Animatronics
Electronic Hardware Document

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OVERVIEW.

This document describes the electronics used in the Animatronic Head ("Head") project. There are two distinct electronic subsystems:

- Brain/Eyes Subsystem.
- Mouth Subsystem.

Each subsystem has its own microcontroller (Particle[1] Photon 1) and electronic connections. The two subsystems communicate with each other using Particle's cloud-based publish and subscribe mechanism, as shown in figure 1, below.

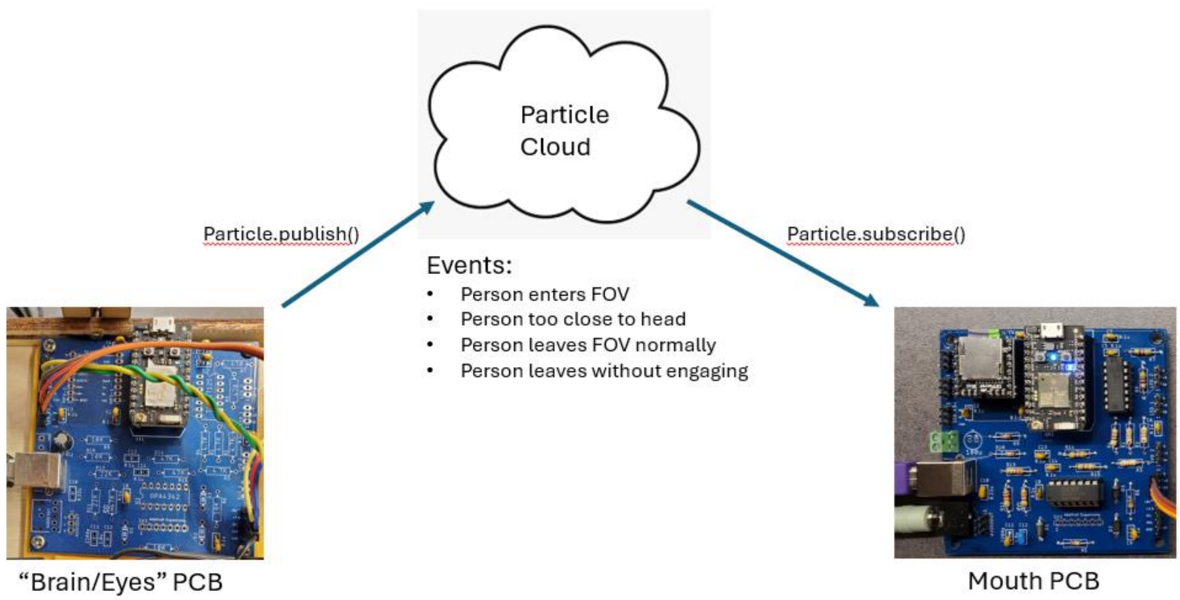

Figure 1. Publish and Subscribe.

The "Brain/Eyes" subsystem connects to an 8x8 time-of-flight (TOF) optical distance sensor and to a multi-servo control module. The latter controls the 6 servos of the eyes assembly. The Photon 1 microcontroller acts responsively to control the eyes position based upon real-time data from the TOF sensor.

In addition to controlling the eyes position when someone is interacting with the Head, the "Brain/Eyes" subsystem detects various significant events and publishes these to the Particle Cloud.   The currently implemented events are:

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[1] Particle.io

- *Person enters FOV*: The TOF sensor data indicates that someone has entered the field of view (FOV) of the sensor and is thus in a position to interact with the Head.
- *Person too close*: The TOF sensor data indicates that someone has moved too close to the Head.
- *Person leaves FOV normally*: The TOF sensor data indicates that the sensor FOV has cleared – the engagement with the Head is over.
- *Person leaves FOV quickly after arriving:* The TOF sensor data indicates that the sensor FOV has cleared after only a very short time from the person arriving.

The “Mouth” subsystem responds to events published by the “Brain/Eyes” subsystem and plays an appropriate audio clip through a small loudspeaker. The Mouth subsystem electronics contains analog signal processing circuity that processes the audio in real time to extract the “envelope” of the clip being played. This “envelope” information is further processed in Photon 1 software to drive the mouth servo in accordance with the audio being played.

A single printed circuit board has been created that is used both for the “Brain/Eyes” subsystem and for the “Mouth” subsystem. The two boards are populated differently for each of these subsystems.

CUSTOM ELECTRONICS PCB.

The schematic for the electronics printed circuit board (PCB) is shown in figure 2, below. This PCB is used both for the “Brain/Eyes” electronics and for the “Mouth” electronics. All of the electronic components are soldered to this PCB for the “Mouth” electronics board. Only a few of the parts need to soldered to this PCB for the “Brain/Eyes” electronics board. The complete wiring for the “Brain/Eyes” and the “Mouth” electronics are covered in their individual sections of this document.

Cadsoft Eagle CAD schematic, board, and manufacturing files can be found at:

https://github.com/TeamPracticalProjects/Animatronics/tree/main/Hardware/Eagle_Files

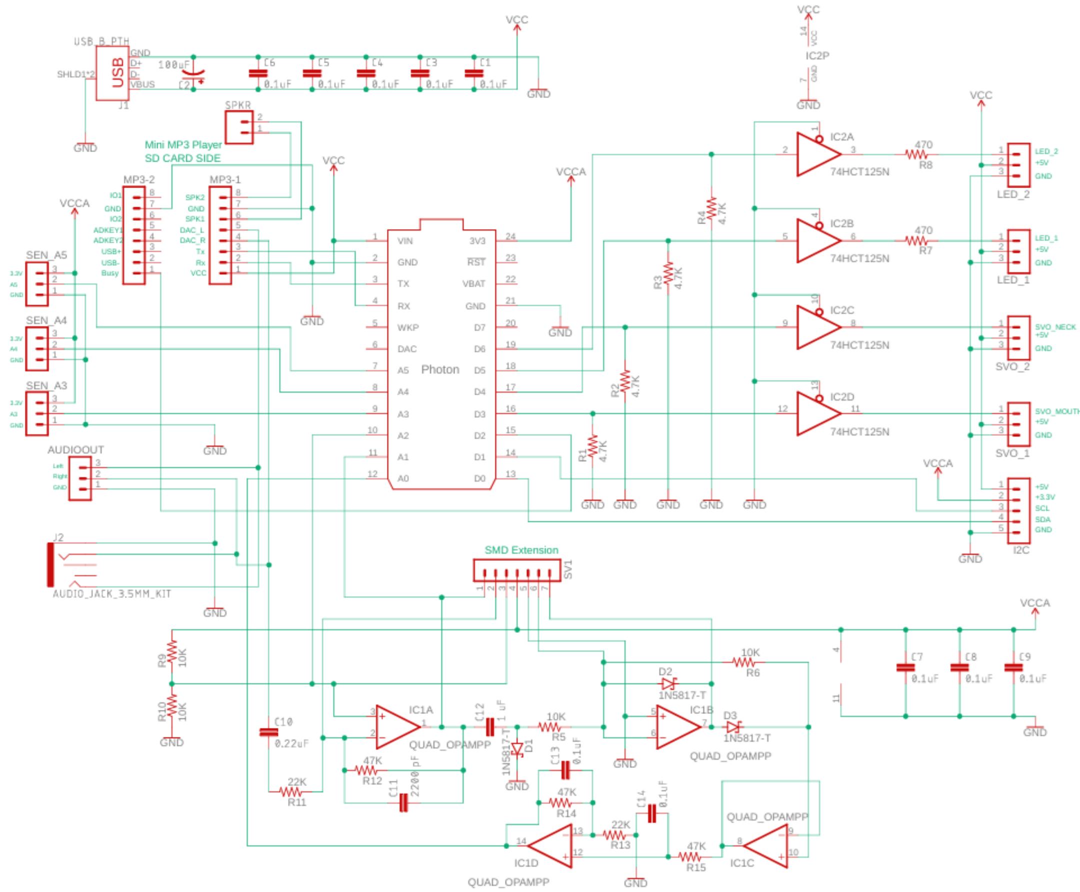

Figure 2. PCB Schematic

Referring the figure 2, the following are the major components on the PCB:

- **<u>Particle Photon 1</u>**. The Photon 1 is the "brains" of the electronics. The software for the Photon 1 can be found in this repository in the folder:

  https://github.com/TeamPracticalProjects/Animatronics/tree/main/Software/Photonfirmware

  The individual items of software are further described in the relevant "Software" documents in the Documents folder of this repository.

  Note that the Photon 1 is currently deprecated. The replacement, Particle Photon 2, is not pin compatible with the Photon 1. Particle sells an adaptor socket that allows a Photon 2 to be accommodated on a board that is designed for a Photon 1:

https://store.particle.io/products/particle-classic-adapter?srsltid=AfmBOooA5hZbtwsB7mYCM3gqoPMlcJ_P1wz3NHvkU10b8lzNYw7uXzgn

In theory, this adapter should allow a Photon 2 to be used on this project. Some pin names may need to be redefined in the software. ***WARNING – we have not tested this and we cannot guarantee either the mechanical fit or the software compatibility if this adapter is used to host a Photon 2 on this project.***

- **Mini MP3 Player**: A DFRobot DFMini MP3 Player module is used to play MP3 formatted sound clips through an external loudspeaker. Pin headers MP3-1 and MP3-2 are used to mount this module to the PCB. NOTE: Online shopping sites offer modules that are purported to be compatible with this module, but we have found that they are not. We strongly suggest using only this module:

  https://www.dfrobot.com/product-1121.html?gad_source=1&gad_campaignid=22392107167&gbraid=0AAAADucPlBMshy5JabdRZz3OzbcjzzS0&gclid=Cj0KCQiAosrJBhD0ARIsAHebCNpf6yC_KutWZjksd8tAMd5SS47LaIrAIc-Uc2D_7pov67EAQUBde-IaAsblEALw_wcB

  The Mini MP3 Player accepts a micro SD card (up to 32 GB) that holds the MP3 files to be played.

- **Quad Op-Amp (IC1) and Associated Electronic Components**: An OPA4342 Quad op-amp forms the heart of the analog signal processing circuitry. This device was chosen for the following characteristics:
  - It is single supply, rail to rail, low voltage capable.
  - It offers FET input, very high impedance.
  - It is low cost.
  - It has a 1 MHz bandwidth – much more than needed for audio applications.
  - It is available in DIP package format.

  The last point is significant, as the PCB is designed for through-hole soldering. However, it may be difficult to find small quantities of this part in DIP packaging. Surface mount package versions may be used with the following adapter breakout board:

  https://www.adafruit.com/product/1210

  In order to use this adapter on the PCB, solder a 7 pin female header to the top row of pins of IC1 and solder another 7 pin female header to the SMD Extension pin header field. You will need to solder the surface mount IC to the Adafruit adapter board and solder male pin headers to this board as well. The resulting "breakout board" can then be plugged into these female pin headers, in place of the 14 pin DIP IC.

- **<u>74HCT125 IC (IC2)</u>**: This quad, non-inverting bus driver is used as a 3.3 volt to 5 volt level shifter. Two of the outputs have current limiting resistors on the board and are intended to directly drive LEDs. The other two outputs do not have current limiting resistors and are intended to drive 5 volt servos.

- **<u>Connectors</u>**: A USB-B connector is used to supply 5 volt power to the PCB. An audio phone jack is available to connect stereo amplified speakers to the PCB, in lieu of connecting a small 8 ohm speaker directly to the PCB. The "SPKR" 2 position terminal block is used to connect a small loudspeaker (8 ohms) directly to the PCB for monaural playing of audio clips. Male pin headers are used for all other external connections to the PCB, as indicated In the relevant sections of this document, below.

"BRAIN/EYES" SUBSYSTEM ELECTRONICS.

Figure 3 is a block diagram of the "Brain/Eyes" electronics subsystem. The subsystem consists of a multi-channel servo board, a TOF sensor and the custom PCB that is configured for this application. There is also a potentiometer (Pot) and a pushbutton that are used for calibrating the 6 servo eye mechanism.

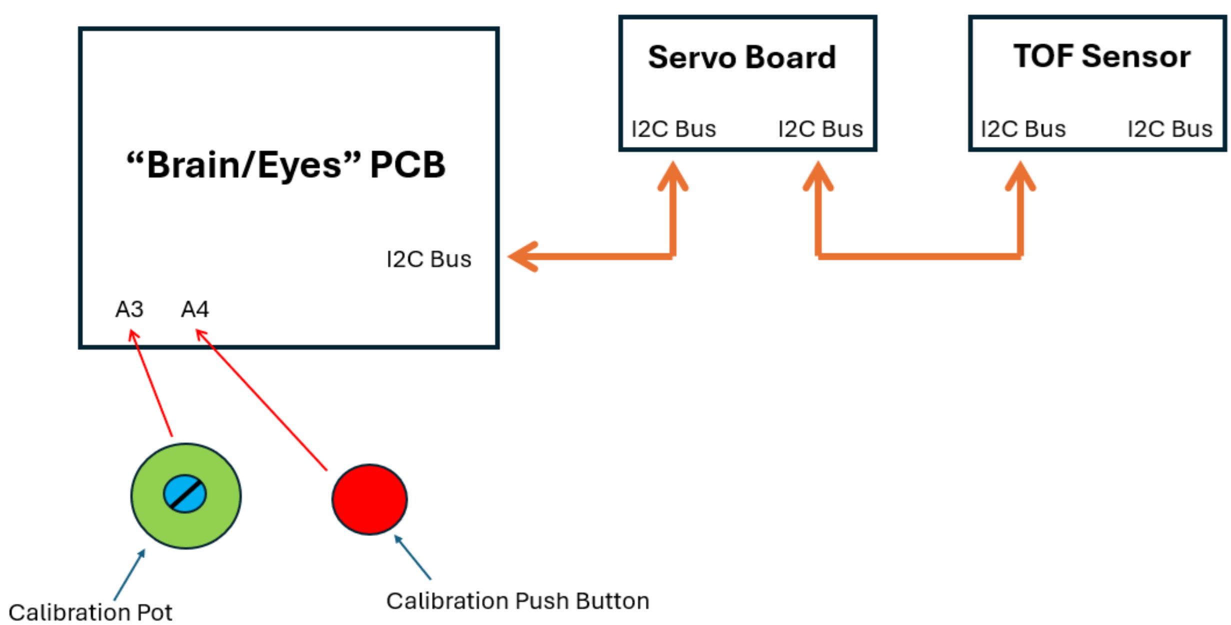

Figure 3. Brain/Eyes Electronics.

The custom PCB connects to multi-channel servo board via the I2C bus pins on the PCB. The I2C bus is chained through the servo board and on to the TOF sensor board.

The calibration Pot is connected to the PCB using the A3 pin header field and the pushbutton is connected using the A4 pin header field.

"Brain/Eyes" PCB.

Figure 4, below, shows the assembled PCB.

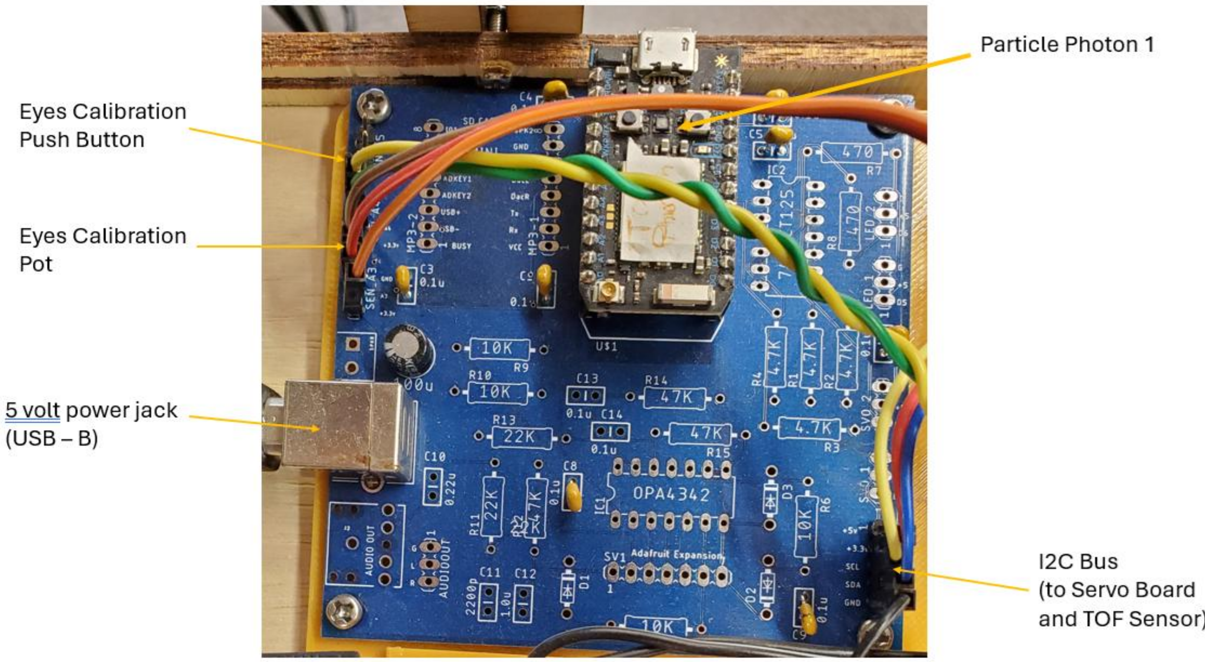

Figure 4. "Brain/Eyes PCB.

Only the following parts need to be loaded onto the PCB in this application:

- Particle Photon 1 (using female pin headers for mounting).
- USB-B power jack.
- Male pin headers on A3, A4, and the I2C connector fields.
- One 100uF power filtering capacitor (C2).
- Seven 0.1 uF decoupling capacitors (C1, C3, C4, C5, C6, C7, C8)

There are two sets of software that need to be flashed onto the Photon 1:

- Eyes calibration software, see: https://github.com/TeamPracticalProjects/Animatronics/tree/main/Software/Photonfirmware/AnimatronicEyesCalibration

- Brain/Eyes firmware, see: https://github.com/TeamPracticalProjects/Animatronics/tree/main/Software/Photonfirmware/AnimatronicEyesTest

See the "Brain Software Document" and the "Eyes Software Document" for details.

Multi-Channel Servo Board.

The Eyes mechanism uses six hobby servos. In order to drive this many servos, an Adafruit 16 channel, 12 bit PWM/servo driver board is used; see:

https://www.adafruit.com/product/815

This board as a 3.3 volt IC2 bus pass-through. It can be used to drive up to 16 servos. The first 6 servo connections are used.

TOF Sensor.

The TOF sensor is a Sparkfun Qwicc Mini Tof Imager module, see:

https://www.sparkfun.com/sparkfun-qwiic-mini-tof-imager-vl53l5cx.html

It is based on an STMicroelectronics VL53L5CX 8x8 pixel Time of Flight (TOF) image array. The module connects using 3.3 volt I2C and Qwicc connectors.

Calibration Pot and Push Button.

The six servos of the Eye mechanism need to be calibrated after the Head is assembled. Special calibration software is used for this purpose. A 10 K linear potentiometer is used to manually calibrate each servo in turn. A push button switch is used to tell the calibration firmware when a pot setting is correct and should be accepted for that servo. Any momentary pushbutton can be used. We used the following part:

https://www.adafruit.com/product/1439

"MOUTH" SUBSYSTEM ELECTRONICS.

Figure 5 is a block diagram of the "Mouth" electronics subsystem. The subsystem consists of a single Servo and a small loudspeaker. There is also a green LED that lights when the mouth is active, i.e. playing a clip. A red backlit push button is provided to mute the mouth, e.g. when showing off the Head. The red backlit is lit when the mouth is muted.

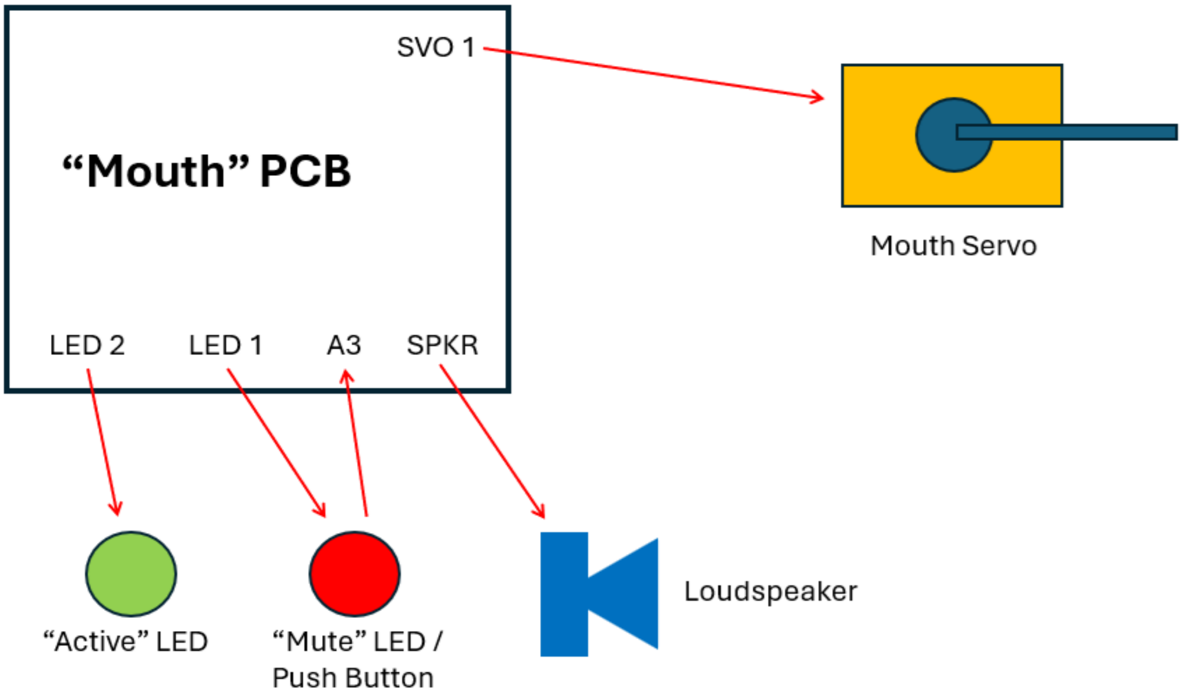

Figure 5. "Mouth" Electronics.

The servo is connected to the SVO-1 pin header connection field on the PCB. SVO-2 and the IC2 bus connector fields are not used in this application of the PCB.

The red push button contacts are connected to the A3 pin header connection field on the PCB and the red backlight is connected to the LED-1 pin header connection field on the PCB. The green LED is connected to the LED-2 pin header connection field on the PCB.

Pin header connection fields A4 and A5 may optionally be jumpered (to GND) to designate one of 4 "personalities". A "personality" is a set of audio clips that are stored on the mini MP3 Player SD card that are to be used when interacting with the Head.

"Mouth" PCB.

Figure 6, below, shows the assembled "Mouth" PCB. Essentially all of the parts are needed for this application.

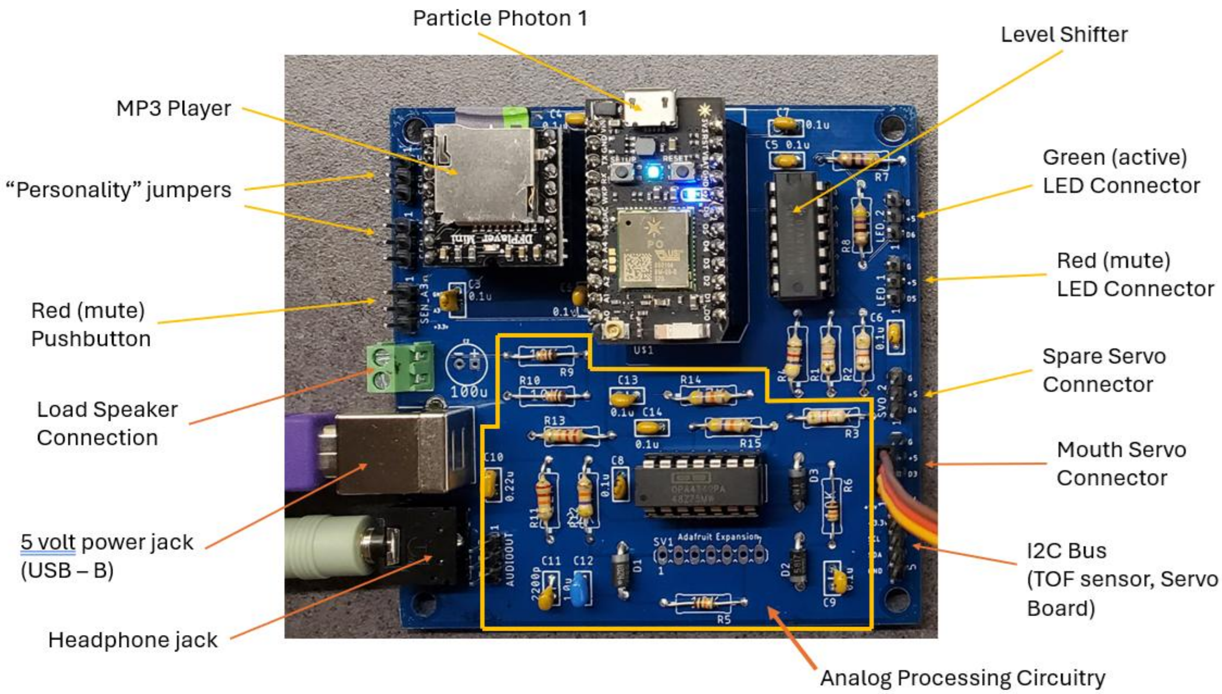

Figure 6. "Mouth" PCB.

Figure 6 also indicates the major components on the board and what is connected to each of the pin header connection fields on the board.

Note that the mini MP3 Player can directly drive a small, 8 ohm loudspeaker. This loudspeaker is connected to the 2 position terminal strip on the PCB. Alternatively, the loudspeaker can be left off and the audio stereo phone jack used to connect amplified audio speakers to the PCB. The phone jack output is for small signals only; headphones or amplified speakers are needed.

The software that is flashed onto the Photon 1 on the "Mouth" PCB is:

https://github.com/TeamPracticalProjects/Animatronics/tree/main/Software/Photonfirmware/AnimatronicMouthDemo

See the "Mouth Software Document" for details.

Mouth Servo.

The "Mouth" electronics can accommodate any standard 5 volt hobby servo. We chose to use a servo with metal gears and slightly more torque than the cheapest models because our mouth mechanism has a bit of weight on a lever arm that is several inches long and not counterweighted.

Mute Backlit Push Button.

We chose the following backlit red push button for the mute functionality:

https://www.adafruit.com/product/1439

Active LED.

We chose the following backlit green push button for the active indicator:

https://www.adafruit.com/product/1440

The push button is not used; only the backlit green LED is wired up.

Loudspeaker.

Any generic small 8 ohm loudspeaker may be connected to the "Mouth" PCB via the terminal strip. The 3D printed mount can accommodate a 1-1/4" diameter loudspeaker, but any 8 ohm speaker will do.

ANALOG PROCESSING THEORY OF OPERATION.

The "Mouth" PCB has analog signal processing circuitry. The purpose of this circuitry is to extract the "envelope" of the sound clip being played. The "envelope" is the amplitude modulation of the voice. The analog signal processing is basically AM demodulation.

The left channel of the headphone stereo output of the mini MP3 player is capacitively coupled into this circuitry. The amplitude of this signal is a little over 1 volt peak to peak when the mini MP3 player is playing at optimum volume.

The analog signal processing circuitry has been designed so that it may be used for other applications in the future. The circuit can be used with a microphone or other audio device by removing the mini MP3 player from its header socket and inserting a custom designed breakout board in its place. Any such alternative audio input should supply a headphone compatible audio signal with a peak-peak voltage of less than 1.5 volts.

Figure 7 is a block diagram of this circuit.

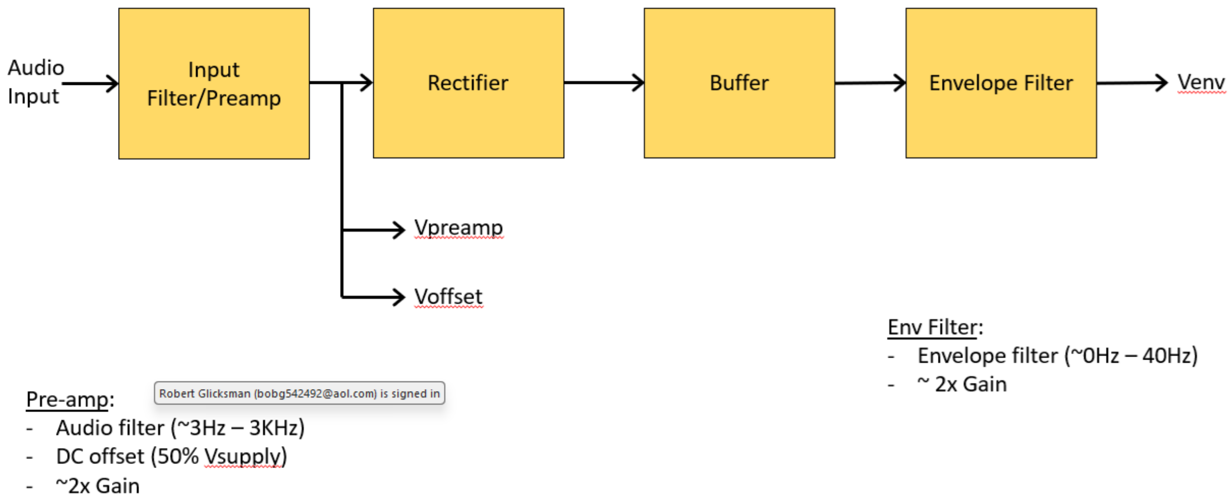

Figure 7. Analog Signal Processing Block Diagram.

The audio input from the mini MP3 player is fed through a pre-amplifier. The pre-amplifier has three functions:

- Offset the capacitively coupled audio signal by approximately +1.65 volts so that the signal is in the range of the single ended 3.3 volt power supply to this circuit.

- Provide a gain of 2 to the signal, so that the peak-peak voltage output is slightly less than 3.3 volts (for compatibility with the Photon 1 A/D converter).

- Band limit the audio signal to about 3 KHz; i.e. "telephone" signal quality.

The pre-amplifier uses one of the 4 op amps in the OPA4342 device.

The output of the pre-amplifier is fed directly into analog channel A1 of the Photon 1. The offset voltage, provided by R9 and R10, is fed directly into analog channer A2 of the Photon 1. These two analog inputs may be used by the Photon 1 software for any digital signal processing purpose. The signal is band-limited and can be sampled at 8 K samples per second (125 microseconds per sample); e.g. slightly higher than the Nyquist rate and compatible with digital audio telephone standards. *NOTE: these inputs to the Photon 1 are not used in this project; they are provided for possible use on future projects*.

The output of the pre-amplifier is capacitively coupled to the rest of the circuitry in order to remove the DC offset. The signal is clamped to be negative (below ground) and then fed through an inverting, idealized half wave rectifier. The resulting signal is positive (with respect to ground) and is half of the voice modulated signal.

The rectified signal is buffered and then filtered to remove the "carrier", leaving the envelope of the signal to input to the Photon A0 analog input. A 2 pole filter with a bandwidth of approximately 40 Hz is used. The 40 Hz bandwidth was experimentally determined to contain most of the amplitude information in the signal while sufficiently removing the carrier, even for a speaker with a bass voice.

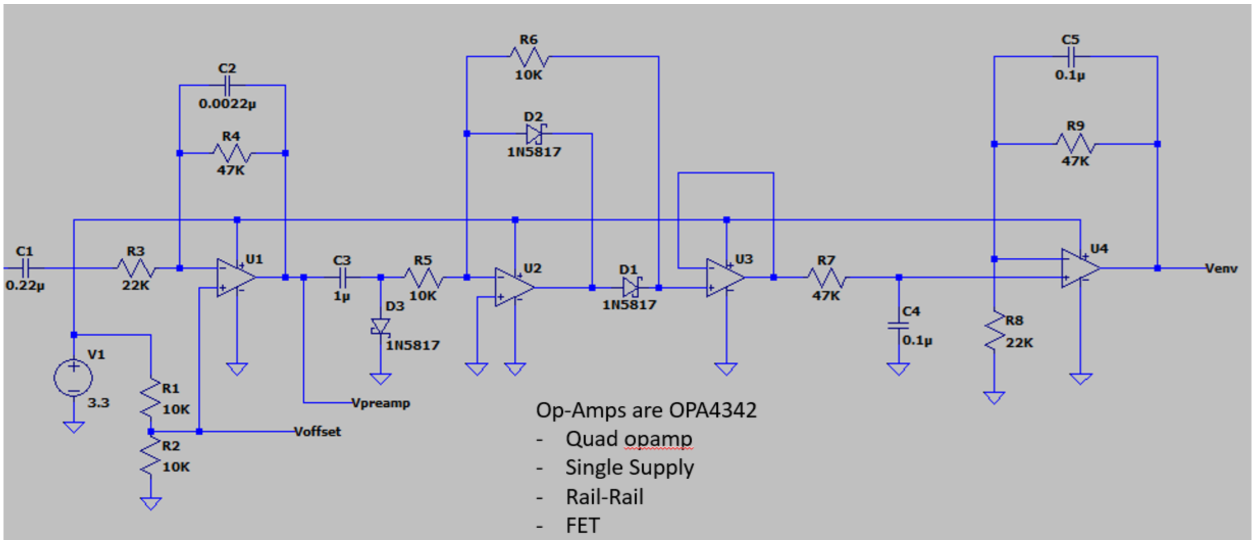

Figure 8. LTSpice Schematic for Simulation.

The analog signal processing circuit was simulated in LTSpice in order to experiment with the design and the overall design parameters. The LTSpice circuit used for the simulation is shown in figure 8. This is the same circuit that is on the PCB.

The simulation results are documented in a PowerPoint slide deck:

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Analog_Processor_V2_Analysis.pptx

The slide deck contains frequency/phase analysis of the pre-amplifier and of the envelope outputs of this circuit. The slide deck also contains time-domain (oscilloscope – like) results of feeding various types of test and simulated signals through the LTSpice simulation. The simulated inputs are .wav files produced from on-line signal generating software and also from actual voice recordings of real spoken sound clips. The .wav files themselves can be found in:

https://github.com/TeamPracticalProjects/Animatronics/tree/main/Data