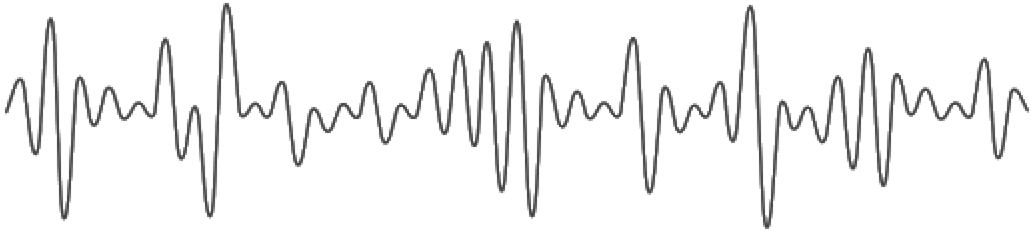
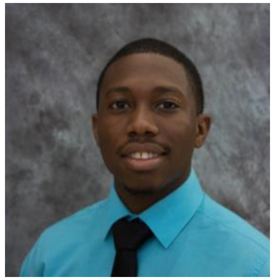
AUDIOVISIBLE

An Audiovisual Spectrum Analyzer
for an Underserved Audience

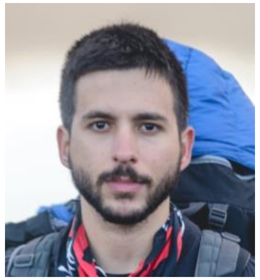


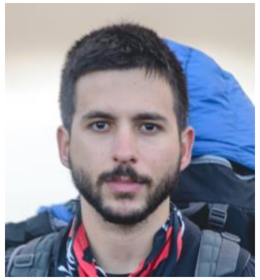
Critical Design Review
UCF – Senior Design – Fall 2020
Group 3


Jaaquan Thorpe, CPE


Danielle Garsten, CPE


Marcos Berrios, PSE


Gustavo Monaco, CPE


Gustavo Monaco, CPE

Motivations

Art is an inherent part of the human condition.

There are still certain forms of art that certain demographics are unable to experience and ultimately enjoy.

Music is an amazing and enjoyable experience.

People who are deaf or hard-of-hearing can’t enjoy music.

Objective

To serve an underserved audience, and serve it well, by delivering the visual experience of music.

Features

CORE

- Multi-color display
- Audio output

ADVANCED

- Waveform Simulation
- Graphic Equalization

THE DEVICE

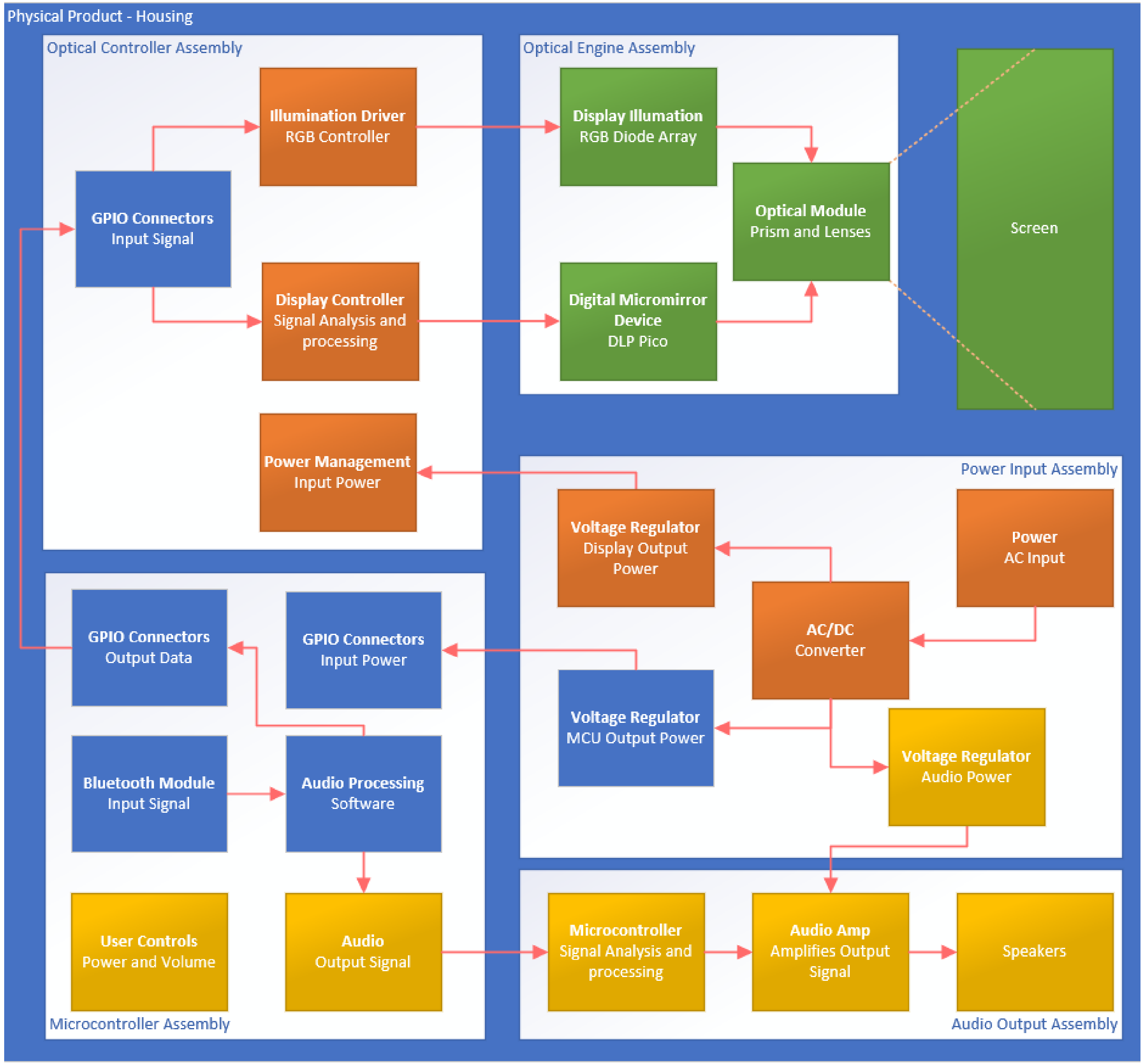
Block Diagram

Jaaquan Thorpe
Hardware Engineer Lead
Optical Design

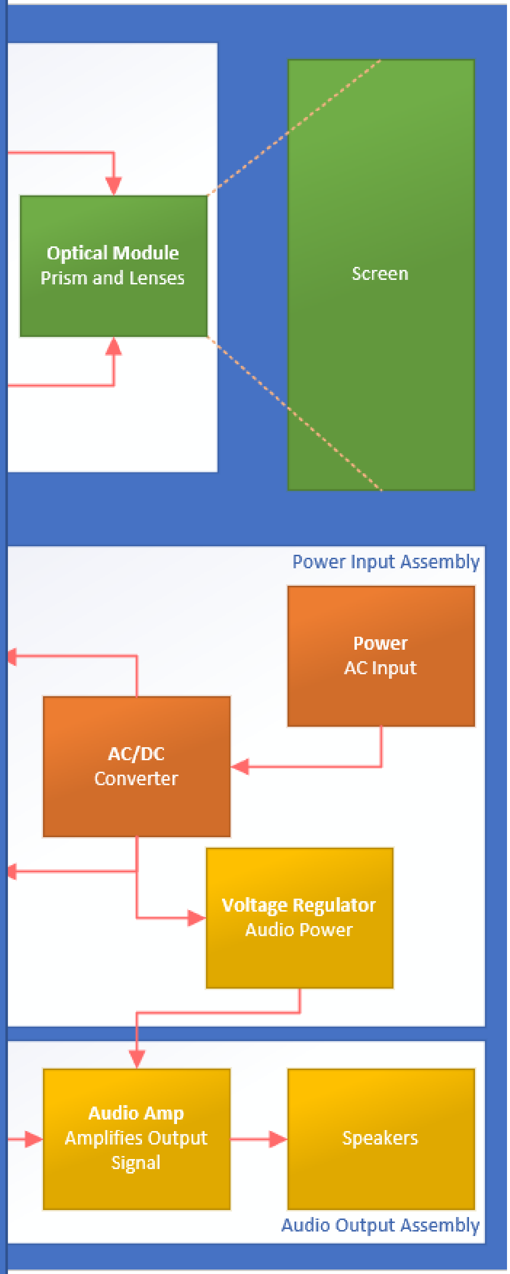
Danielle Garsten
Project Manager
Software Engineer

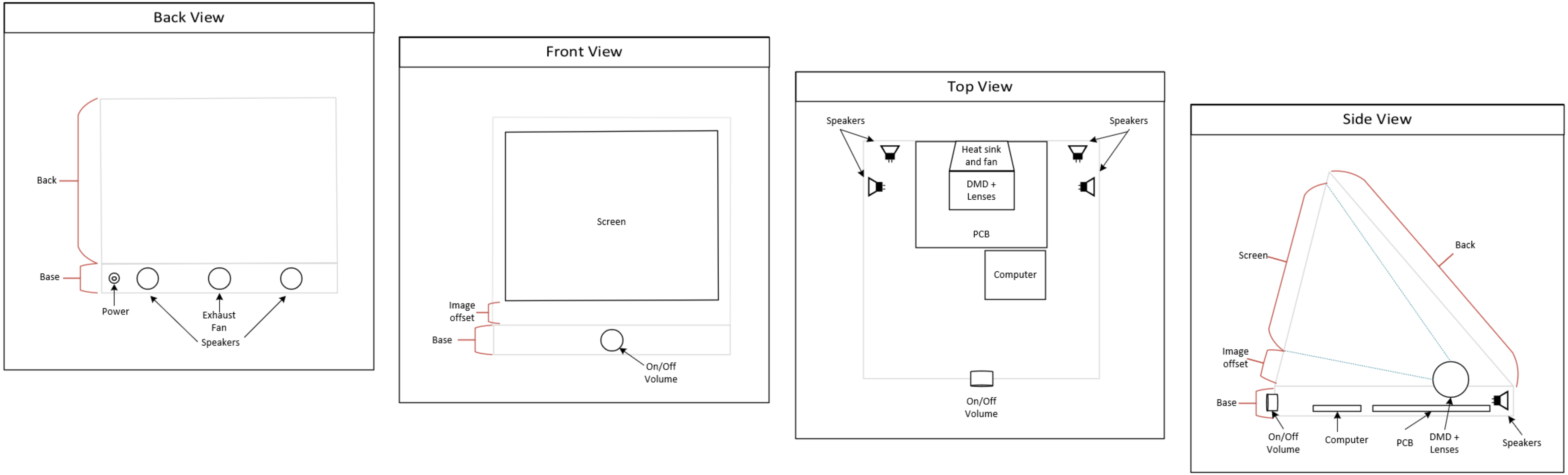
Marcos Berrios
Optical Design Lead
Hardware Engineer

Gustavo Monaco
Software Engineer Lead
Production Lead



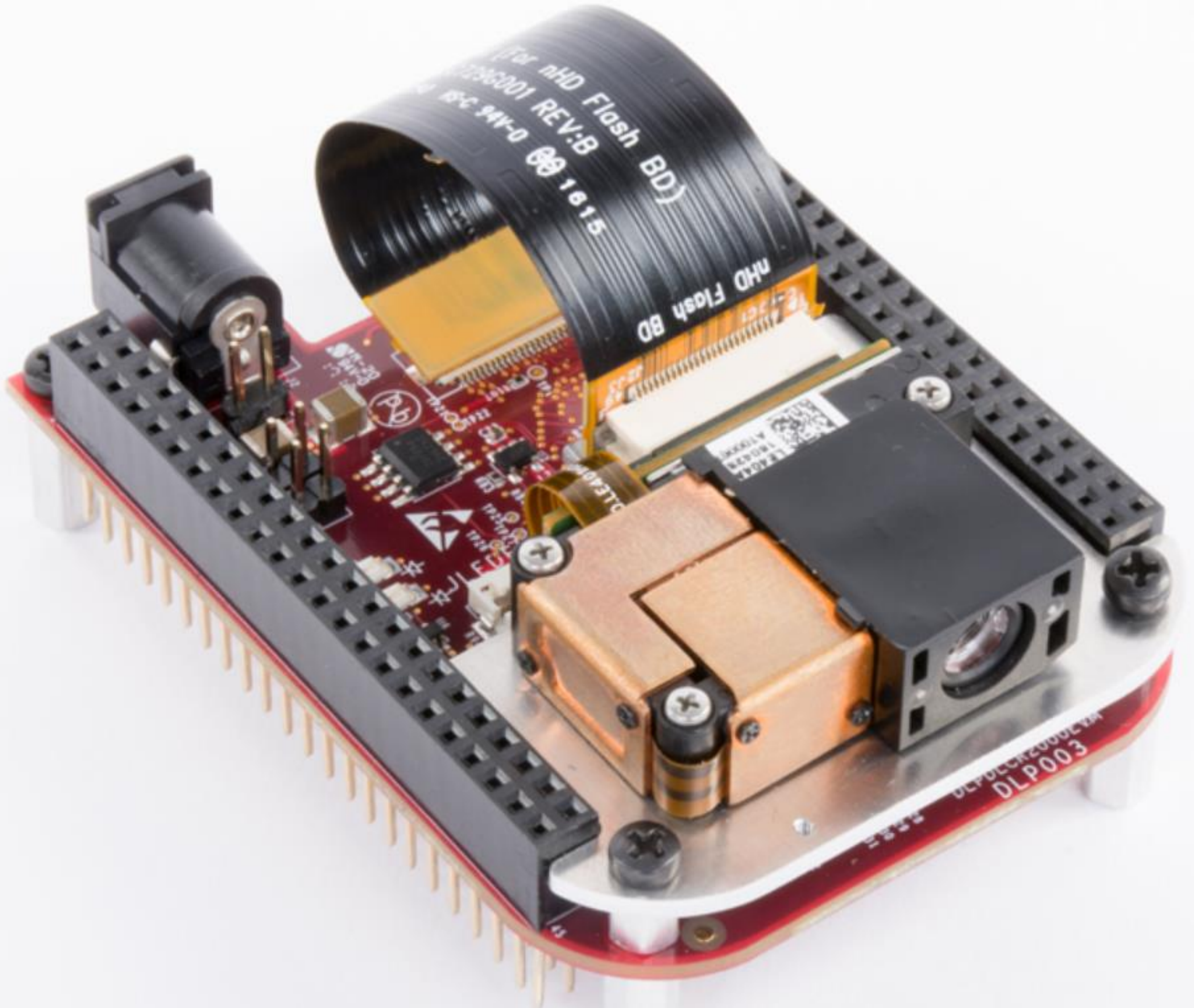
The Enclosure



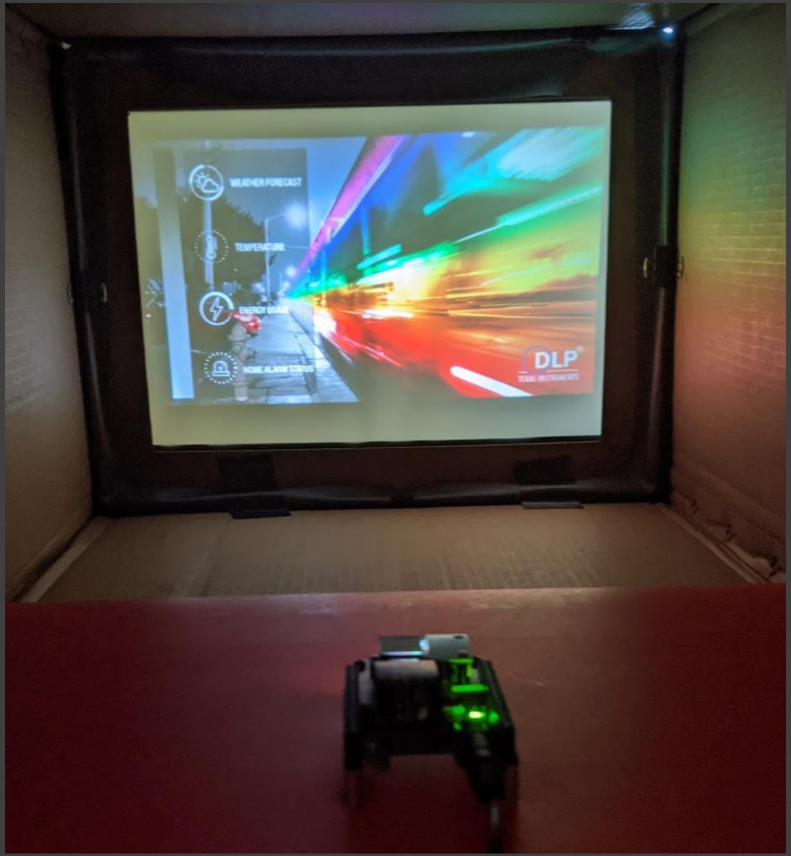


Enclosure Schematics

DLP® LightCrafter™ Display 2000 Evaluation Module



DLPDLCR2000EVM

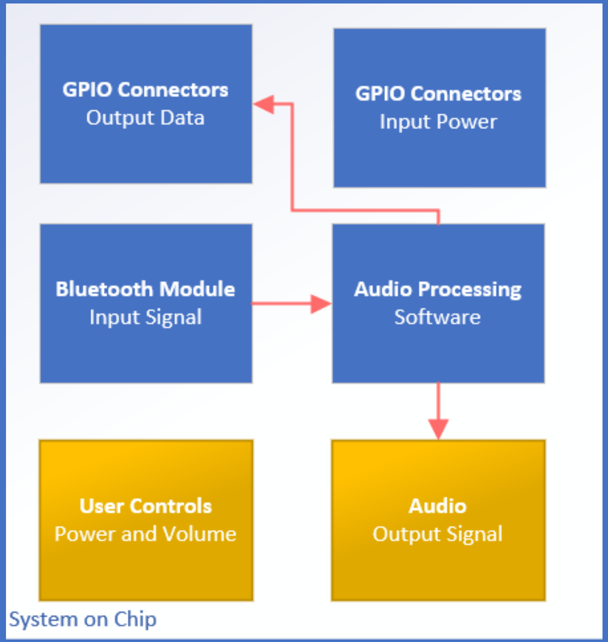


Proof of Concept*

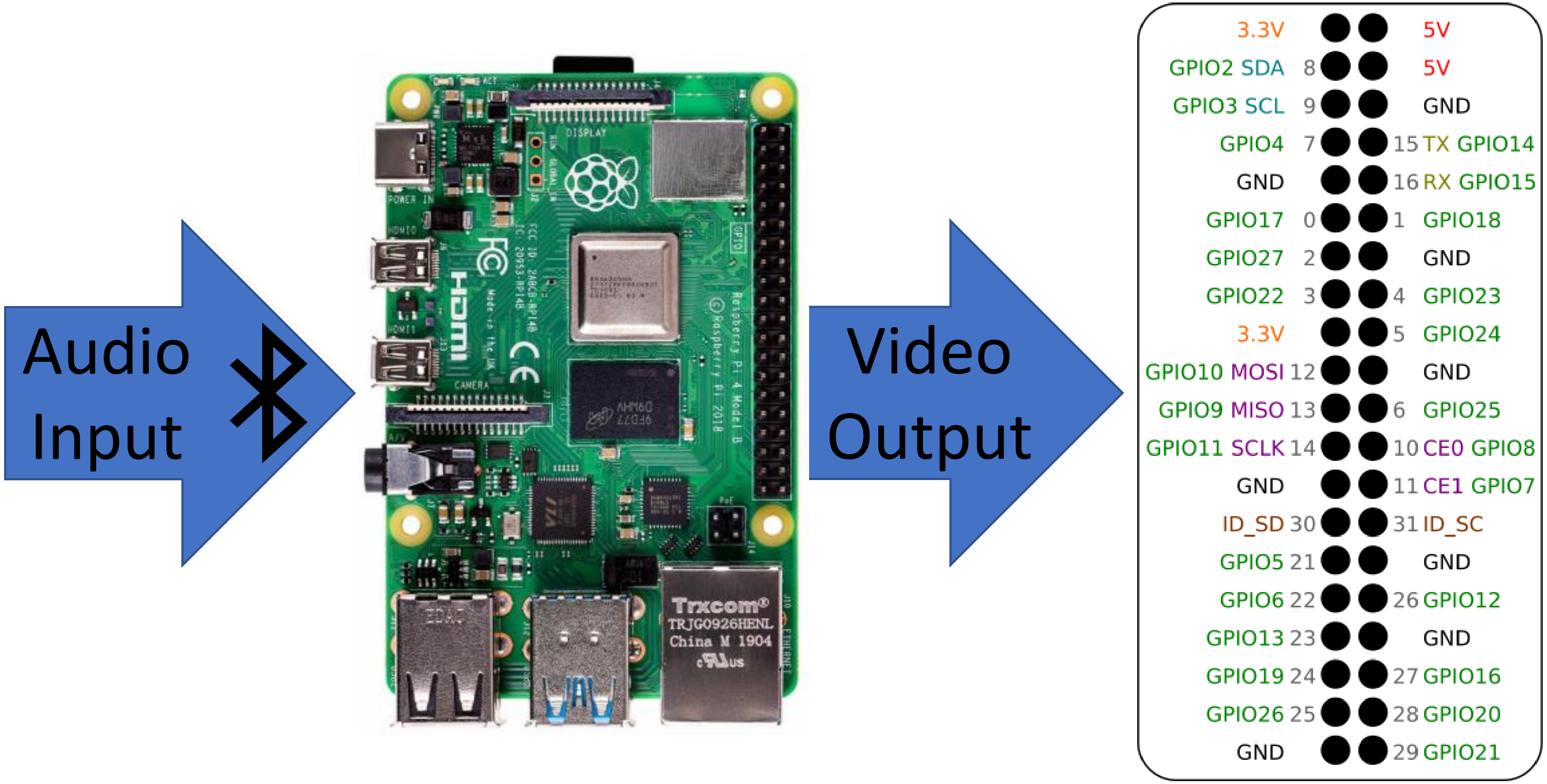
- Enclosure dimensions
- LED Brilliance
- DMD Resolution
- Room Lighting
- Projection Screen
- Heat radiation
- Focus

*Using the Evaluation Module

The Computer



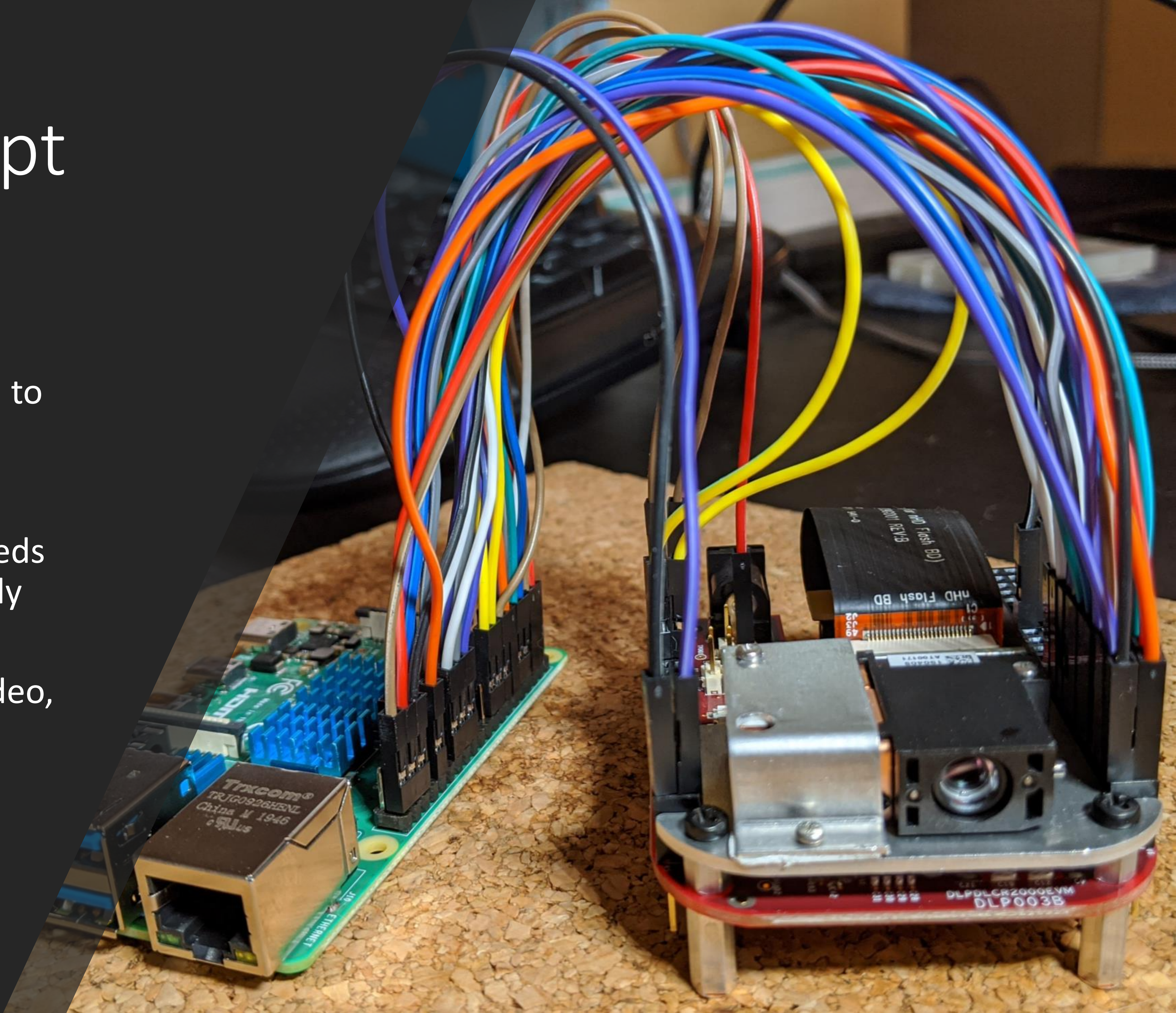
Raspberry Pi 4 – System On a Chip



Proof of Concept

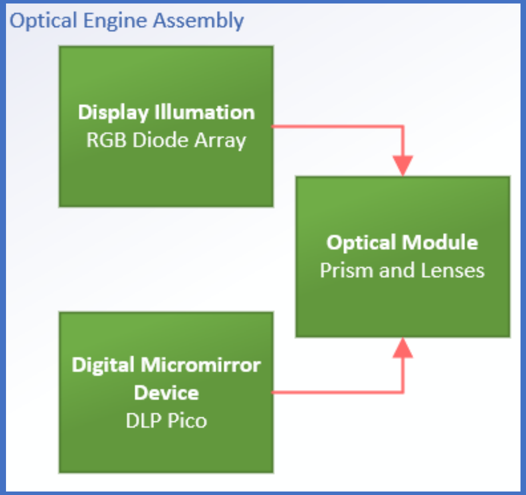
Challenges found:

- Evaluation module is designed to work with a Beaglebone Black
- I2C Protocol
- Raspberry Pi pin mappings needs to be modified to work differently using an overlay
- Evaluation module displays video, but in terrible quality.
- More testing is required.



Marcos Berrios, PSE
College of Optics and Photonics

- Experience in diffraction-based optical metrology tools
- Current focus in diffractive waveplate technology
- Background in music theory and performance

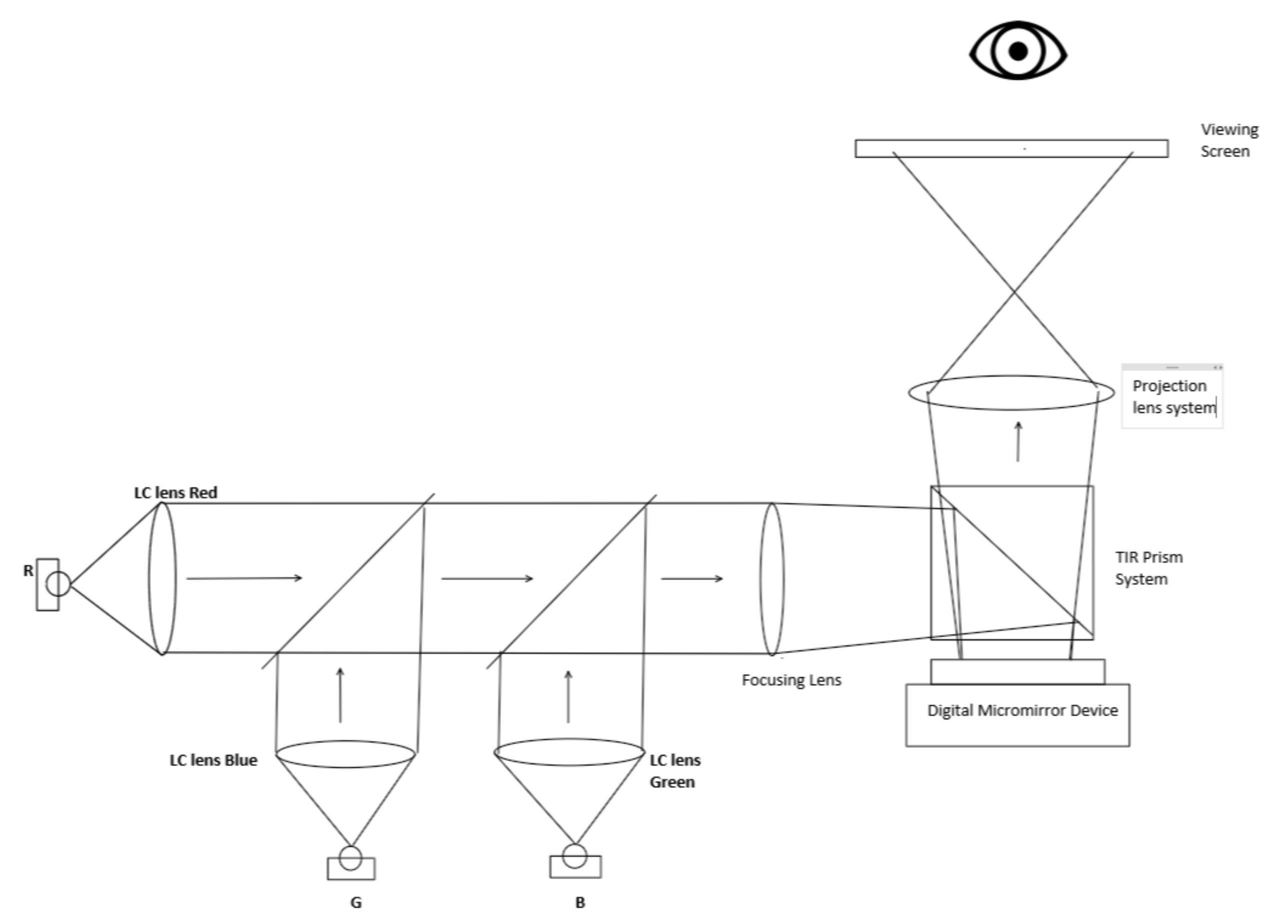


Optical Engine

Optical Engine: Overview

The optical engine is based off Digital Light Processing (DLP) technology.

It will create an image by using an RGB diode array to illuminate a Digital Micromirror Device, and will use projection optics to project that image through a viewing screen.



Preliminary sketch of optical system

Optical Engine:

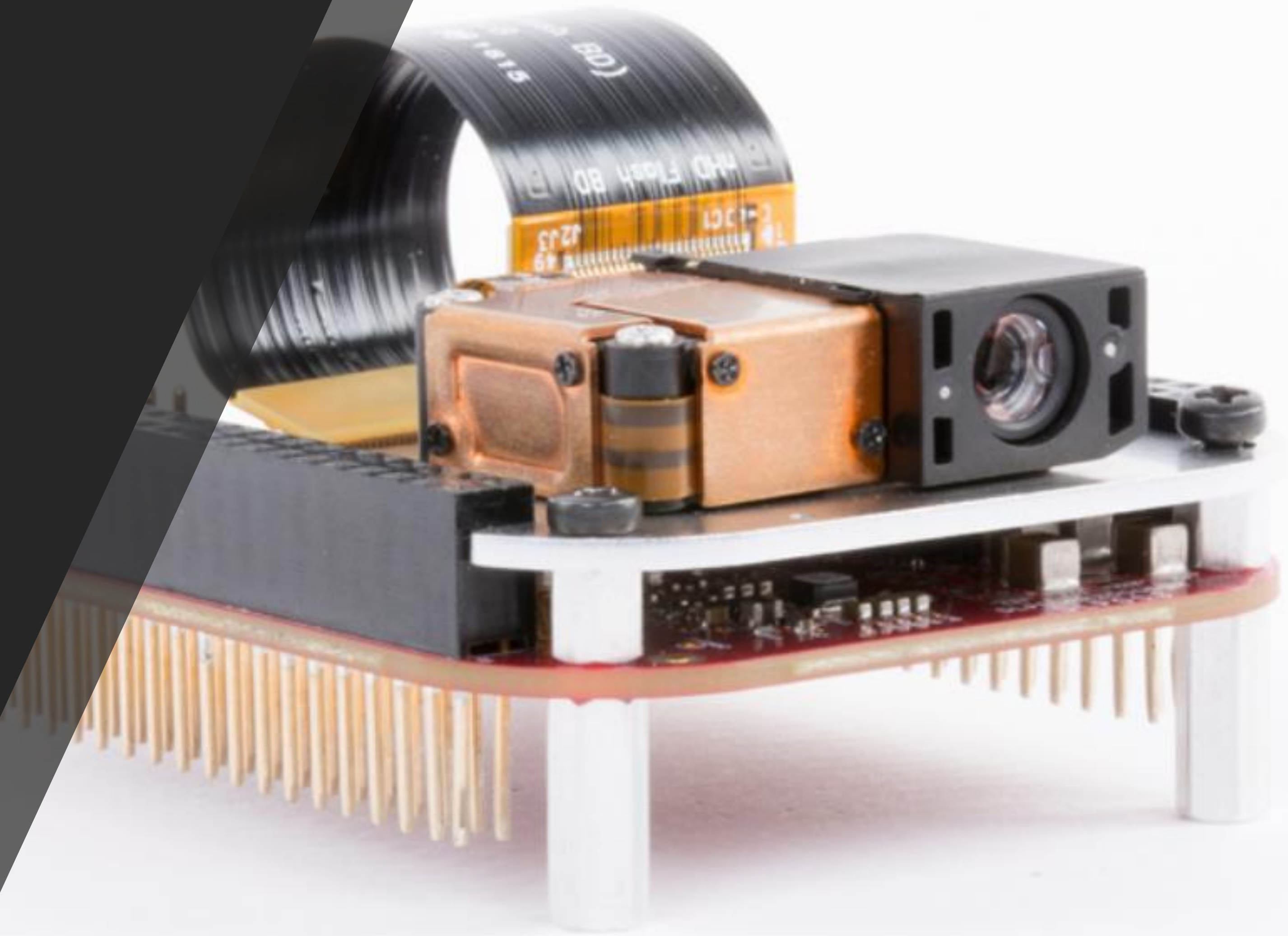
The Expectation

- Production of an image is critical to the success of the project
- The colors should be bright and easily identifiable
- The image should be bright enough to view by the unassisted eye

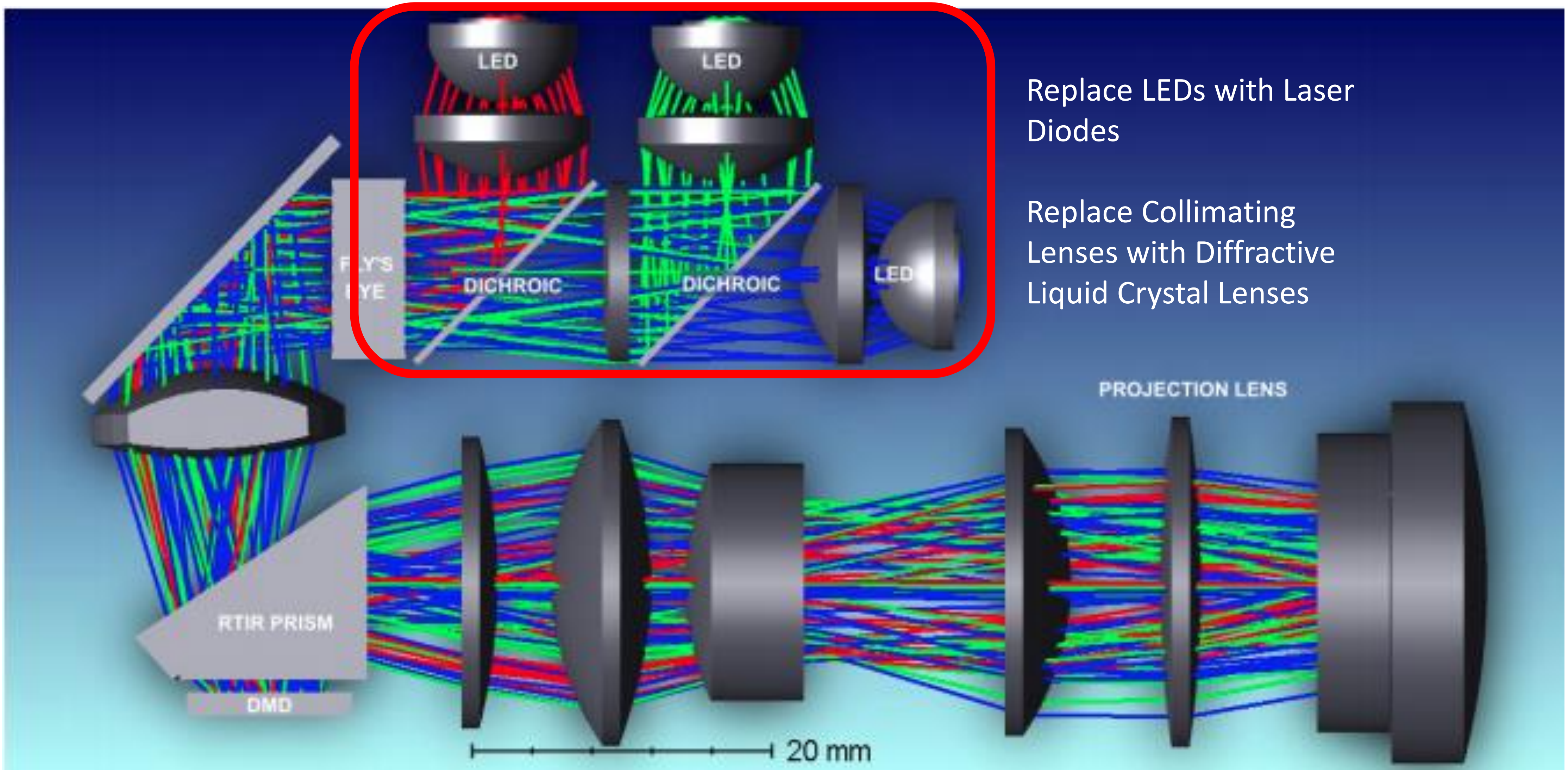
Optical Engine: The plan

We have purchased a pocket projector kit from Texas Instruments and intend to utilize the DMD chipset inside, while replacing the illumination optics with optics of our own

- Replacing the illumination LEDs with RGB laser diodes
- Replacing the optics inside with diffractive waveplate lenses provided by BEAM Co., fabricated by the students



Zemax Rendering of the Original Projector System*



Replace LEDs with Laser Diodes

Replace Collimating Lenses with Diffractive Liquid Crystal Lenses

Laser Diode Characteristics

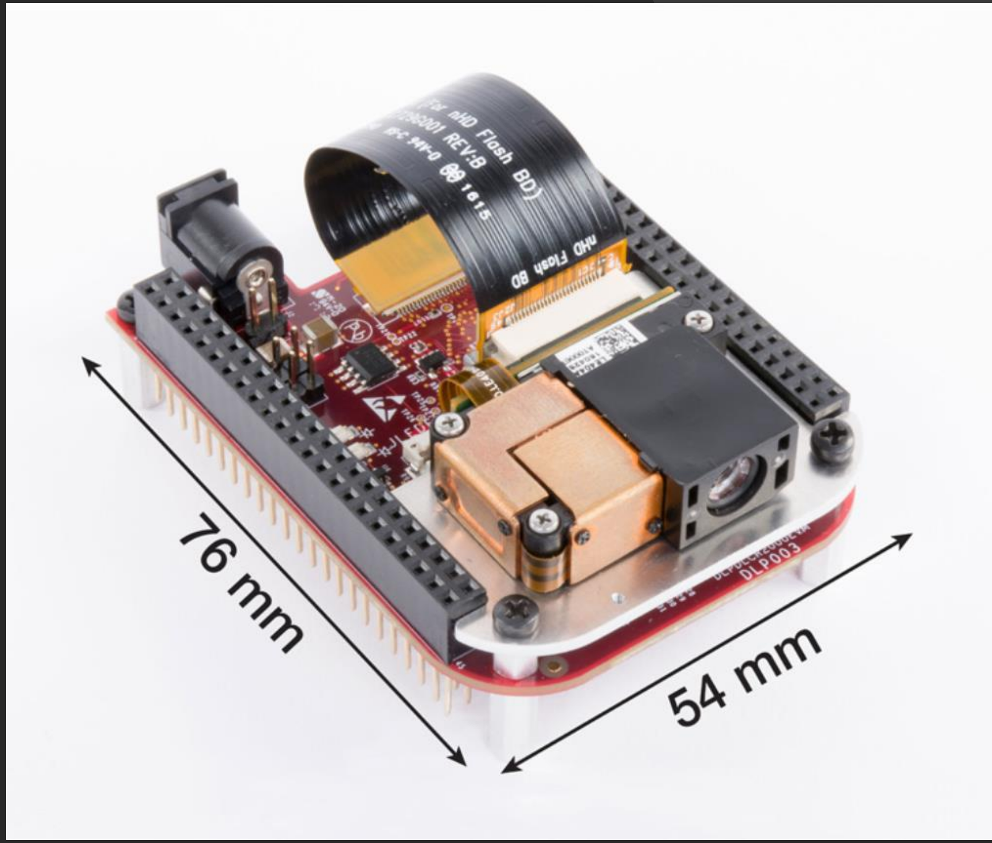
	Red	Green	Blue
Wavelength (nm)	648	520	450
Operating voltage (V)	2.4	6.5	5.1
Max voltage (V)	3	7.5	6
Threshold Current (mA)	65	65	22
Max Current (mA)	150	90	110
Max output power (mW)	100	85	80
Minimum Divergence (°)	7	5	10

Lens Design: The Challenge

For proper illumination of the display elements, lasers need to be collimated to a beam diameter no smaller than 5mm. This means that ideally each laser will have a lens with a focal length tuned specifically to it.

Focal lengths

- Red (Slow axis divergence = 7˚): 20 mm focal length
- Green (Slow axis divergence = 5˚): 28 mm focal length
- Blue (Slow axis divergence = 10˚): 14 mm focal length



Lens Design: Compromises

Due mainly to constraints on time and available materials, designing and fabricating a custom lens for each diode was not feasible. In order to complete the project within the allotted time, a compromise was made to standardize the focal length of the lenses and adjust the size of the output beams using apertures.

They will all be made with a focal length of 28mm, and each lens will still be crafted to have maximum diffraction efficiency at their respective wavelengths

Optical Testing: The Next Frontier

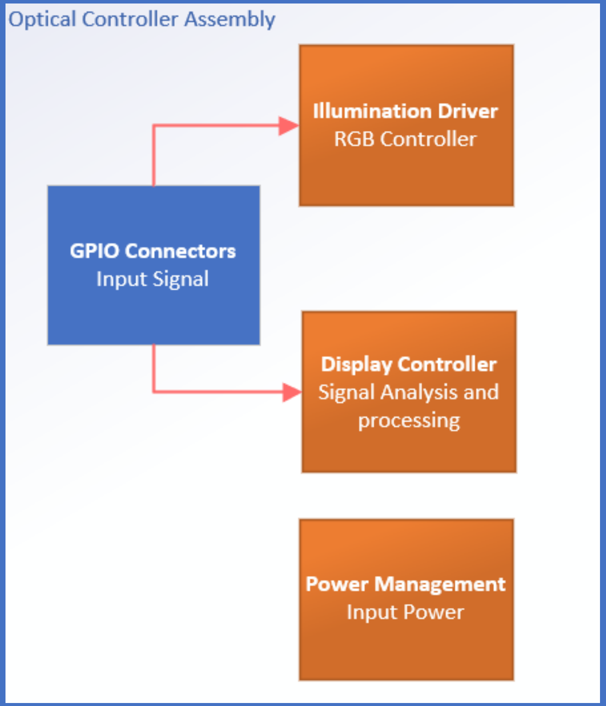
Due to shipping delays and issues with mailing addresses, we have finally acquired all of the laser diodes this past week.

Upcoming tasks:

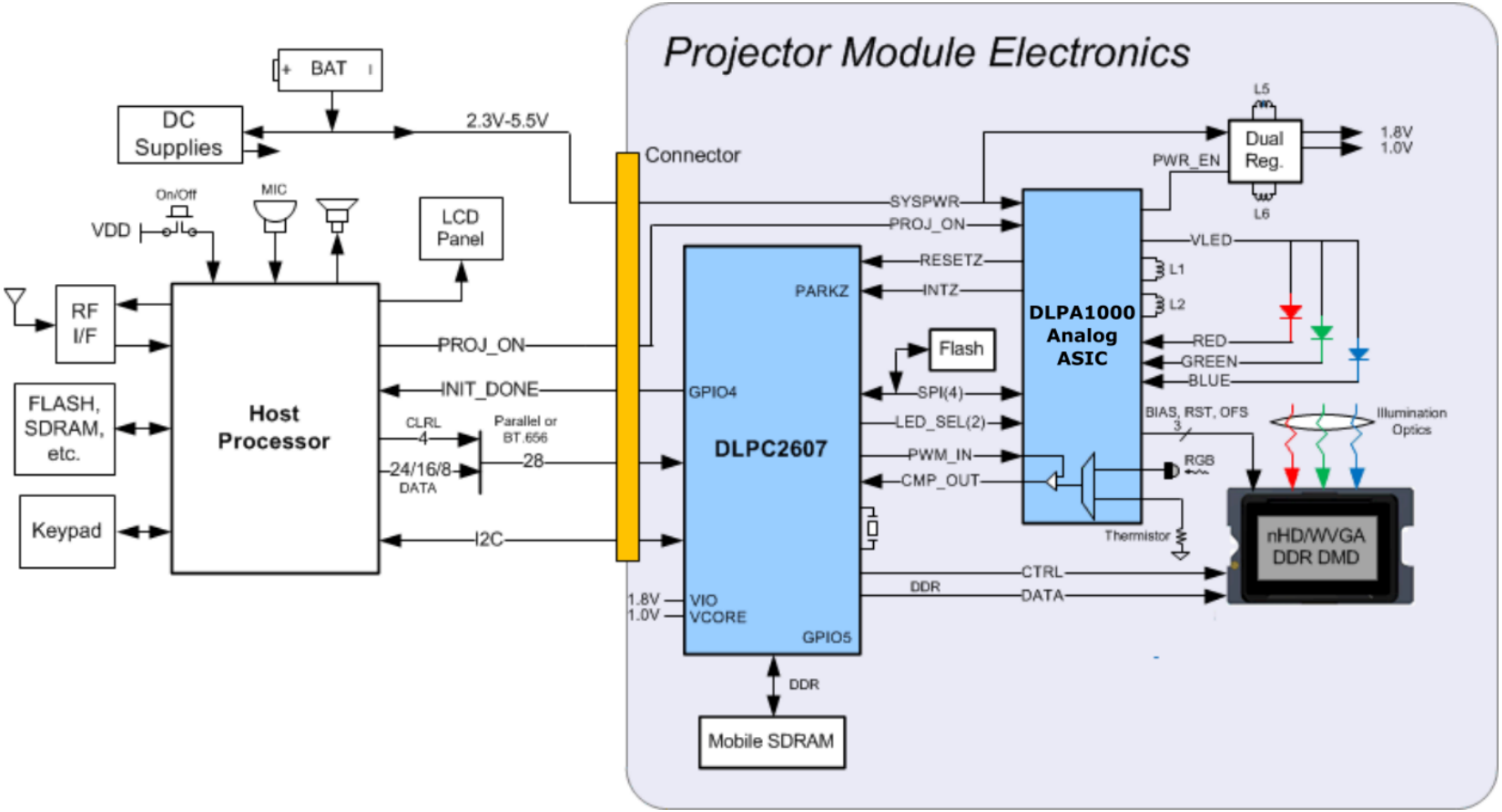
- 9/19: Diode output testing
- 9/21: Lenses begin fabrication
- 10/5: Lenses finish fabrication
- 10/6-10/10: Test lenses and mount optics

Jaaquan Thorpe, CPE
Department of Electrical and Computer Engineering

Area of focus:
- Embedded Systems
- Web Development
- Cloud Computing



Optical Controller

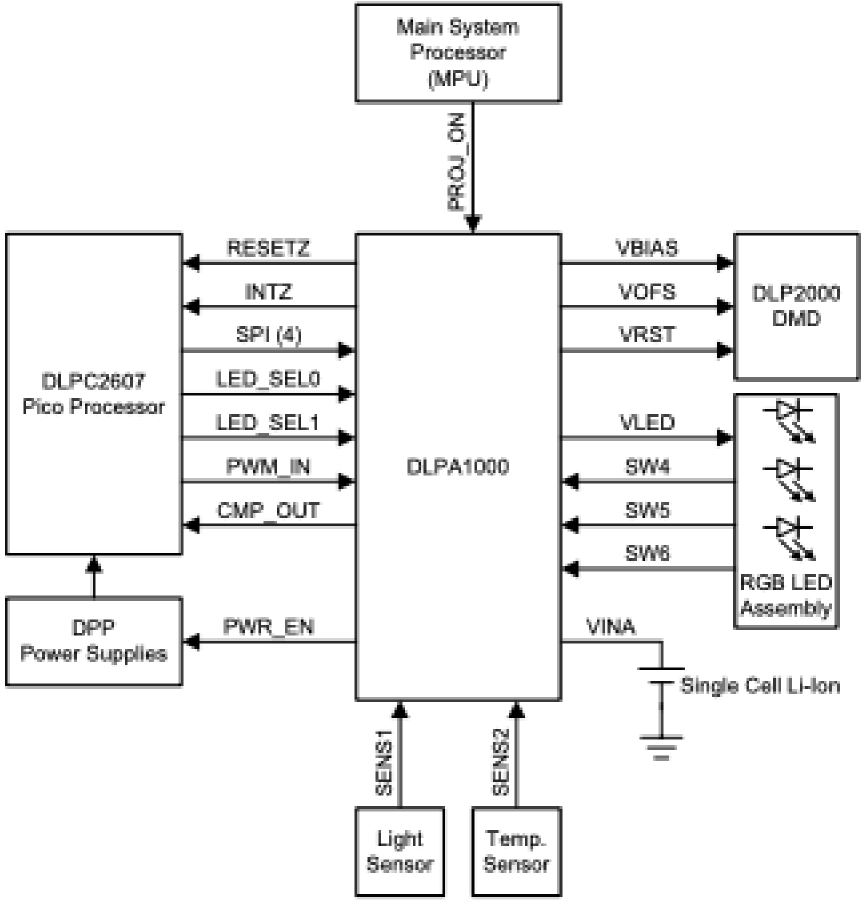


Projector Module Electronics
BAT
DC Supplies
2.3V-5.5V
Connector
On/Off
MIC
VDD
LCD Panel
RF I/F
FLASH, SDRAM, etc.
Keypad
Host Processor
PROJ_ON
INIT_DONE
CLRL
4
Parallel or BT.656
24/16/8 DATA
28
I2C
SYSPWR
PROJ_ON
RESETZ
INTZ
PARKZ
GPIO4
DLPC2607
Flash
SPI(4)
LED_SEL(2)
PWM_IN
CMP_OUT
1.8V
1.0V
VIO
VCORE
GPIO5
DDR
Mobile SDRAM
DLPA1000 Analog ASIC
Dual Reg.
PWR_EN
L5
L6
1.8V
1.0V
VLED
L1
L2
RED
GREEN
BLUE
BIAS, RST, OFS
3
Illumination Optics
RGB
Thermistor
CTRL
DDR
DATA
nHD/WVGA DDR DMD

DLPC2607 Controller

- Low-powered digital controller for display applications
- Supports Pixel Clock up to 33.5MHz
- Supports up to 60Hz Frame Rates
- Must be used in conjunction with DMD for a reliable operation of the DMD
- Uses an external SPI serial flash memory device for configuration support.
- The device will be programmed over I2C.
- Has two functional modes controlled by a single pin:

1. If pin set to high, projector powers up and projects image.
2. If pin set to low, projector powers down to save power.



DLPA1000 PMIC/LED Driver

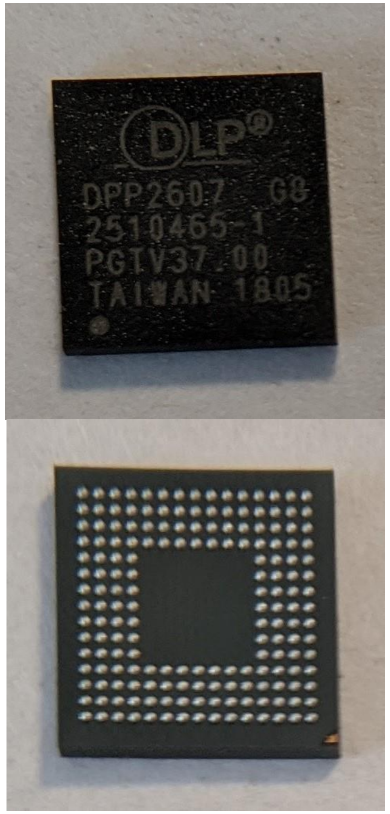
- High-Efficiency RGB LED Driver With Buck-Boost DC-to-DC Converter and Integrated MOSFETS
- Protection Sensors:
- Overcurrent and Undervoltage Protection
- Low-Battery and Undervoltage Lockout
- Thermal temperature and Light Sensor

DLP2000 0.2 nHD DMD

- Is a digitally controlled micro-opto-electromechanical system (MOEMS) spatial light modulator (SLM)
- With the proper optical system, an image or video is displayed
- Well-suited for portable equipment where small form factor and low power is important.
- Is an array of highly reflective aluminum micromirrors (up to 8 million mirrors).

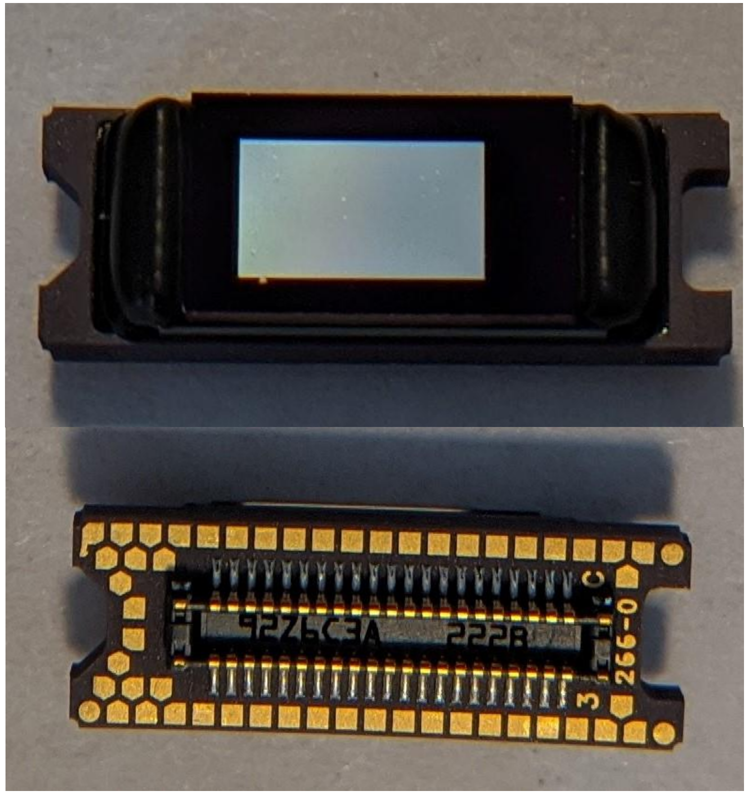
DLP Optical Module

DLPC2607 Controller



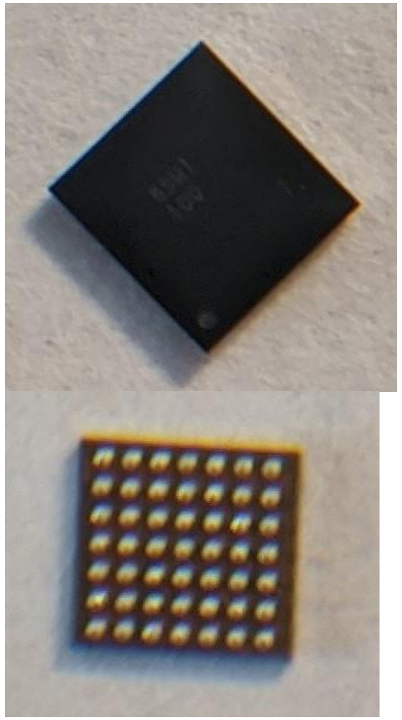
Digital Image Processor

DLP2000 0.2 nHD DMD



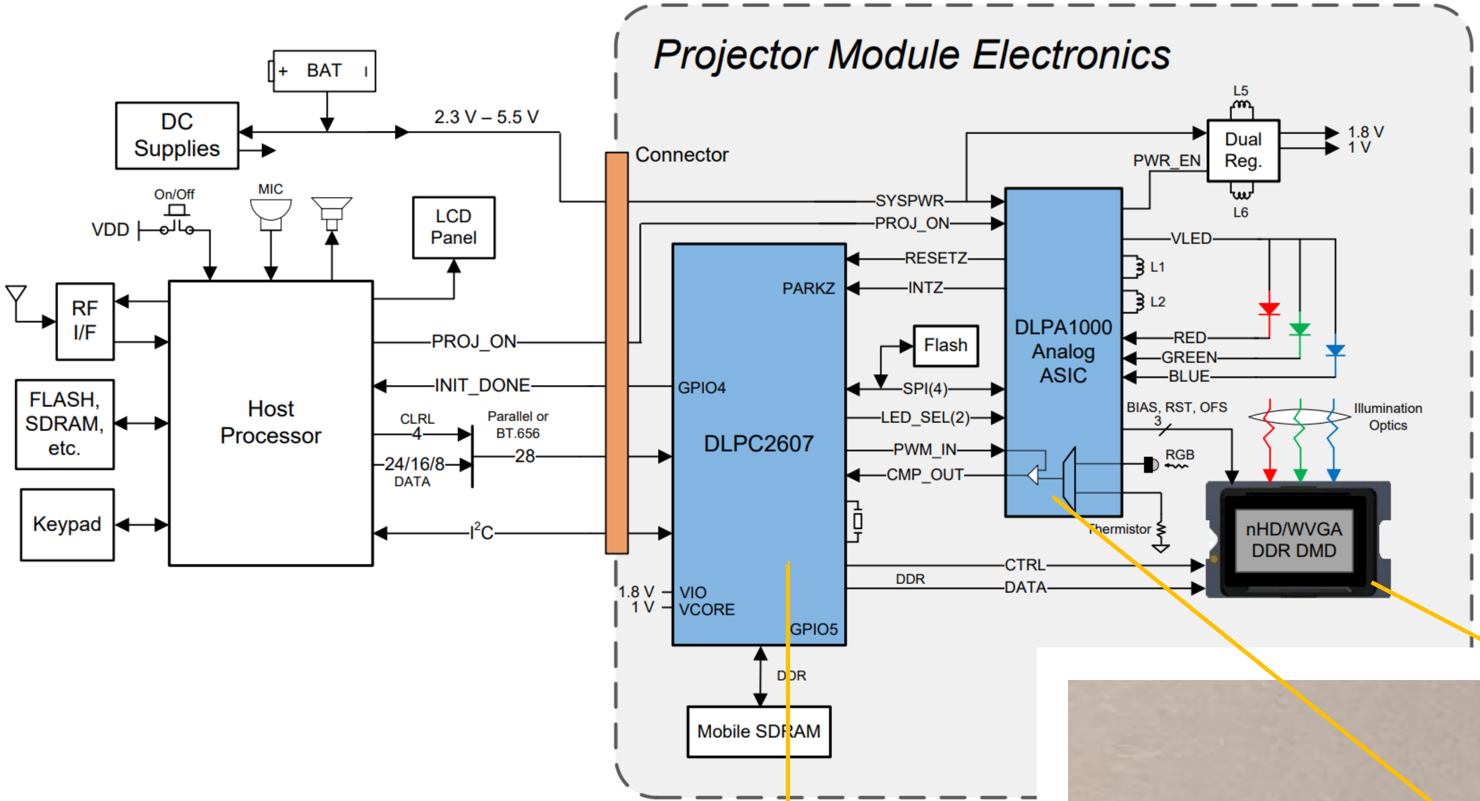
The display device producing the projected image.

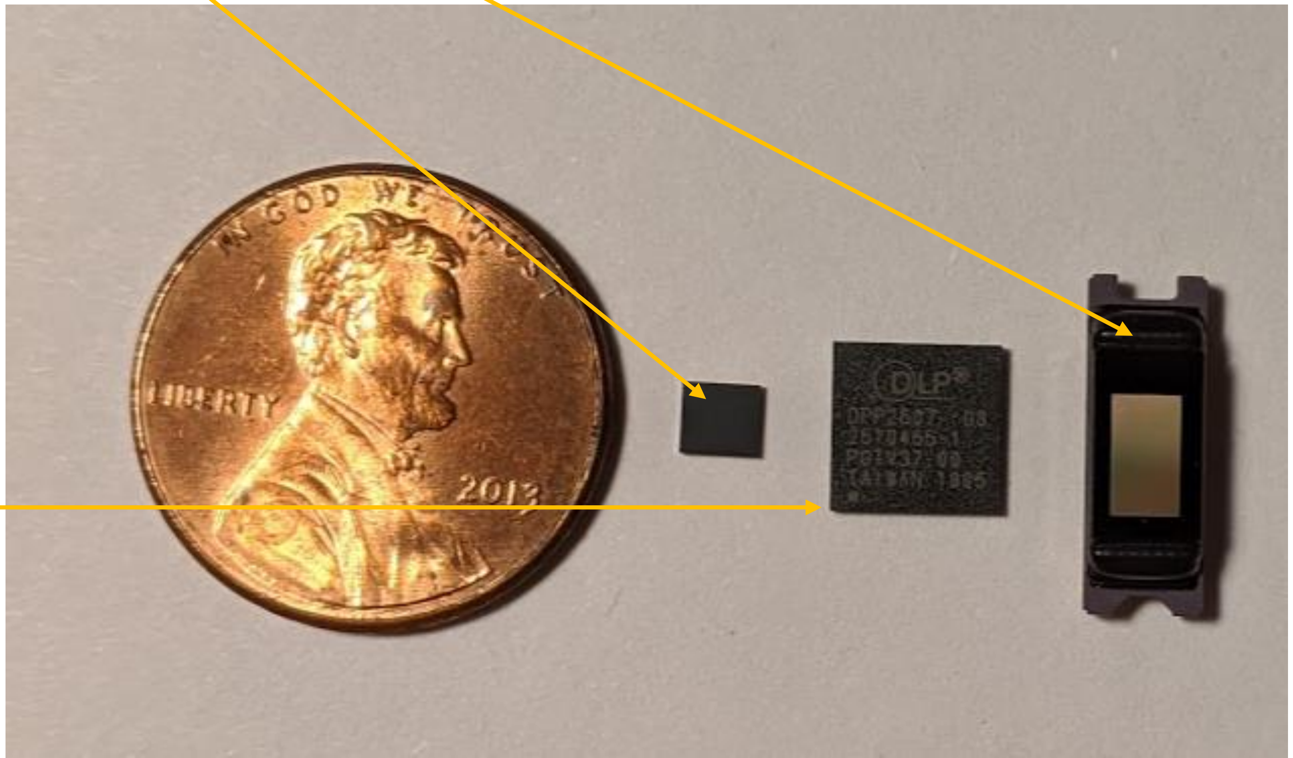
DLPA1000 PMIC/LED Driver



Provides the needed analog functions for the projector

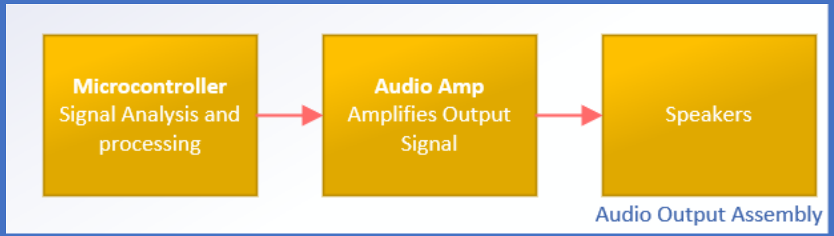
Component Testing





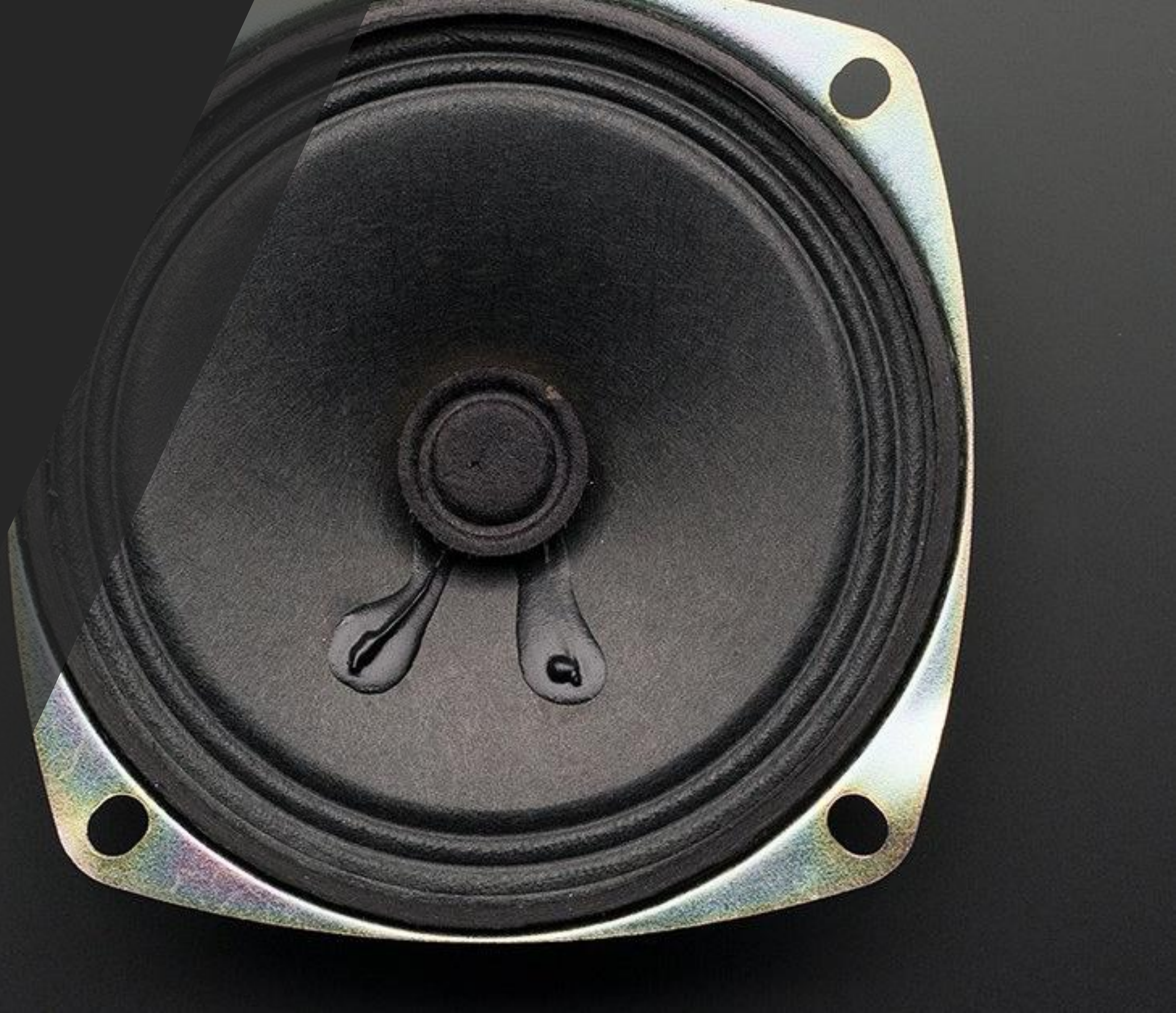
How can we test these components?

Audio Output

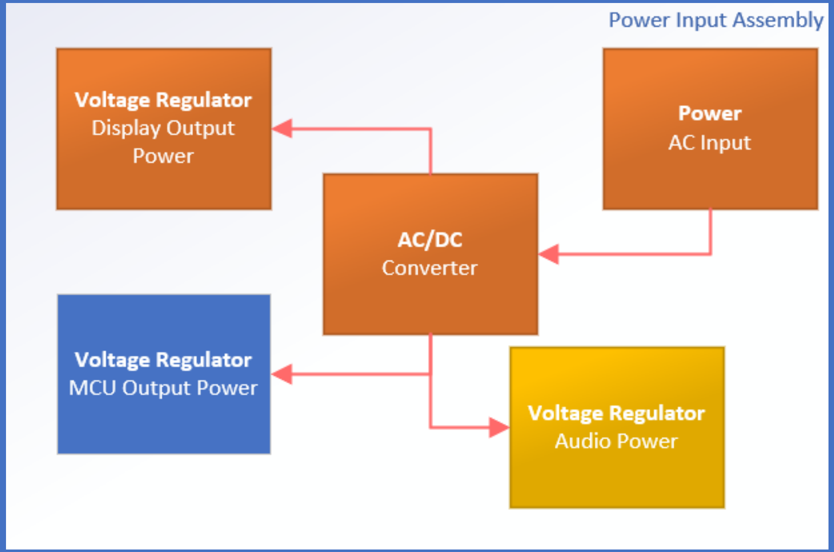


Speakers

Right: 8 ohm/1 Watt speaker will be connected to the Raspberry Pi to detect accuracy and show the intention of essential features.



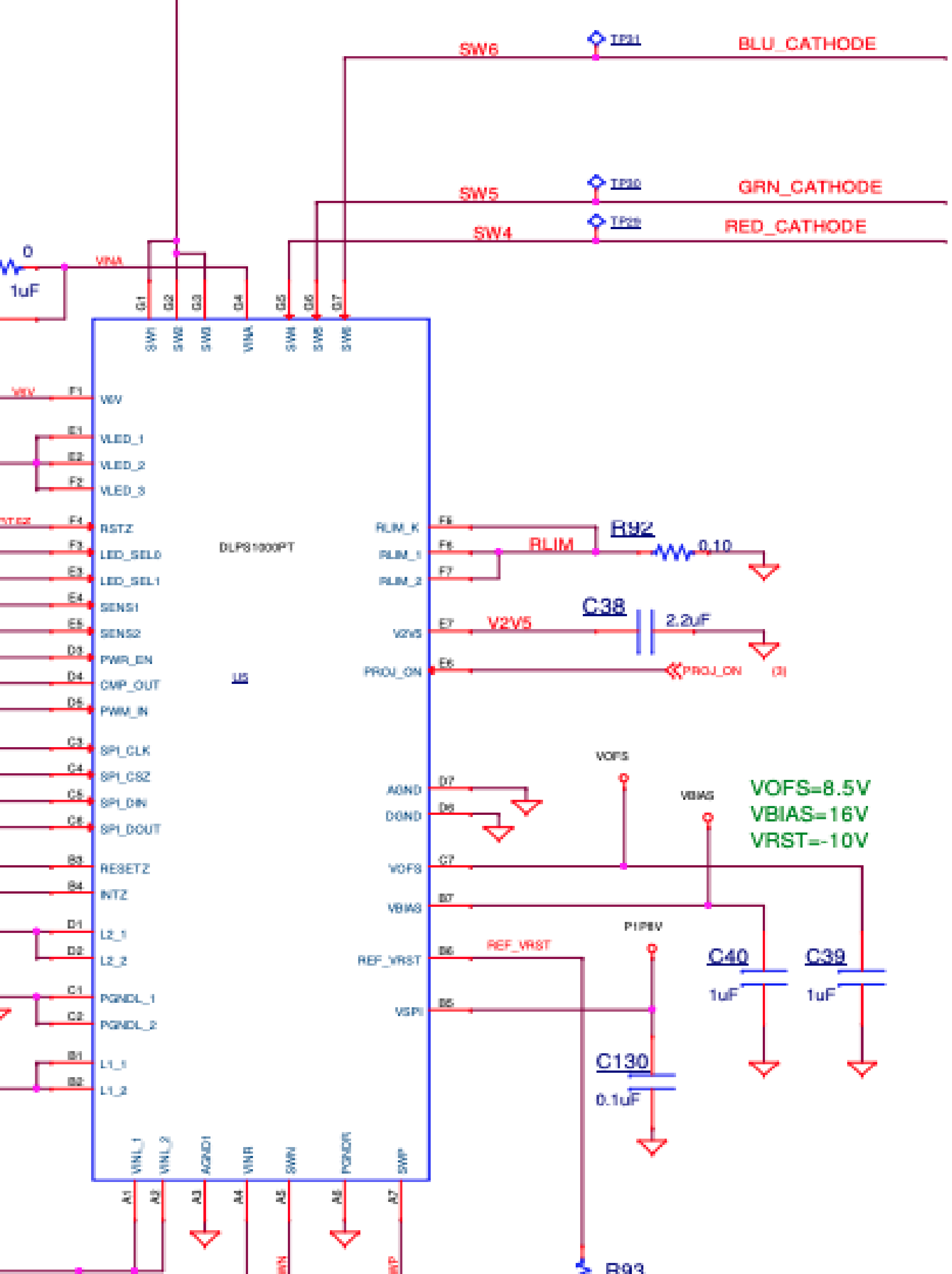
Power Input



Power Input Assembly
Voltage Regulator
Display Output
Power
Power
AC Input
AC/DC
Converter
Voltage Regulator
MCU Output Power
Voltage Regulator
Audio Power

Adjustable AC/DC Power Adapter

- This adapter provides 5-15V (adjustable), with a variety of port options (Universal).
- It will power the Optical Module directly from the wall outlet.
- The direct purpose of the plug is for the prototyping portion of the project.

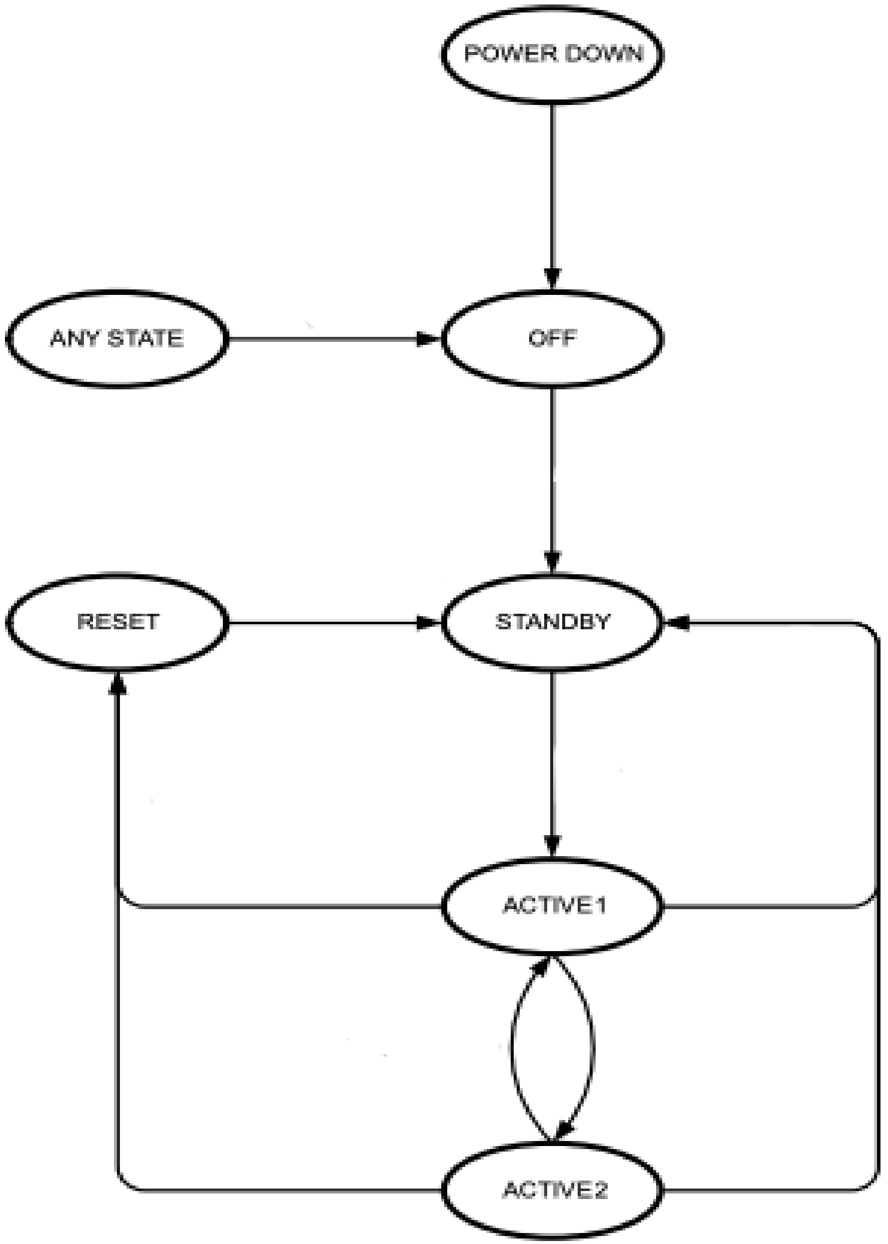


Strobe Decoder: six NMOS switches

DMD Regulators: Only 5 modes of operation.

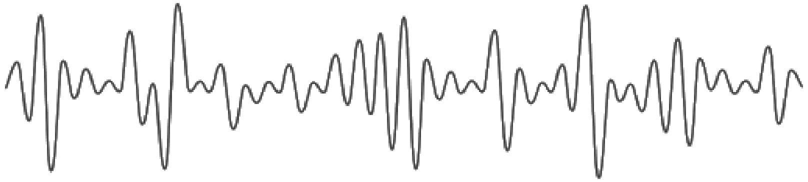
Modes of Operation

Mode	Description
OFF	This is the lowest-power mode of operation. All power functions are turned off, registers are reset to their default values and the IC does not respond to SPI commands. RESETZ and PWR_EN pins are pulled low. The IC will enter OFF mode whenever the PROJ_ON pin is pulled low.
RESET	Logic core and registers are reset to default values, the IC does not respond to SPI commands, RESETZ and PWR_EN pins are pulled low, but the analog reference system is kept alive. The device enters RESET state when the input voltage drops below the UVLO threshold.
STANDBY	All power functions are turned off, but the IC does respond to the SPI interface. The device enters STANDBY mode when PROJ_ON pins is high, but DMD_EN bit is set to 0. Also, device enters STANDBY mode when a fault on the DMD regulator occurs or the temperature increases above thermal shutdown threshold (TSD).
ACTIVE1	The DMD supplies are powered up but LED power (VLED) and the STROBE DECODER are disabled. PROJ_ON pin must be high, DMD_EN bit must be set to 1, and VLED_EN bit set to 0.
ACTIVE2	DMD supplies, LED power and STROBE DECODER are enabled. PROJ_ON pin must be high and DMD_EN and VLED_EN bits must both be set to 1.



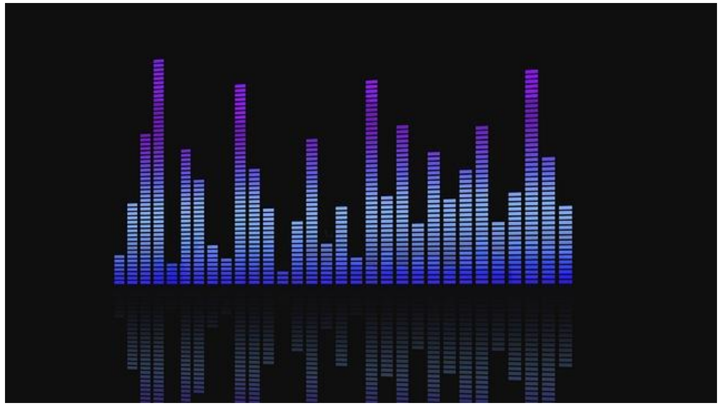
Audio Visualizations

Waveform



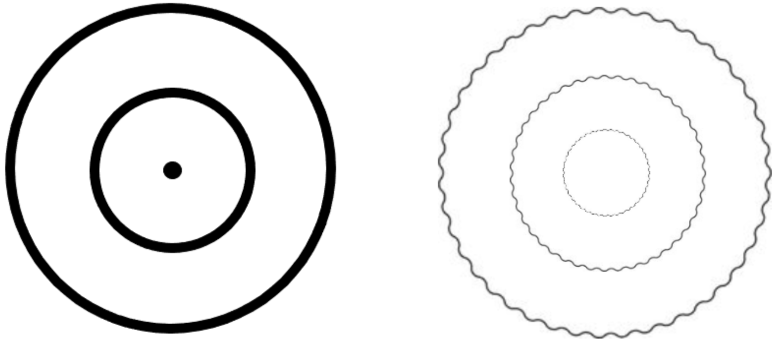
Using a couple of mathematical techniques, like the Fast Fourier Transform to process audio signals and find frequency magnitudes.

Equalization



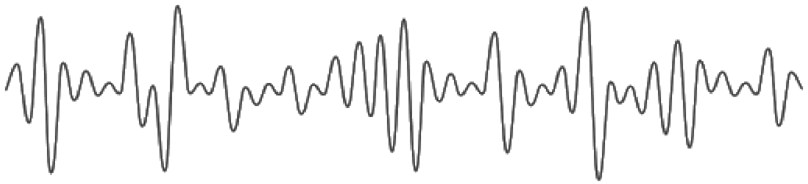
The overall composition is split using linear filters into a series of frequency “bands”.

Concentric Shapes



Like the radial ripple pattern seen when a wave propagates in all directions, the outermost ring could expand with the beat of a bass drum, the inner circles could vibrate according to the tones in the higher frequency register.

Waveform

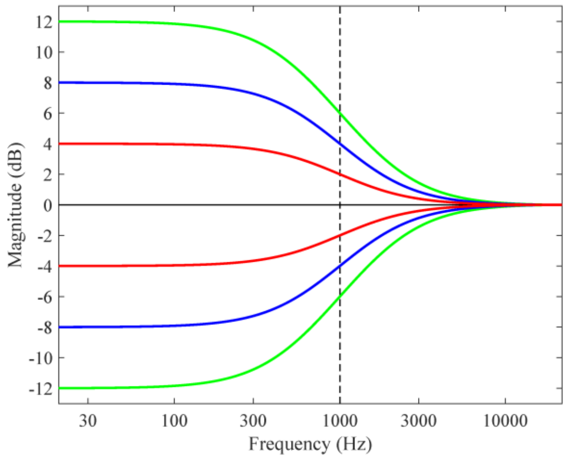


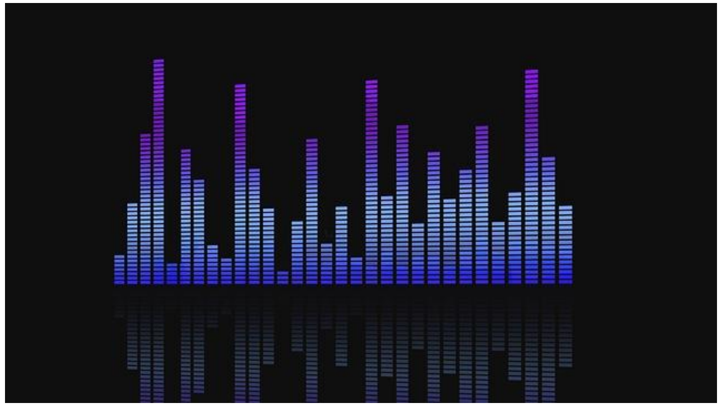
According to Cochran et. al [1], “The Fast Fourier Transform is a computational tool which facilitates signal analysis such as power spectra analysis and filter simulation by means of digital computers.”

When applied in a research setting, Choi [2] says the following “waveform equalization…[equalizes] a digital information signal reproduced from a recording medium by multiplying the reproduced digital information signal and delayed signals thereof by tap coefficients, wherein each of the tap coefficients is adaptively controlled.”

Equalization

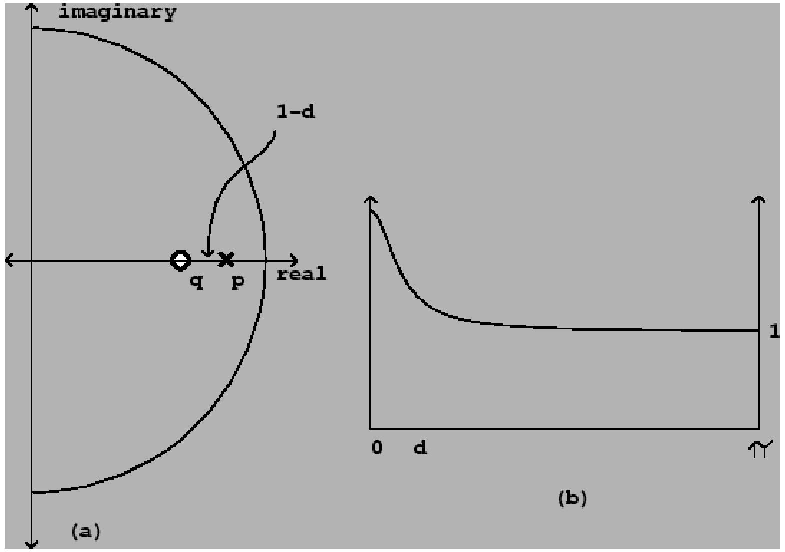
Using a parametric equalization methods (Välimäki), we will see gain, center frequency, and a quality factor. The feedback and ranges in the frequency are adjusted based on what filters need to be applied. Depending on the shifts and crossover frequency, the magnitude can become one, unified response following the application of filters. The following image shows the unification (Välimäki):



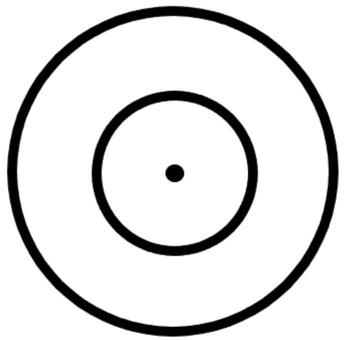


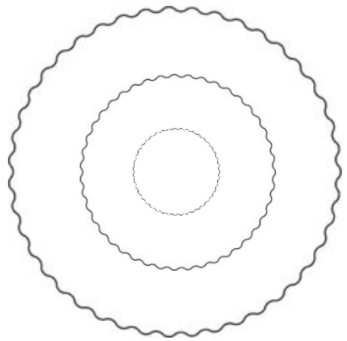
According to Välimäki [3] et al, “The term equalizer (EQ) has its origins in early telephone engineering, when high frequency losses over long distances had to be corrected so that the spectrum of the sound at the receiver matched the sound spectrum that was initially transmitted.”

According to Puckette [4], the usual application of filters to remove unwanted signals is done using a shelving filter. Shelving filters provide the ability to boost or lower frequencies above or lower a certain set point. A visualization is seen below (Puckette):



Concentric Shapes





According to Hahn [5], “We now consider the case of two circles C, and C2 that do not intersect each other. In this case we can map this pair of circles by a Mobius transformation to a pair of concentric circles having the origin of the w-plane as their center. But a ‘circle’ is orthogonal to a pair of concentric circles if and only if it is a line passing through the center of the concentric circles. Therefore, the image of the pencil of circles conjugate to C) and C2 must be the set of all ‘circles’ passing through the origin and the point at infinity in the w-plane.”

The mathematic explanation of concentric circles in practice given by Hahn explains how the geometry interacts with the regular, form objects involved in the engineering process (in this case, a regular circle) and gives us some insight into the processes behind the functions.

Danielle Garsten, CPE
Department of Electrical and Computer Engineering

- Focus on AI and MR
- Hoping to pursue Software Engineering
- Aspiring to pursue a Masters or PhD

Software Design & Approach

```python
# AUDIOVISIBLE - Waveform from Microphone - UCF 2020
import pyaudio
import struct
import matplotlib.pyplot as plt
import numpy as np
from scipy import signal

mic = pyaudio.PyAudio()

FORMAT = pyaudio.paInt16
CHANNELS = 1
RATE = 20000
CHUNK = int(RATE/20)

stream = mic.open(format=FORMAT, channels=CHANNELS, rate=RATE, input=True, output=True, frames

fig, ax = plt.subplots(figsize=(14,6))

ax.set_ylim(-200, 200)
ax.set_xlim(0, CHUNK)

x = np.arange(0, 2 * CHUNK, 2)
line, = ax.plot(x, np.random.rand(CHUNK))

while True:
    data = stream.read(CHUNK, exception_on_overflow=False)
    data = np.array(struct.unpack(str(2 * CHUNK) + 'B', data), dtype='b')[::2]
    # data = abs(data)
    line.set_ydata(data)
    fig.canvas.draw()
    fig.canvas.flush_events()
    plt.pause(0.005)
```

Software Approach

1. For the Python code to be able to get the Bluetooth signal from a phone
2. Be able to make a simple neural network with that signal
3. Make a simple visual on a computer
4. Be able to set up this code on the Raspberry Pi
5. Make sure the visuals are projecting alongside the music
6. Increase the complexity of the visual

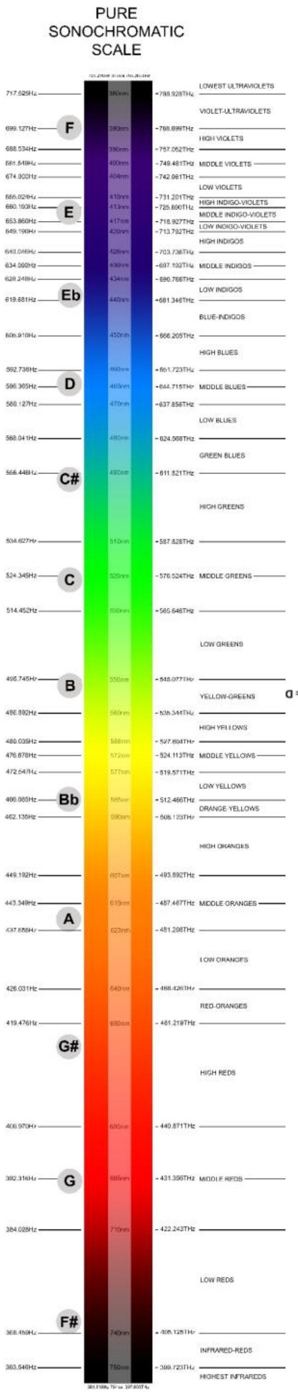
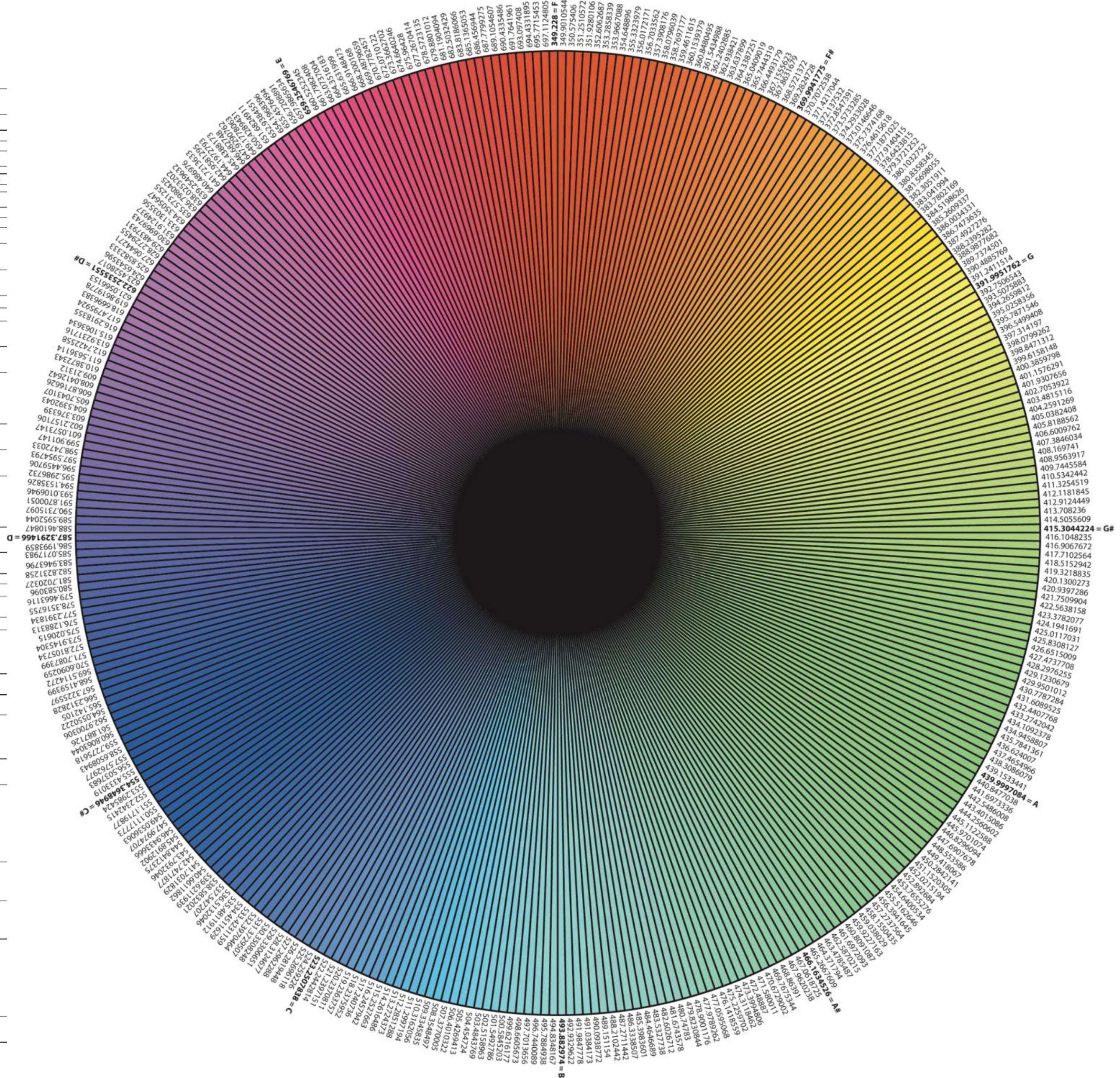
Software Design

- Our Python code will be able to read in a song played over Bluetooth.
- It will then detach components of it from beat to melody to pitch to customize the visual from shape to color to size.
- Then, the embedded piece will be able to allow the software to run in the hardware and for the optical module to operate under the Python code.

UX/UI

- It will include an on/off button
- The idea is that a user chooses a song to send and the visual will appear alongside the song
- Very simple UX

Sonochromatic Scale


PURE
SONOCHROMATIC
SCALE
F
E
Eb
D
C#
C
B
Bb
A
G#
G
F#
LOWEST ULTRAVIOLETS
VIOLET-ULTRAVIOLETS
HIGH VIOLETS
MIDDLE VIOLETS
LOW VIOLETS
HIGH INDIGO-VIOLETS
MIDDLE INDIGO-VIOLETS
LOW INDIGO-VIOLETS
HIGH INDIGOS
MIDDLE INDIGOS
LOW INDIGOS
BLUE-INDIGOS
HIGH BLUES
MIDDLE BLUES
LOW BLUES
GREEN BLUES
HIGH GREENS
MIDDLE GREENS
LOW GREENS
YELLOW-GREENS
HIGH YELLOWS
MIDDLE YELLOWS
LOW YELLOWS
ORANGE-YELLOWS
HIGH ORANGES
MIDDLE ORANGES
LOW ORANGES
RED-ORANGES
HIGH REDS
MIDDLE REDS
LOW REDS
INFRARED-REDS
HIGHEST INFRAREDS

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Budget and Finance

Item	Qty	Vendor	Amount
PCB Board Kit	3	OSHPark	$20
DLP LightCrafter Display 2000 EVM	1	Texas Instrument	$99
DLP Display Controller	1	Texas Instrument	$17
Raspberry Pi 4	1		$55
DLP 0.2 nHD DMD	1	Texas Instrument	$27
Audio Speaker (4ohm)	1	SkyCraft	$2
PMIC/LED driver	1	Texas Instrument	$2
Semiconductor Laser Diode	3	CivilLaser	$65
MSP430 Launchpad Dev. kit	1	Texas Instrument	$10
Projector Screen	1	eBay	$14
Total Donations	1	BEAM Engineering Co.	($100)
		Subtotal	$211
		Initial Budget	$500
		Budget Available	$289

Completed Tasks

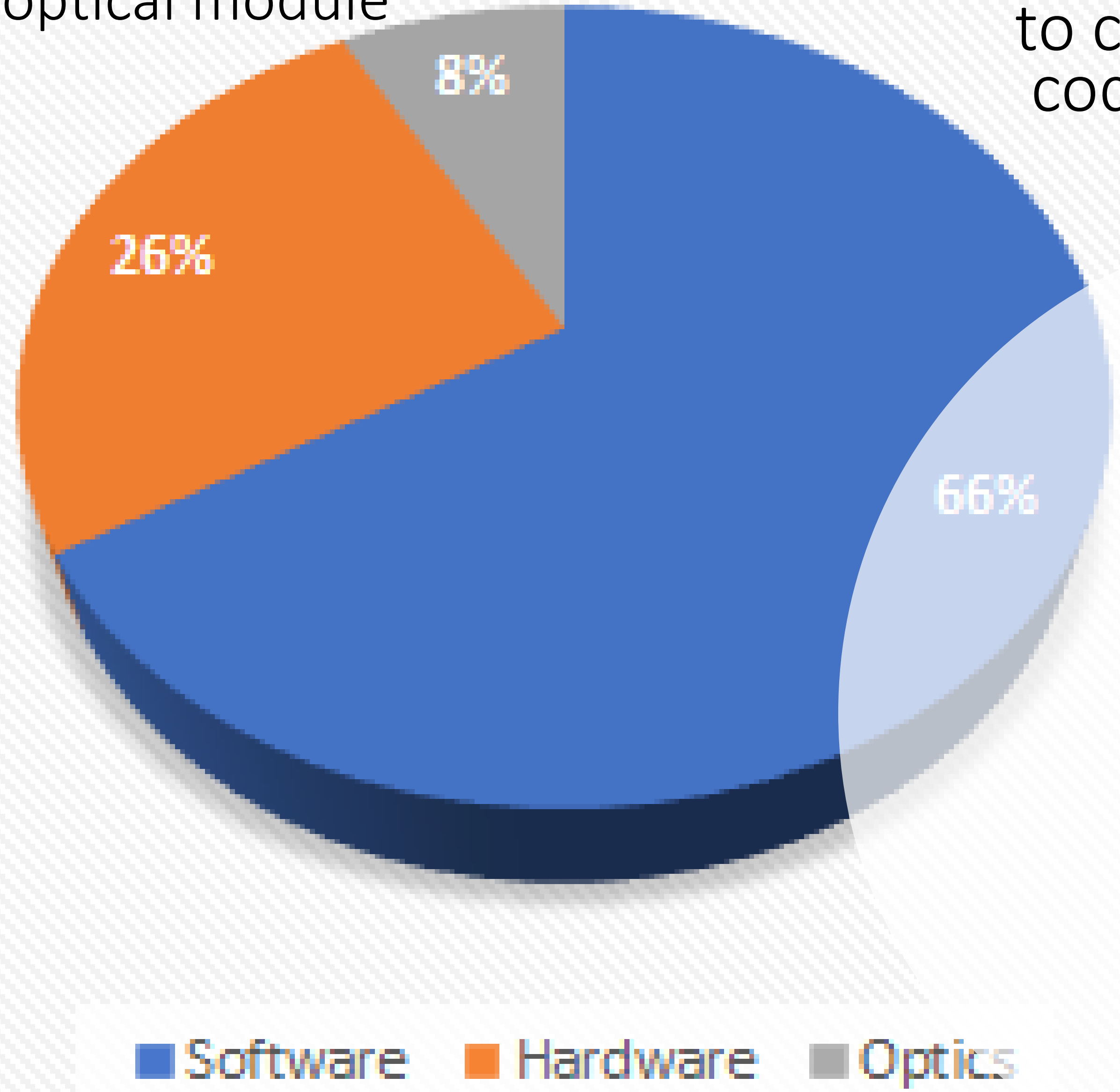
- Gathered all the parts
- Planned the hardware outline
- Left a guideline for the Software parts, both the Python and the embedded aspects
- Optical assembly is mostly completed

Need to be Completed

For Optics, we need to assemble the diodes to the optical module

For software, we need to complete the python code and embedded C code

For hardware, we are mostly complete with the PCB, just making minor adjustments



Successes & Difficulties

Successes

- Planning and getting ahead
- Being able to communicate in a professional manner
- Respect
- Bluntness
- Scheduled meetings

Difficulties

- Lack of time
- Coordinating meetings sometimes
- Recursive mistakes, mostly on the thesis

Plans for Success