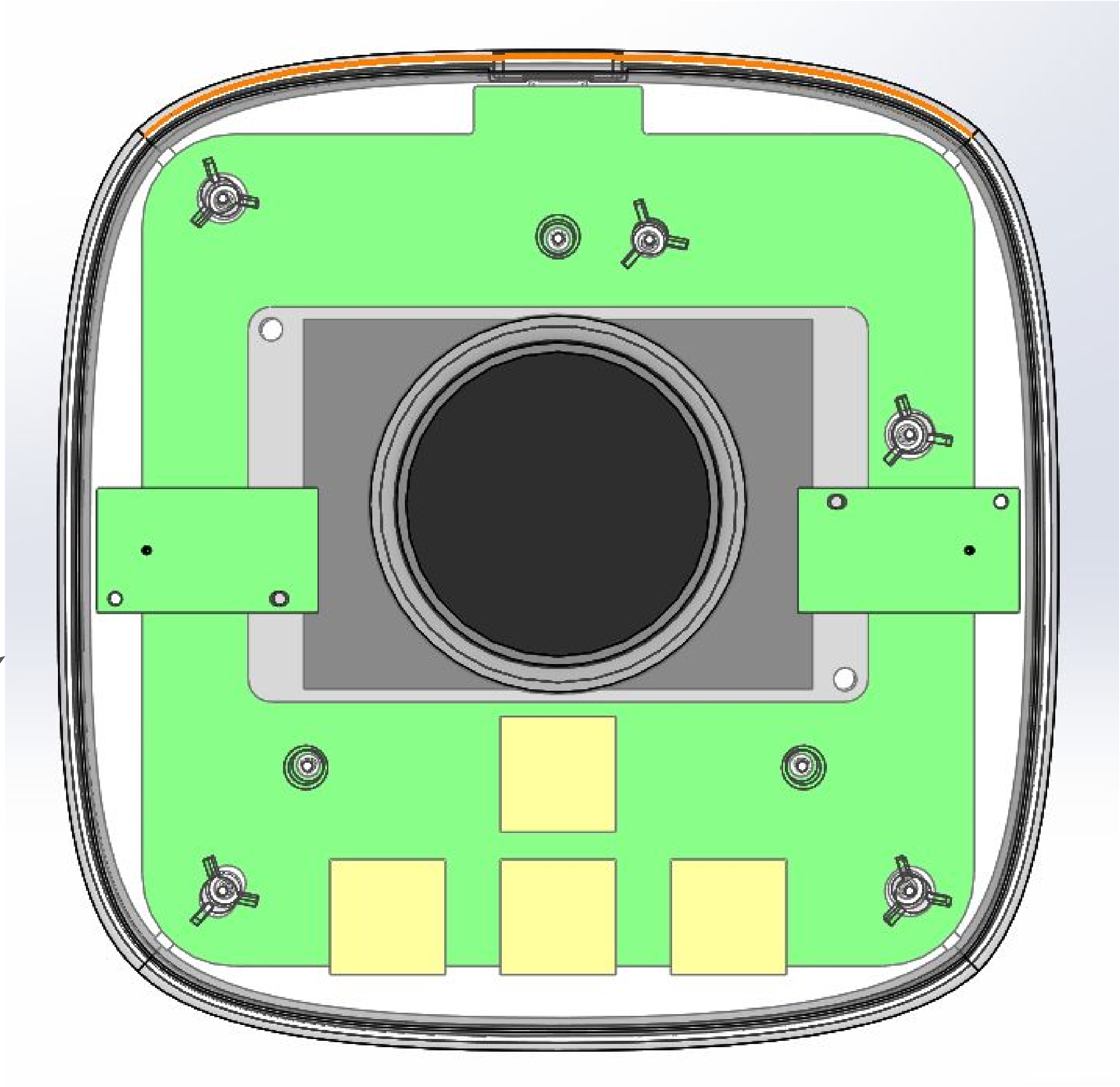




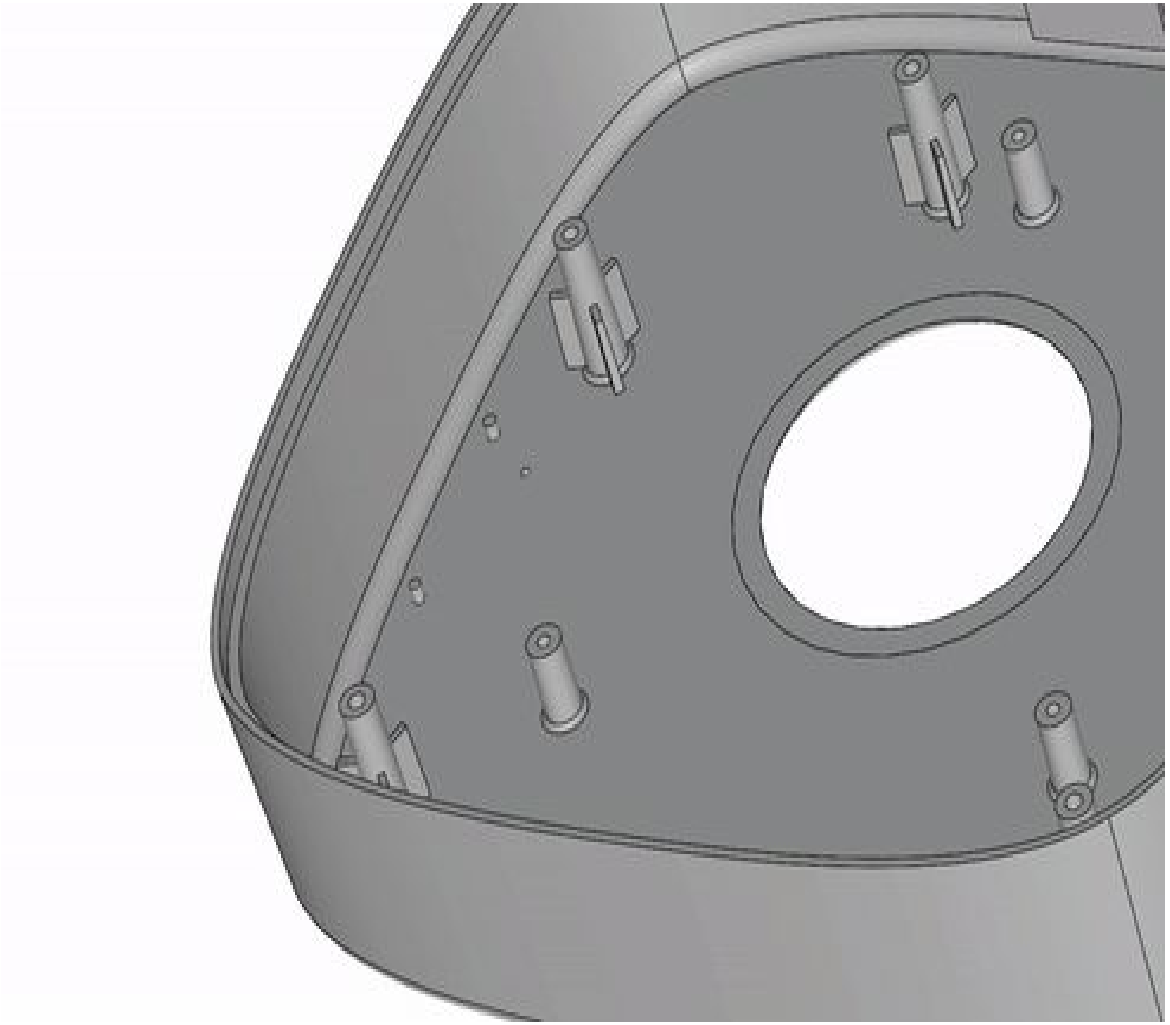
Next Considerations

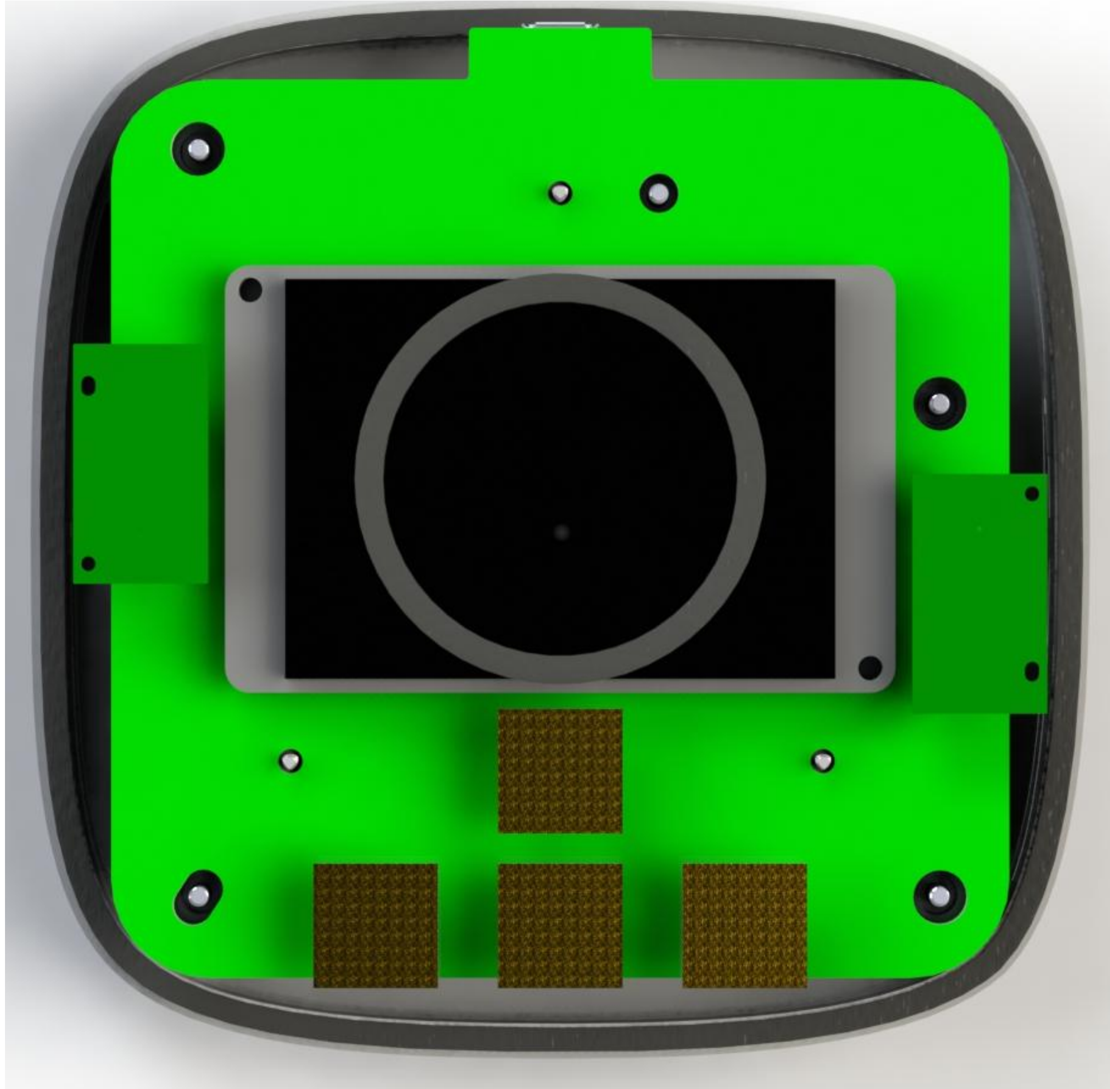






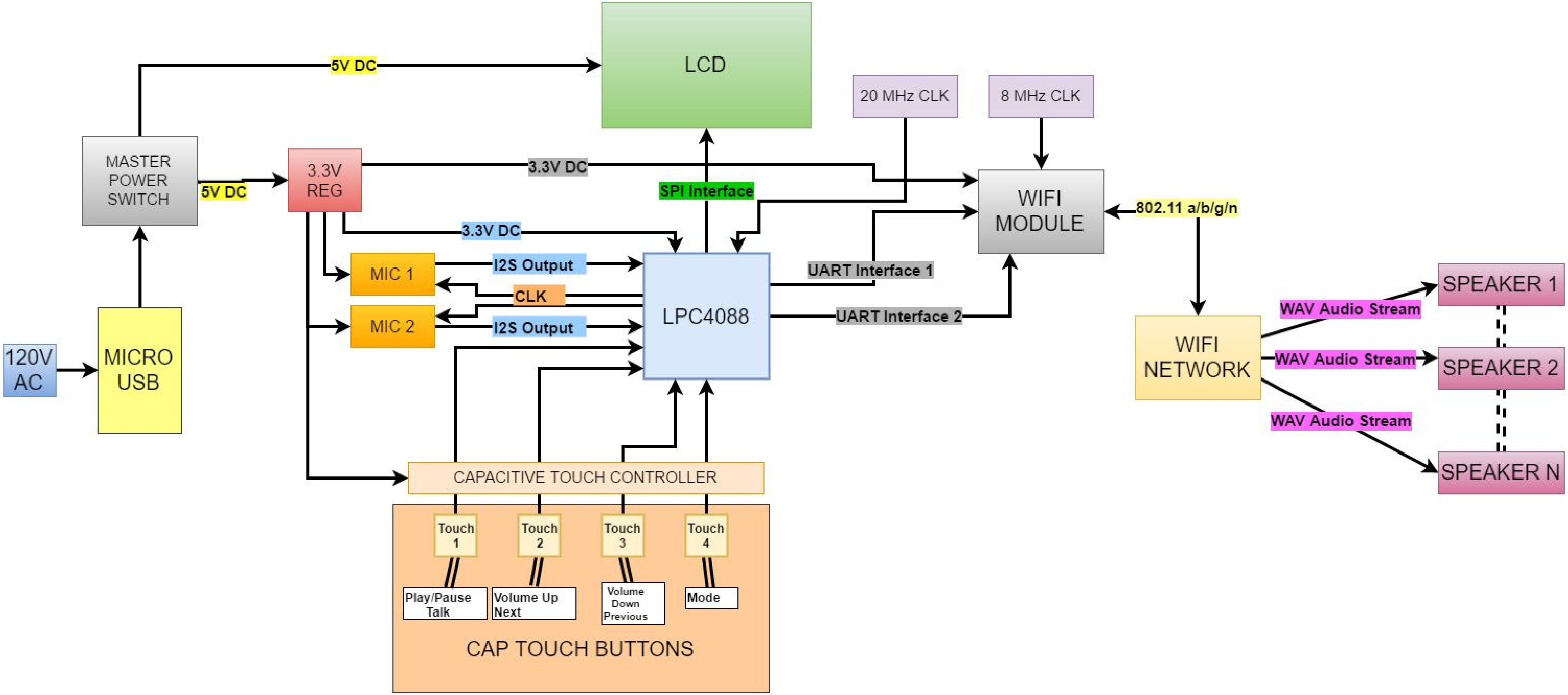
Final Placement





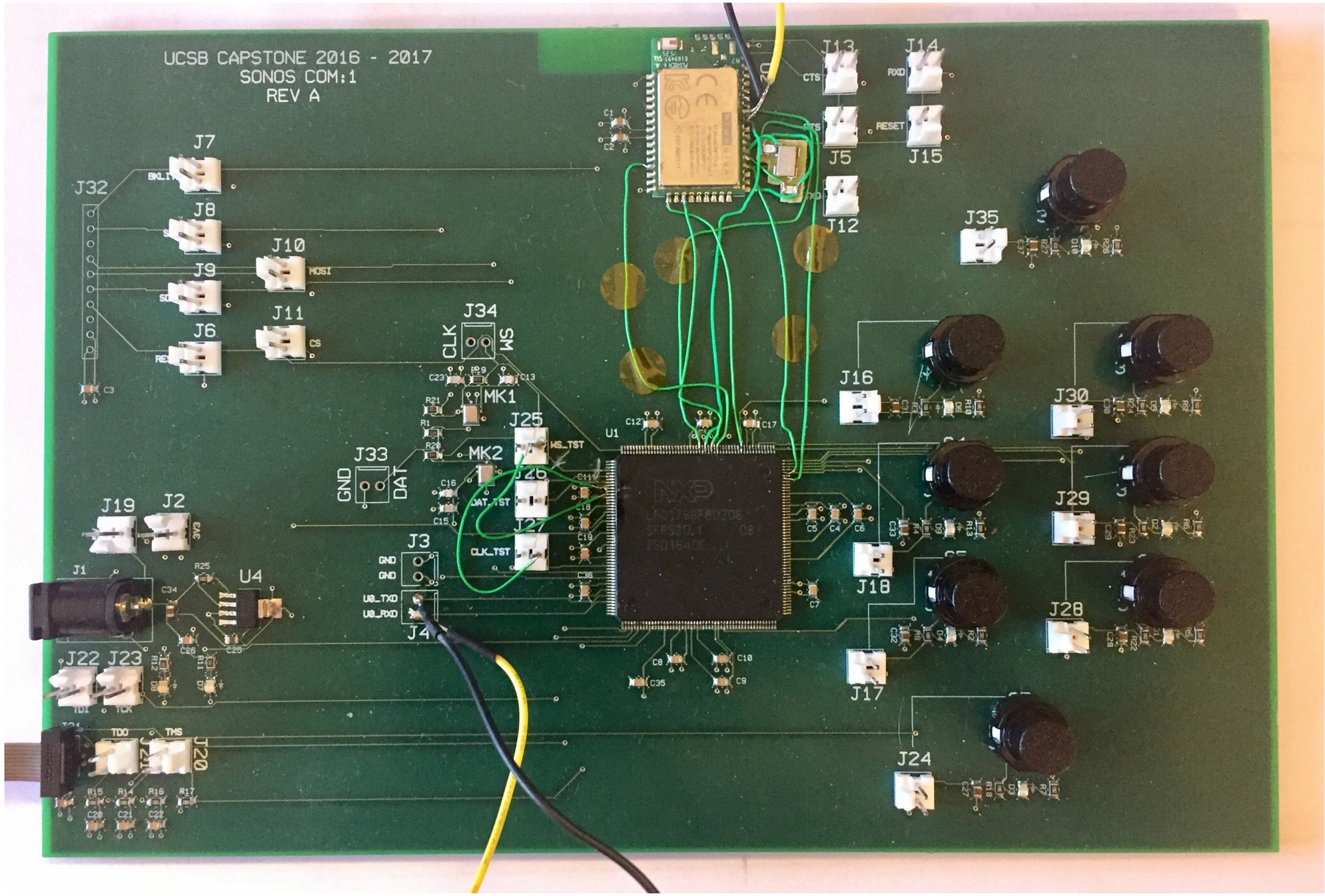
Hardware Design

Functional Hardware Block Diagram



 27

First Spin PCB



Manufacturing and rework sponsored by

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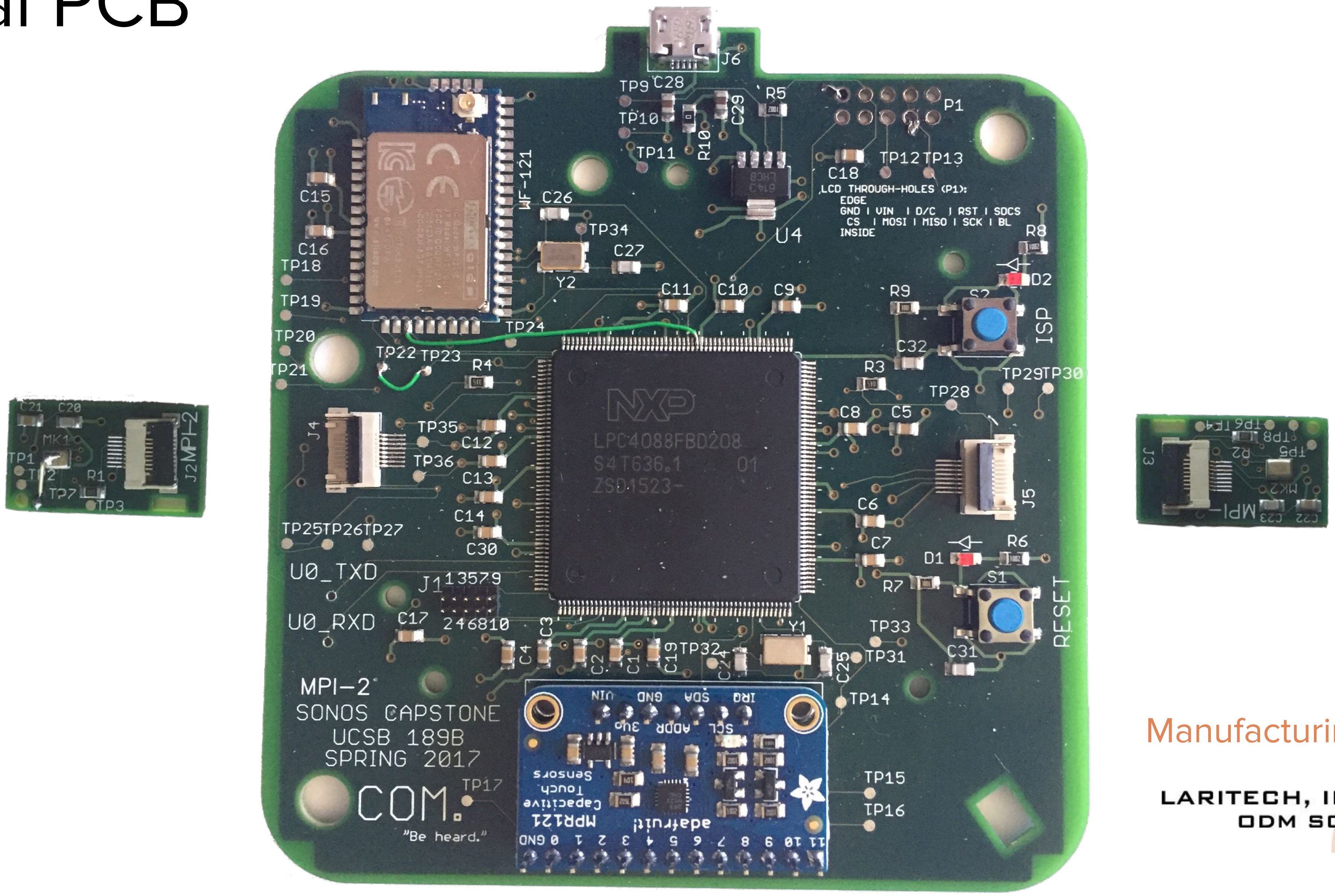
ODM SOLUTIONS

Final PCB



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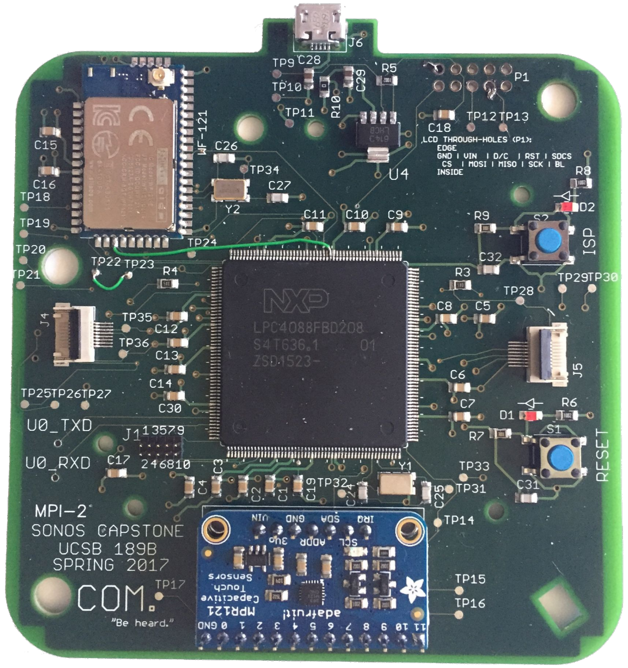
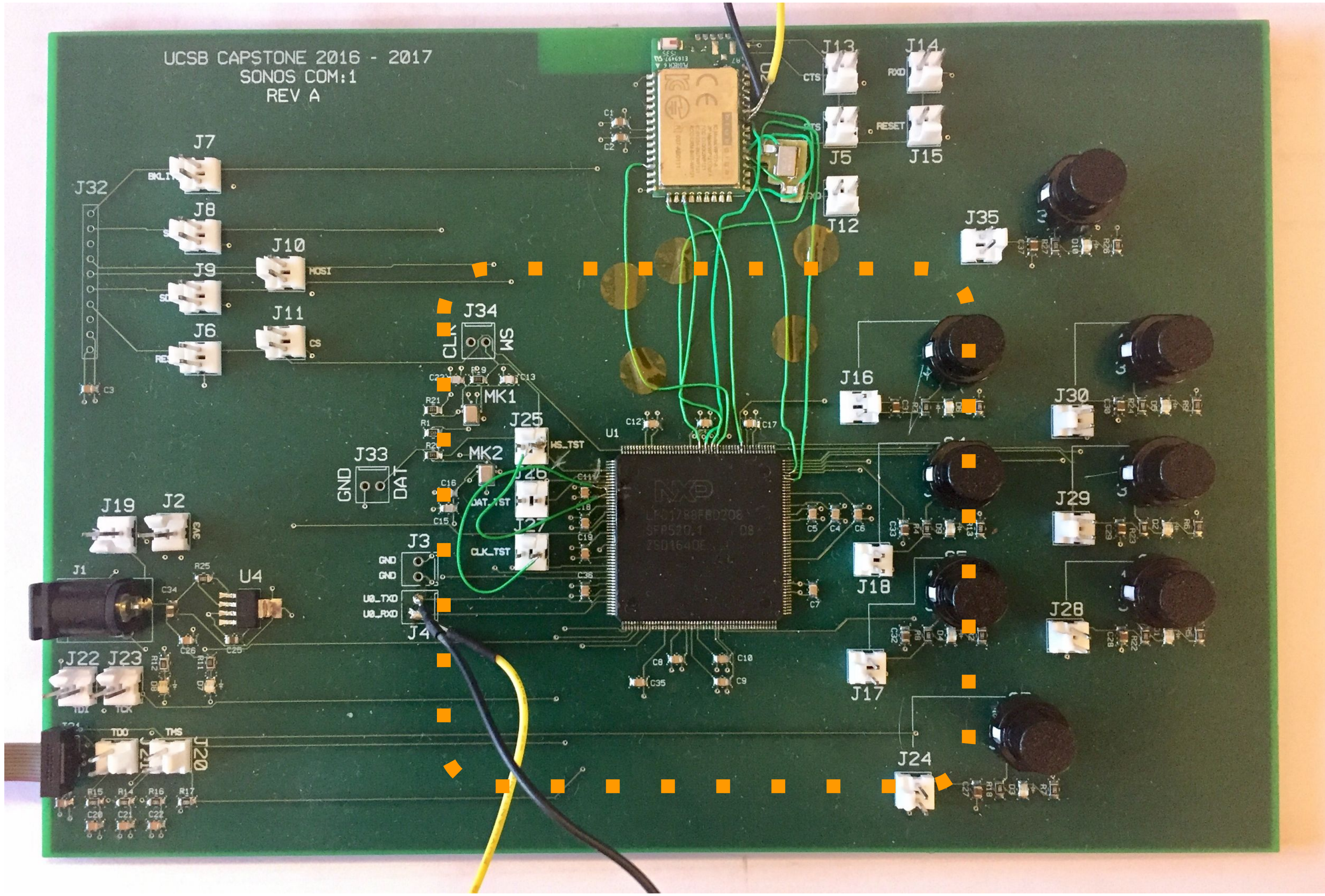
Comparison



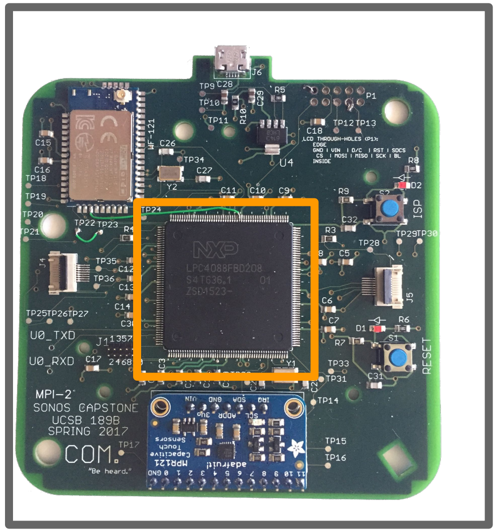
MPI-2
SONOS CAPSTONE
UCSB 189B
SPRING 2017
COM.
"Be heard."



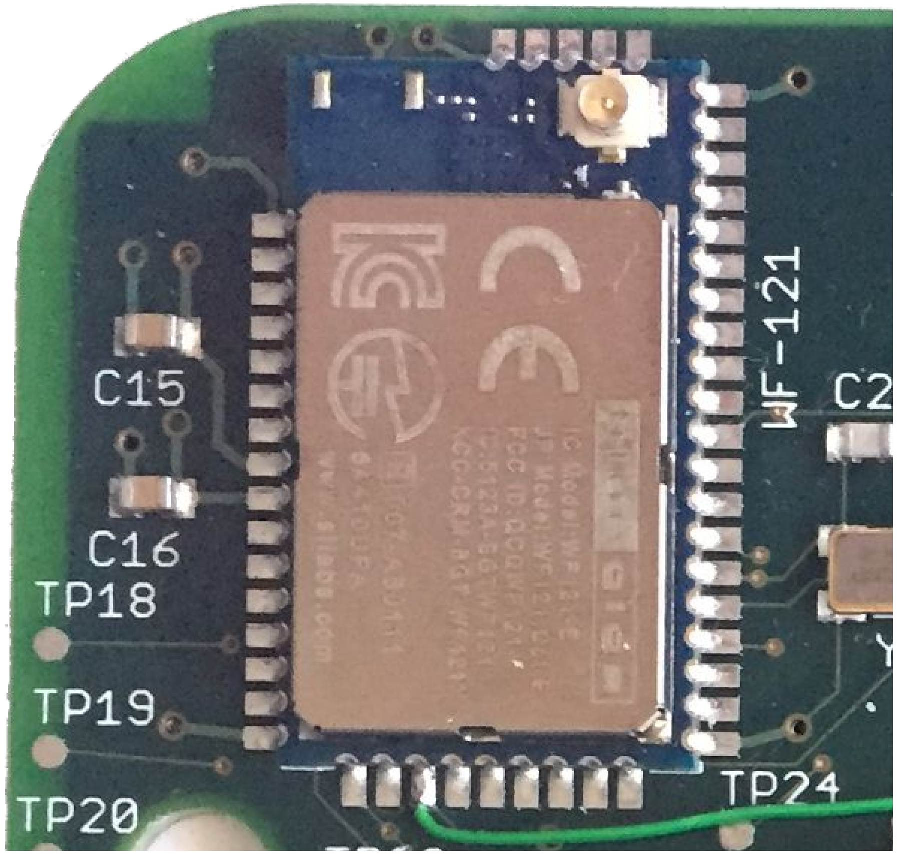
UCSB CAPSTONE 2016 - 2017
SONOS COM:1
REV A

MCU - NXP LPC4088

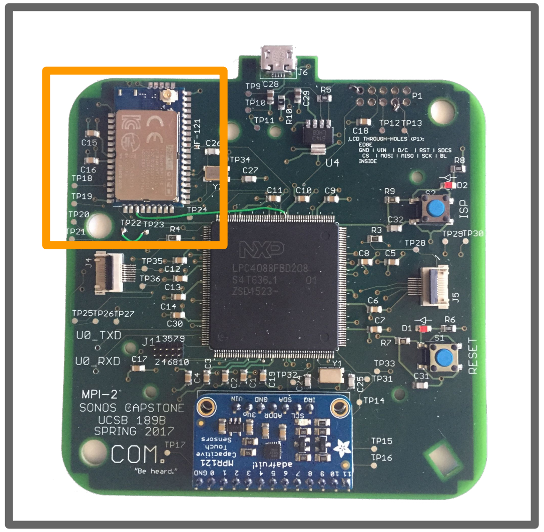
- ARM Cortex-M4 based digital signal controller.
- Features utilized
  - Three UARTs (Wifi/ISP)
  - I2S Rx (Mics)
  - I2C (Cap Touch)
  - SPI (LCD)
  - GPIO (ISP/RESET/IRQ)
- A general MCU that our instructors and TA are familiar with.
- Well Supported
- I2S Mics
- Ultimately, not the right MCU for this job. More on this in a later slide.
- Memory
  - 512 kB of flash program memory
  - up to 96 kB of SRAM data memory
  - up to 4032 byte of EEPROM data memory



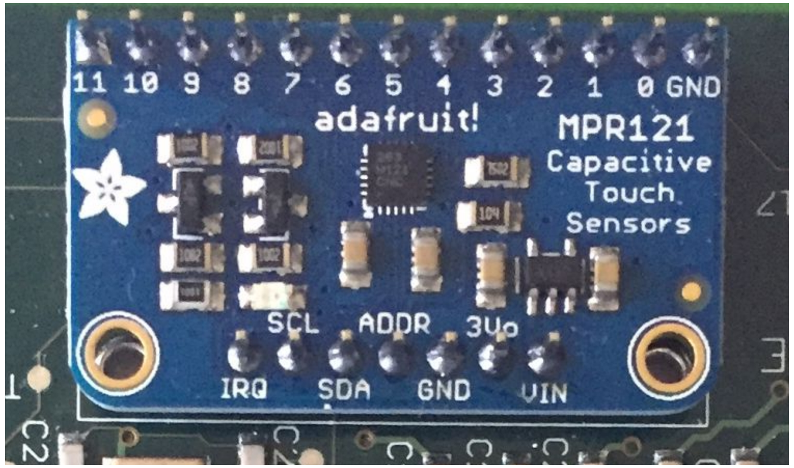
WiFi - WF121 Module



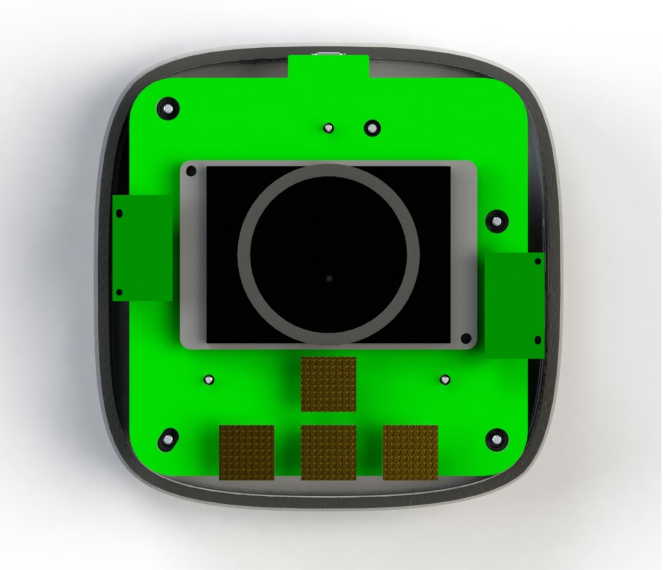
- UFL connector for external antenna.
- Two UART connections only one with flow control
- Tx and Rx lines swapped due to labeling misunderstanding
- Supports 802.11 b/g/n
- RF shield
- Why this device?
  - Easy to use software library.(bglib)
  - Supports WiFi b/g/n
  - Access Point mode and Standalone Client Mode
- Two UARTS
  - API
  - Data
- Available in two packages

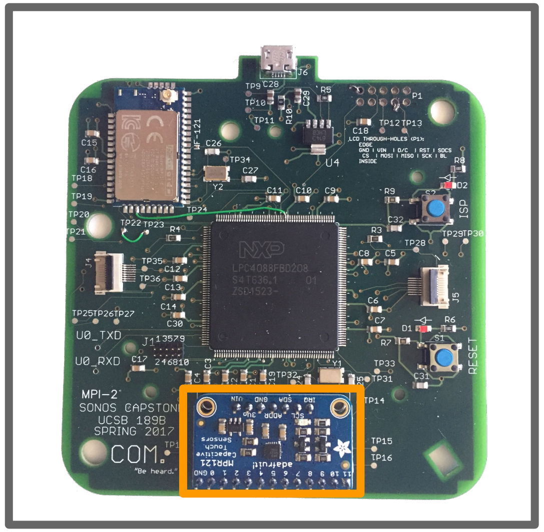


Capacitive Touch Design

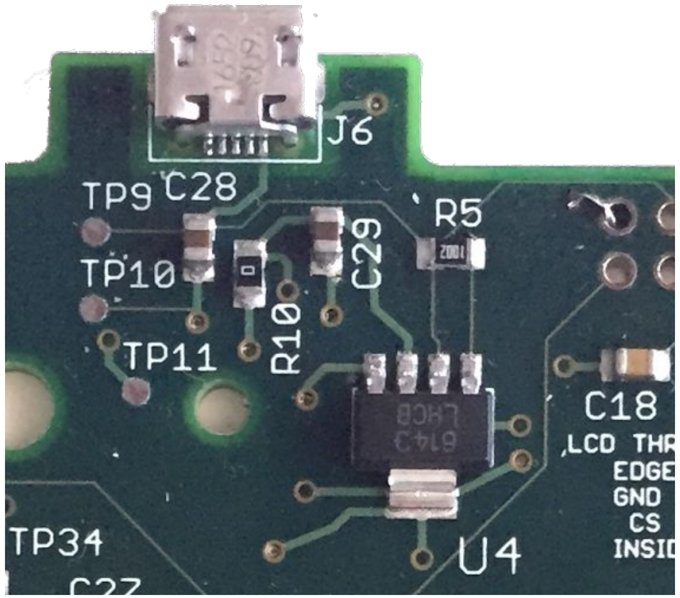


- Twelve possible input connections for capacitative control
- I2C communication
- Output IRQ signal for registering a touch
- Prevention of false triggering.
- Chose solution AD7142
  - 0 pf to 250 pf
  - 1.69 for 2,500
  - Twelve possible inputs
- 12.5 mm pads chosen as standard reflection and index finger size

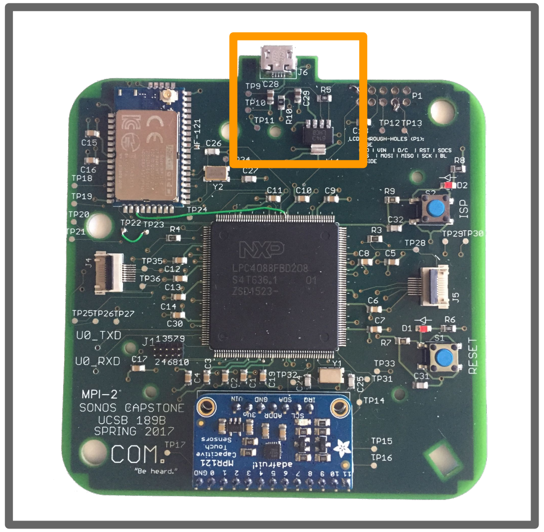




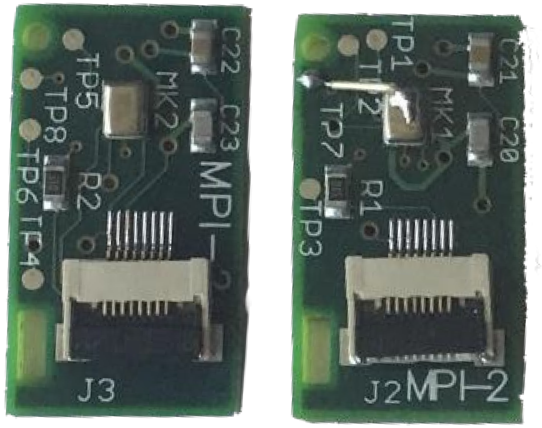
Power System



- Micro USB connector.
  - Power cable is readily available in most homes.
  - PCB extension allows for ease of physical constraints
- 5V ➔ 3.3V Voltage Regulator
- Output Voltage Ripple Tolerance of 1.5%
- -40℃ to 125℃
- Low-dropout voltage 38 mV at 150mA load current

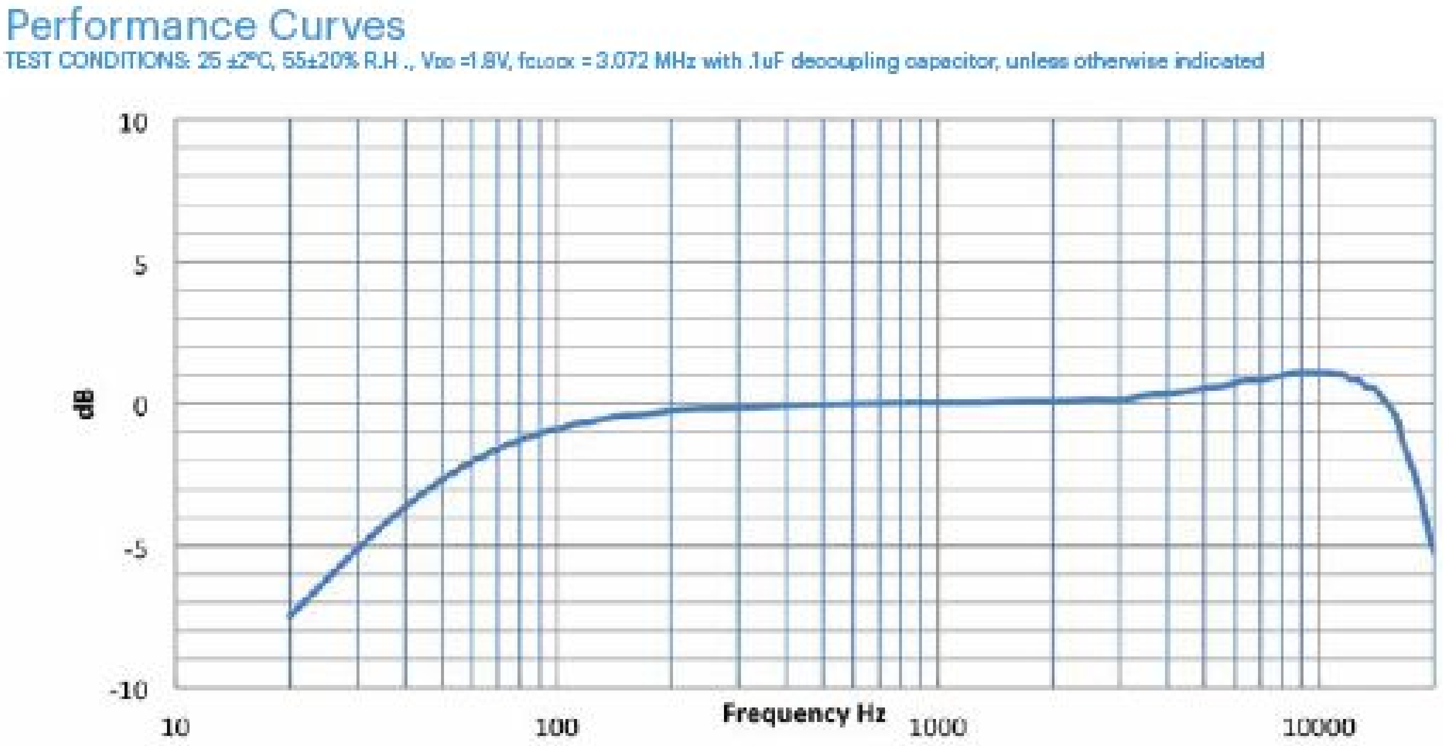


Microphones - SPH0645LM4H-B

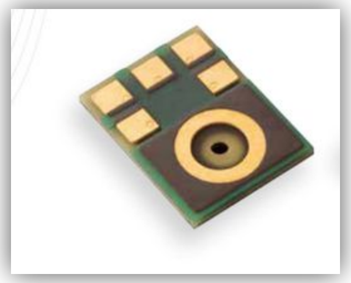


- I2S Output
  - Decimation is done directly in the microphone and eliminate the need for an ADC or codec
  - Fewer conversions

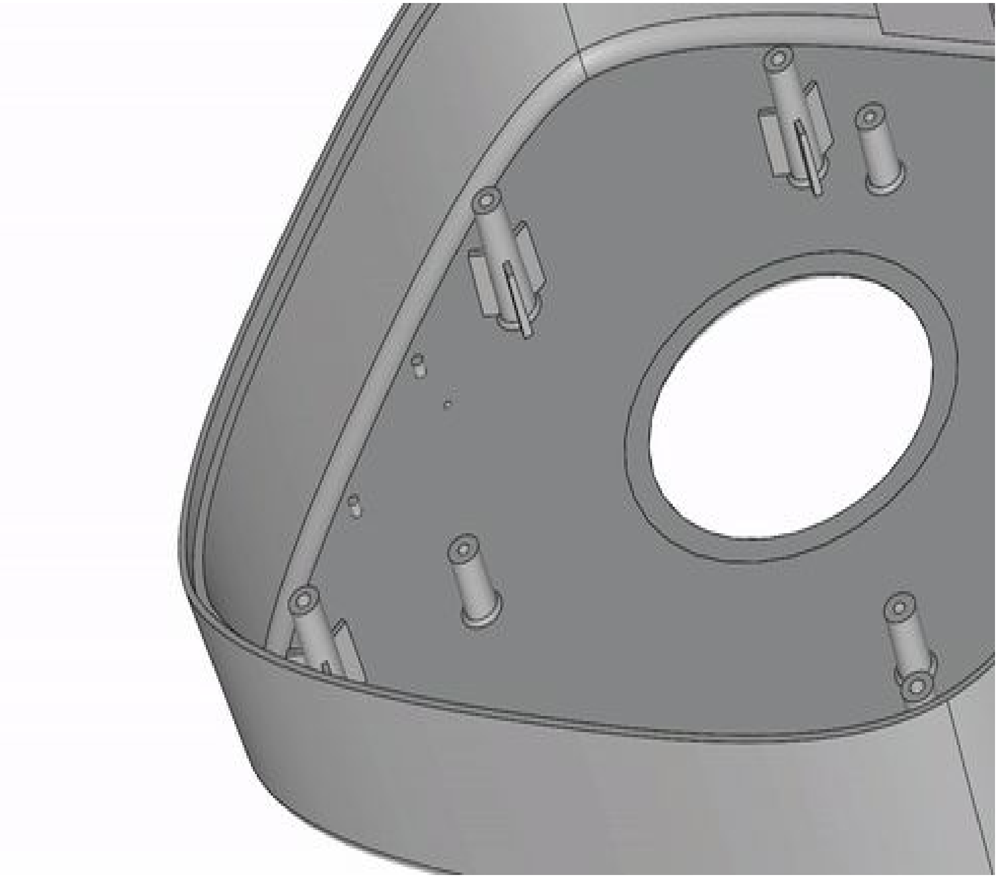
    Analog(voice) →Digital → Digital transmission→ COM.
- Left and right Mic (Dual Channel)
- RF Shielded
- Omni-directional
- High SNR of 65dB(A)
- Frequency Response vs. Sensitivity (human voice: 85 Hz - 260Hz)



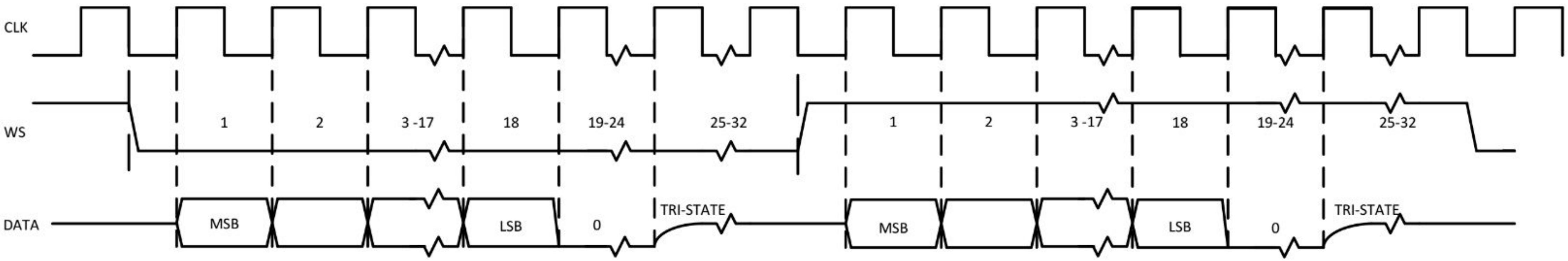
Microphones



- Perform under 3 different modes: active, sleep and powered off
- Align to the hole drilled to the outer case
- Control the data by word selecting signal and clock



Microphone Data



18 bits of resolution

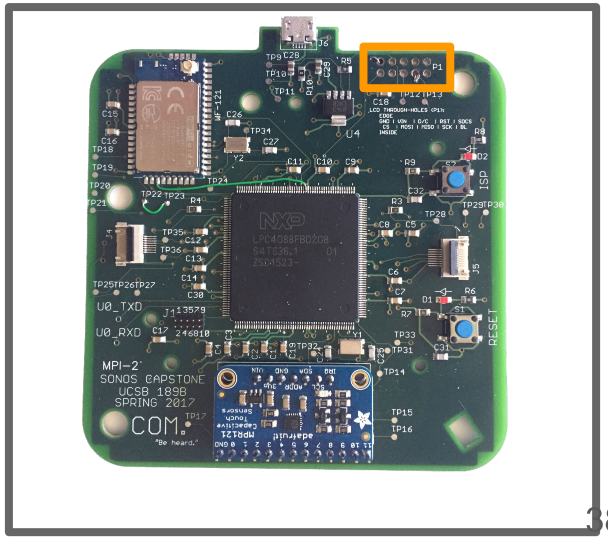
6 bits padded 0

8 bits of tristate

Totalling 32 bits on each channel with with a word select frequency 1/64 of the clock frequency.

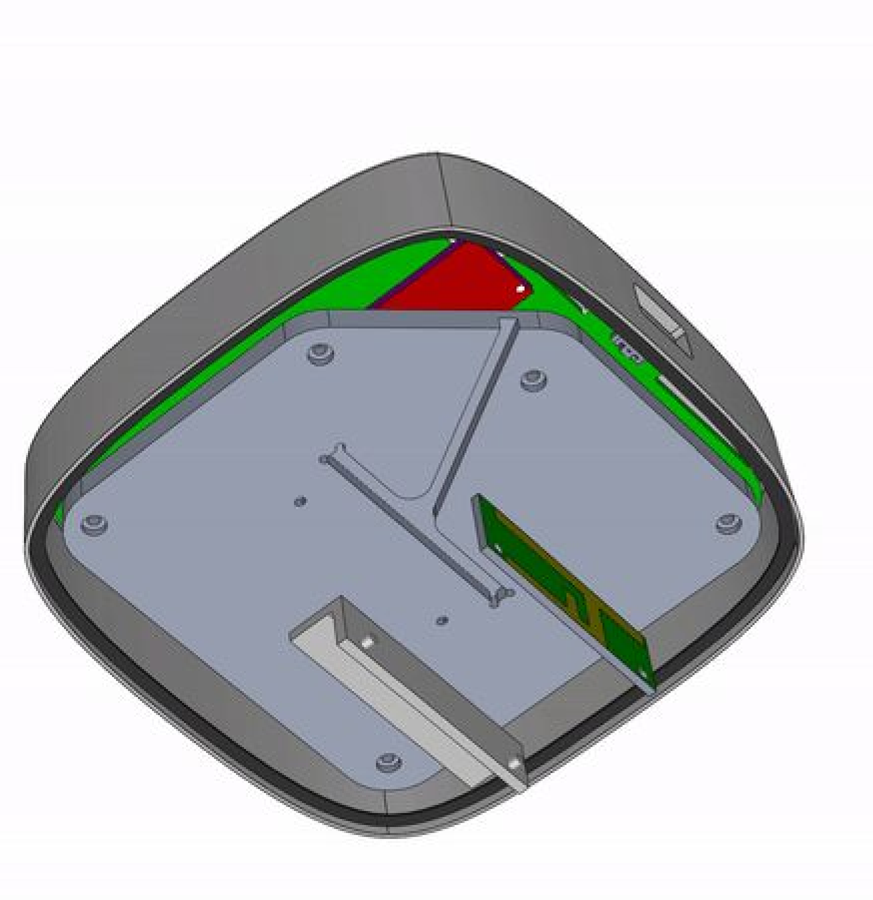
Display - 2.2” Adafruit Display

- 2.2” display chosen to provide more screen real estate in final design.
- SPI interface
- Library ported from C++ to C and LPC Open framework
- Past experience with display



Inverted F Antenna

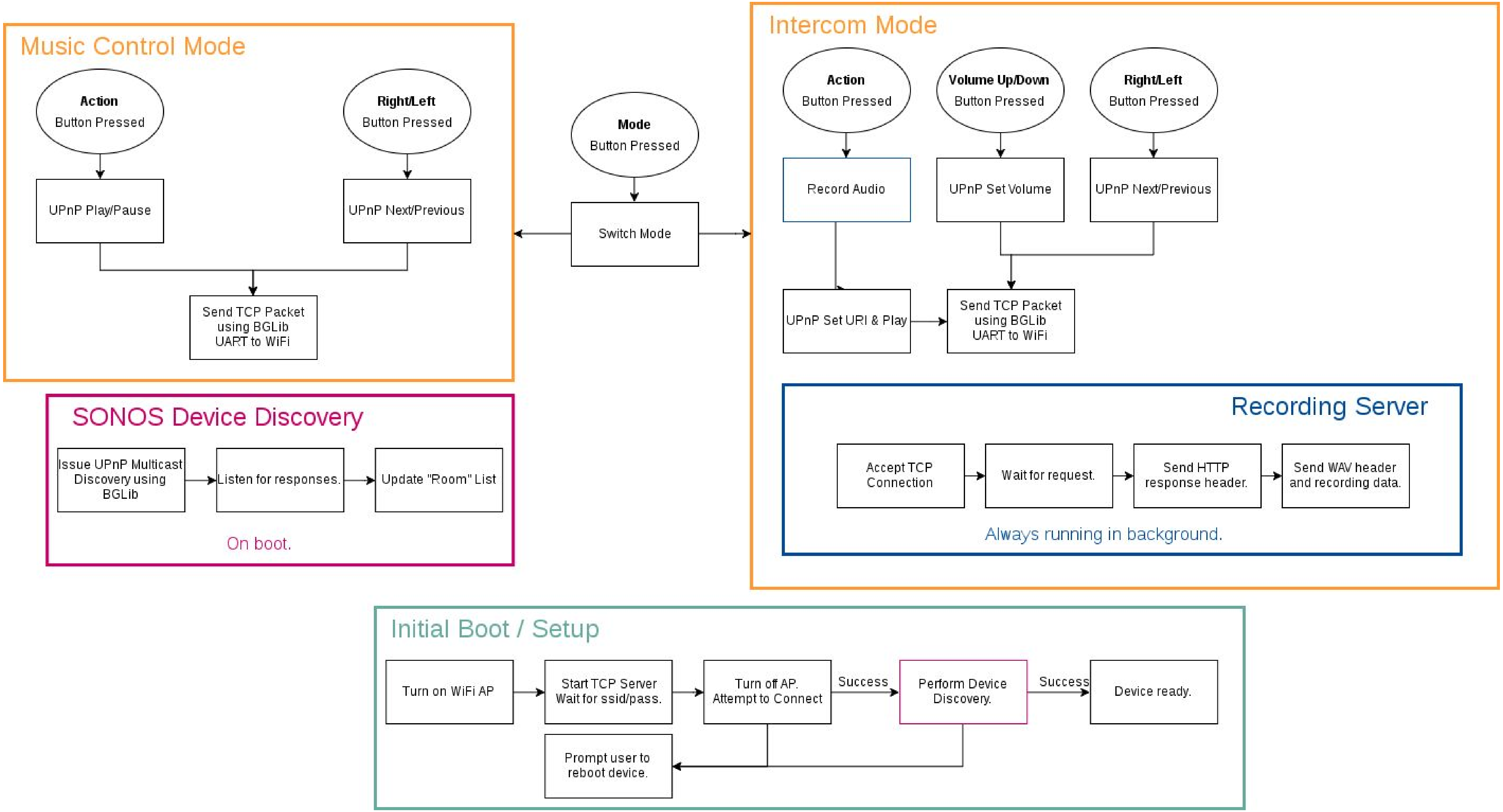
- Orientation, current location, and antenna choice is due to distancing the antenna away from the noise generated by the other components in our device.
- We used the Heatsink to our advantage as it shields the antenna from the rest of the components in our device. And it helps radiate the signals coming out from the antenna.



Precautions:

- The surfaces you place the COM. on will need to be taken into consideration. (i.e. Placing the devices on a metal surface will yield worse results than putting on a wooden surface.

Software Design



Music Control Mode
Action
Button Pressed
Right/Left
Button Pressed
UPnP Play/Pause
UPnP Next/Previous
Send TCP Packet
using BGLib
UART to WiFi
Mode
Button Pressed
Switch Mode
Intercom Mode
Action
Button Pressed
Volume Up/Down
Button Pressed
Right/Left
Button Pressed
Record Audio
UPnP Set Volume
UPnP Next/Previous
UPnP Set URI & Play
Send TCP Packet
using BGLib
UART to WiFi
Recording Server
Accept TCP
Connection
Wait for request.
Send HTTP
response header.
Send WAV header
and recording data.
Always running in background.
SONOS Device Discovery
Issue UPnP Multicast
Discovery using
BGLib
Listen for responses.
Update "Room" List
On boot.
Initial Boot / Setup
Turn on WiFi AP
Start TCP Server
Wait for ssid/pass.
Turn off AP.
Attempt to Connect
Success
Perform Device
Discovery.
Success
Device ready.
Prompt user to
reboot device.

Program runs directly on hardware.

C Language

No operating system.

LPC Open Framework.

Modular by design.

`captouch/`

`mics/`

`screen/`

`util/`

`wlan/`

`main()`

main()

```c
// abridged version
int main(void) {
    master_init();
    delay_init();
    screen_init();
    mics_init();
    wlan_init(wlan_init_cb);
    captouch_init(captouch_handler);

    while(1) {
        wlan_process();
        mics_process();
        captouch_process();
    }

    return 0 ;
}
```

init functions for each module

main loop

captouch/

- When you initialize this module, you provide a pointer to a function to handle touch events.
- Simple to use interface.

sensor port 4 on controller board

```
void captouch_handler(uint8_t touched){
    if (touched & (0x01 << 1)) {
        //Left (previous)
    } else if (touched & (0x01 << 4)) {
        //Top (mode)
    } else if (touched & (0x01 << 2)) {
        //Bottom Center (play/pause, record)
    } else if (touched & (0x01 << 6)) {
        //Right (next)
    }
}
```

mics/

- Samples are read as 32 bit integers via I2S. We retain **16 of the 18 valid bits of data**.
  - Necessary due to memory constraints. And we can store in increments of 8 bits.
- Peripheral to Memory DMA is used to record audio into two buffers of equal size (explanation for why two buffers in next slide).
- Currently capturing 4 32-bit samples at a time into a uint32_t array, then, once DMA transfer has completed, moving into a uint16_t array for storage, only retaining 16 most significant bits.

mics/

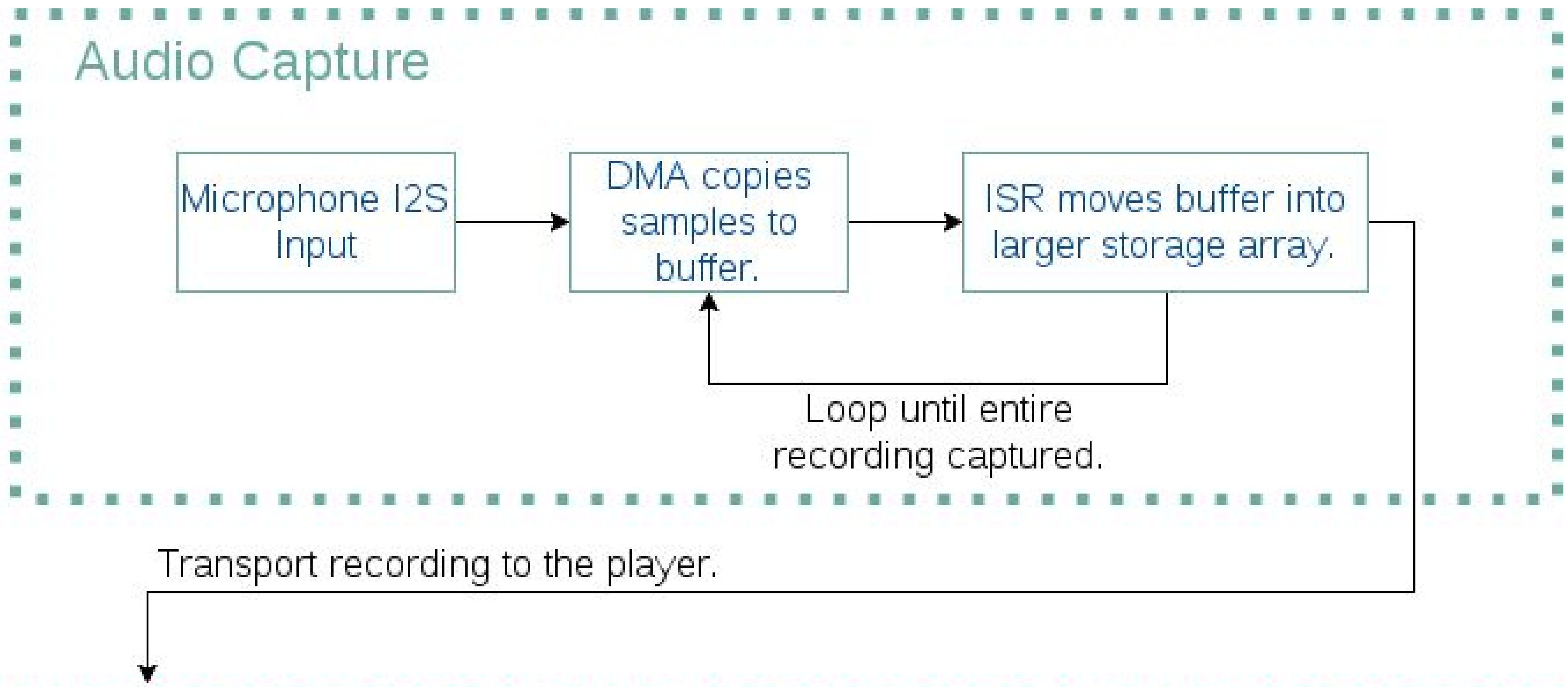
Why is the recording split into two buffers?

- Not enough memory in the first RAM bank. So we're using RAM and RAM2 banks on the 4088.
- I explicitly store half of the audio recording in another bank to leverage its additional storage.

```
volatile uint8_t recording[RECORDING_SIZE];

__DATA(RAM2) volatile uint8_t recording2[RECORDING_SIZE];
```

- Actual recording size is `2 * RECORDING_SIZE`.
- `#define RECORDING_SIZE 24000` (48,000 bytes total)

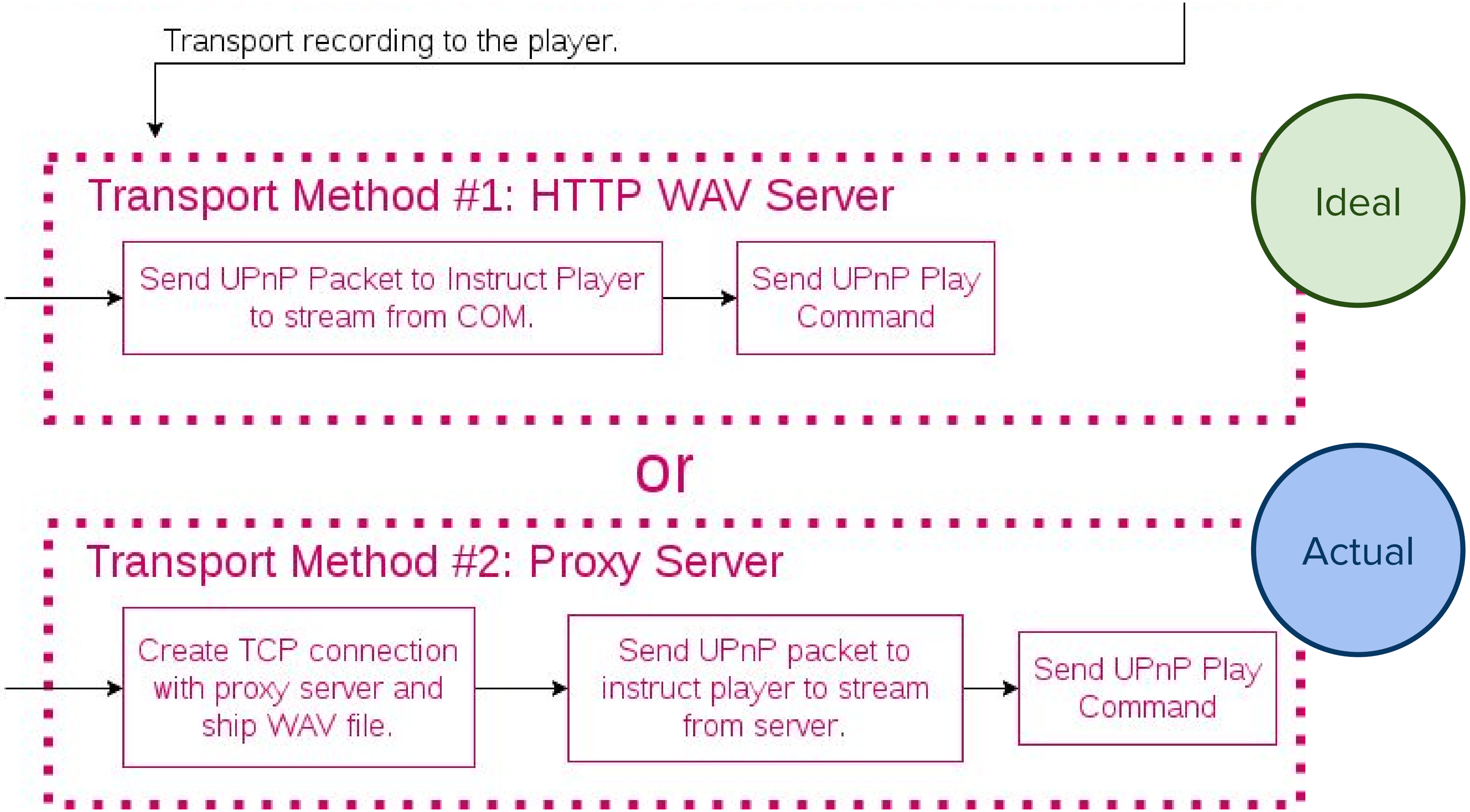
Recording Data Flow



Recording Data Flow

Both methods are supported in code.

```
#define PUBLISH_DONT_SERVE
```



Recording Playback

- Could not use Method #1 (Built-in HTTP Server)

Slower transfer speed from our device
+
player attempting to play before finished downloading
=
< 1 sec of audio played from 3 sec recording

- Method #2 (Proxy Server) as a solution for now.

wlan/

- WiFi code was designed as a state machine so that it will not block the CPU while waiting for responses and events from the WiFi module.
- UPnP
  - Handles basic UPnP commands to control SONOS devices.
  - Can issue requests to fetch device and track information.
  - Can discover devices (and rooms) on your home network.
- WAV audio file server
  - Provides an HTTP server that serves WAV file of recording.
- Generic HTTP request support.
  - Issues a custom HTTP request, and stores the response for further processing and analysis.
- Setup TCP server, used in the device setup process.

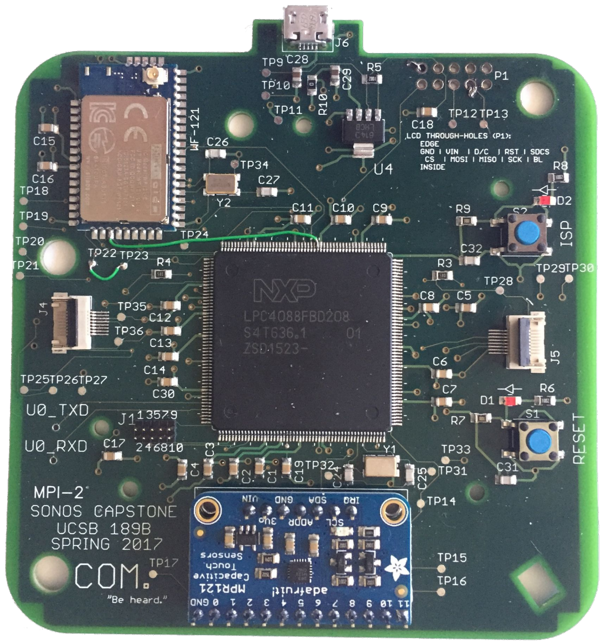
util/

- Delay Functions
  - Utilizes the system timers
  - Extremely accurate delay function
- Queue utility functions modified from third party.

screen/

- Ported over an existing C++ Adafruit library to C and our LPCOpen platform.
- Icons
  - Bitmaps indicate which pixels need to be colored
  - X BitMap
- Text
  - There are functions that take in a string and calculate which pixels need to be colored

Summary



+

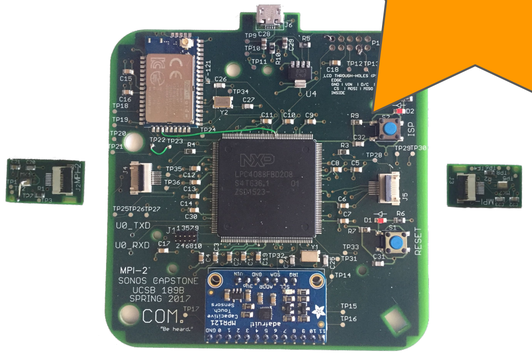
```
void mics_init(void) {
//      mics_pin_mux_debug_pincheck(); //IF WIRES CONNEC
        mics_pin_mux();
        I2S_AUDIO_FORMAT_T audio_Confg;
        audio_Confg.SampleRate = MIC_SAMPLE_RATE;
        /* Select audio data is 2 channels (1 is mono, 2
        audio_Confg.ChannelNumber = 1;
        /* Select audio data is 16 bits */
        audio_Confg.WordWidth = 32;

        Chip_I2S_Init(LPC_I2S);
        Chip_I2S_RxConfig(LPC_I2S, &audio_Confg);
        Chip_I2S_RxModeConfig(LPC_I2S,0,0,0);

        Chip_I2S_DMA_RxCmd(LPC_I2S, I2S_DMA_REQUEST_CHAN
        /* Initialize GPDMA controller */
        Chip_GPDMA_Init(LPC_GPDMA);
        /* Setting GPDMA interrupt */
```

+


Bathroom

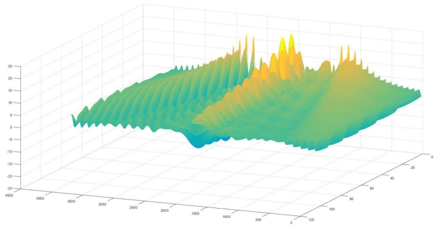
Tangible Outcomes

CE/EE



Hardware

Physical Units
& Test Results

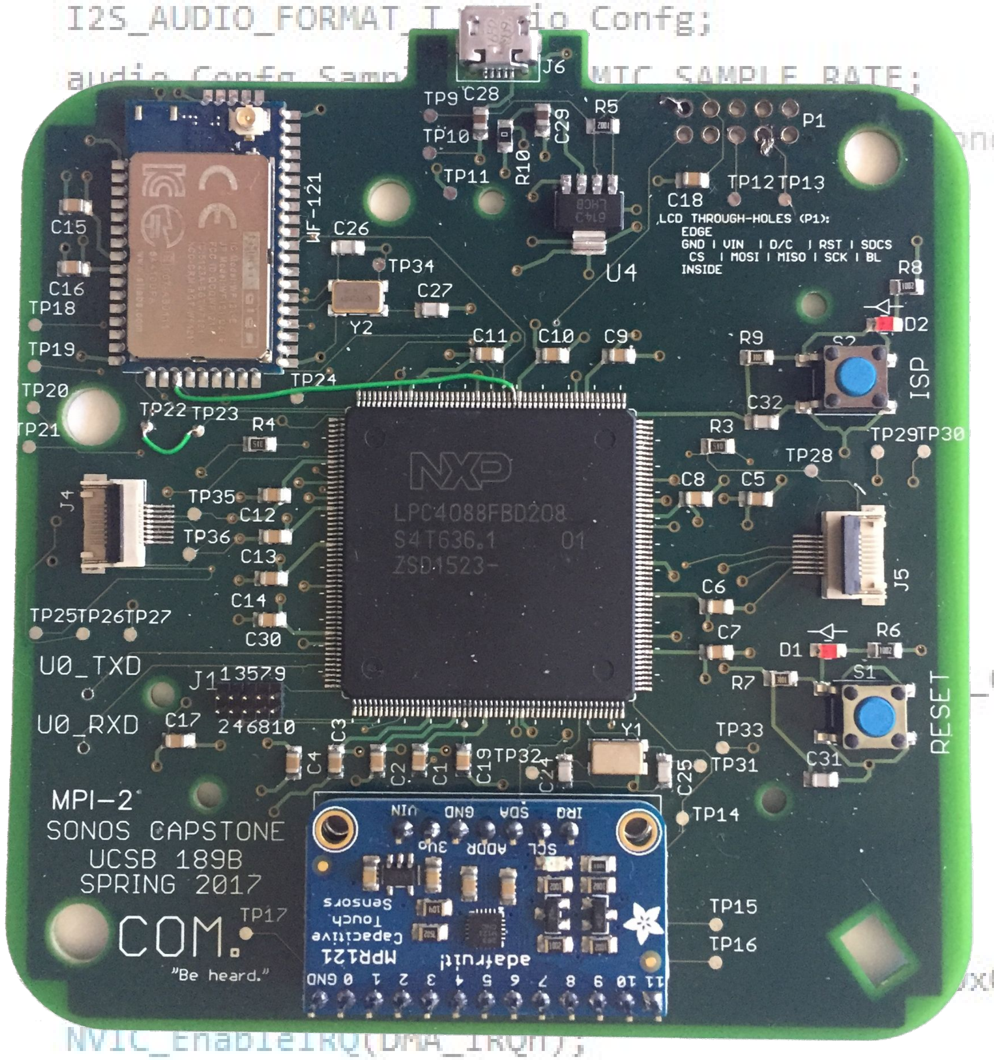


Microphone
and DSP
Research

CE

...

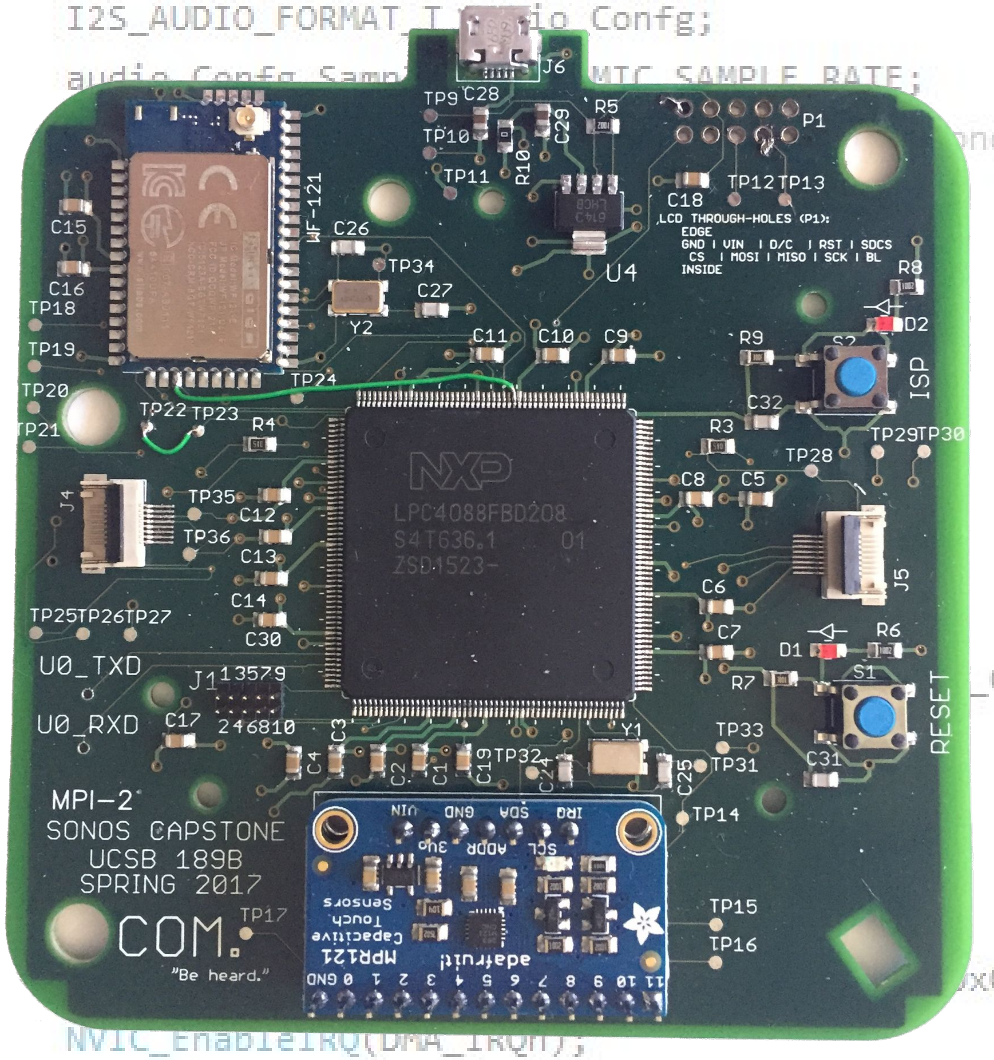
Embedded
Software



It's been designed **and** built.

It’s real.

```
void mics_init(void) {
//      mics_pin_mux_debug_pincheck(); //IF WIRES CONNECTED TO MICS NO NEED TO GO THROUGH DEBUG
        mics_pin_mux();
        I2S_AUDIO_FORMAT_T [...]io Confg;
        audio_Confg.Samp[...]MIC_SAMPLE_RATE;
        [...]ono, 2 is stereo) */
        [...]_CHANNEL_2, ENABLE, 4);
        [...]x01));
        NVIC_EnableIRQ(DMA_IRQn);

        dmaChannelNum_I2S_Rx = Chip_GPDMA_GetFreeChannel(LPC_GPDMA, GPDMA_CONN_I2S_Channel_1);
        activeCb = NULL;
```



It’s the COM.

```
void mics_init(void) {
//      mics_pin_mux_debug_pincheck(); //IF WIRES CONNECTED TO MICS NO NEED TO GO THROUGH DEBUG
        mics_pin_mux();
        I2S_AUDIO_FORMAT_T audio_Confg;
        audio_Confg.SampleRate = MIC_SAMPLE_RATE;
```


```
is mono, 2 is stereo) */
g);
QUEST_CHANNEL_2, ENABLE, 4);
        NVIC_SetPriority(DMA_IRQn, ((0x01 << 3) | 0x01));
        NVIC_EnableIRQ(DMA_IRQn);

        dmaChannelNum_I2S_Rx = Chip_GPDMA_GetFreeChannel(LPC_GPDMA, GPDMA_CONN_I2S_Channel_1);
        activeCb = NULL;
```

Thank You

Sonos, Laritech, and UCSB

Any Questions?