Audio Pitch Shifting and Transmission through Optical Fiber

6.101 Final Project
Emmanuel Havugimana and Wings Yeung
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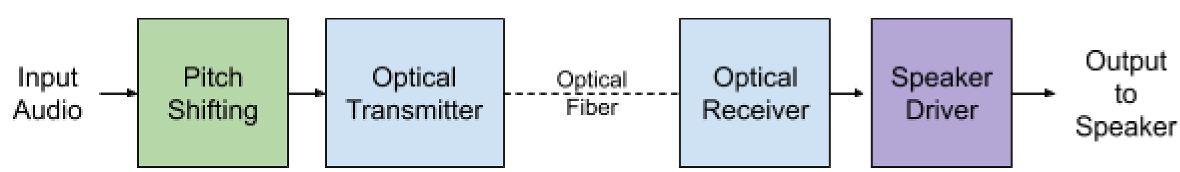
Introduction

In this project, we wanted to play with music and optics. The goal of this project was to shift an incoming audio, pass the shifted signal through an optical fiber, and then play the audio through a speaker. In addition, we wanted to explore PCB design and create a PCB for a certain part of the circuit. However, complications arose (which will be discussed in the report), and we were unable to create a PCB of our design in time.

This report describes the design choices and complications made. The completed system was all done on breadboards and can shift incoming pure tones up by one octave. The incoming audio either comes from a local oscillator or an external source such as a phone. The shifted audio then goes through the optical fiber and then to the speaker with negligible perceivable noise.

Block Diagram (Wings)



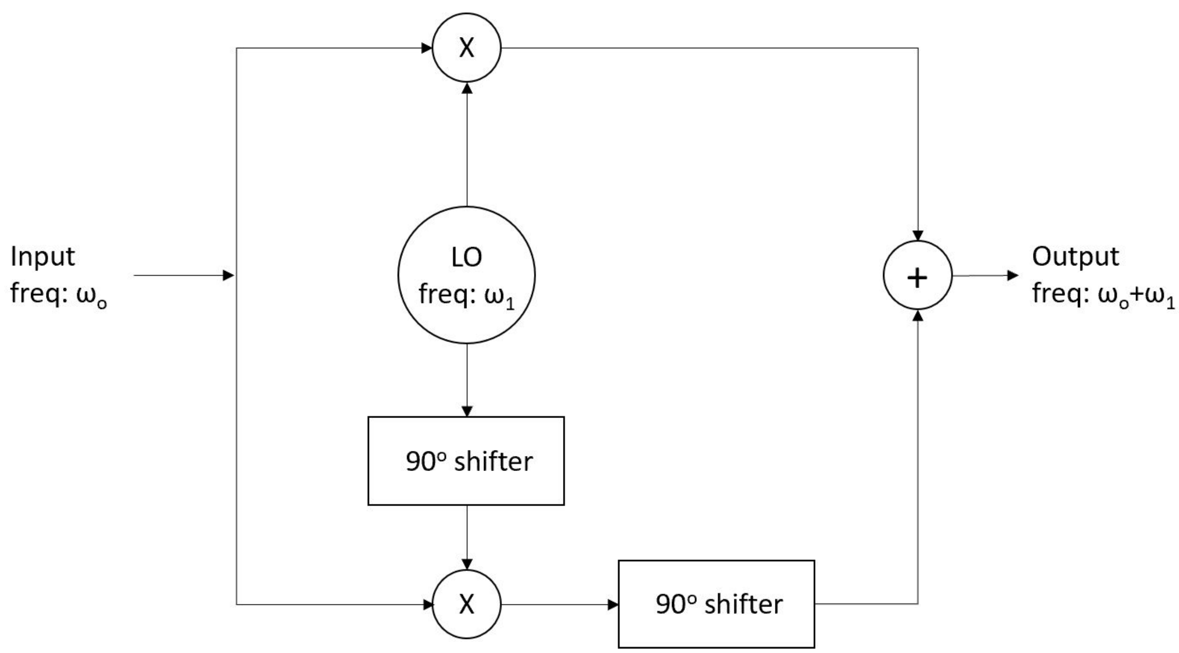
There are three main discrete components in our design. The first, highlighted in green is the pitch shifter. The second, in blue, is the optical components which include a transmitter and receiver connected by an optical fiber. The third, in purple, is the speaker driver to ensure the speaker is driven by enough current to produce sound.

The pitch shifting and optical transmitter can operate independently from the optical receiver and speaker driver. Therefore, they can operate on independent voltage sources and do not need to share a common ground.

Pitch Shifting (Wings)

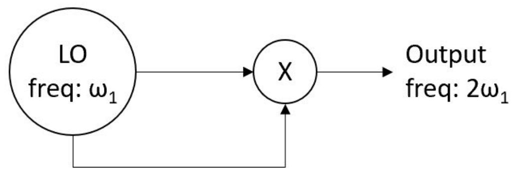
Pitch is related to the frequency of the signal, and by changing the frequency, the pitch of the signal can be changed. The most basic way to alter a signal's frequency is by multiplying the original signal with another frequency. However, multiplying two frequencies outputs the sum and the difference of the frequencies. When not properly accounted for, this will create a noisy output. For example, when mixing a 2 kHz and 5 kHz sine wave, the output will have 7 kHz and 3 kHz components.

To avoid this problem, we attempted to create a single sideband mixer. A single sideband mixer will multiply two frequencies and select either the sum or difference of the two frequencies. A single sideband mixer can be implemented with a local oscillator that can create the cosine and sine of a singular frequency, multiplier, and a 90° phase shifter.



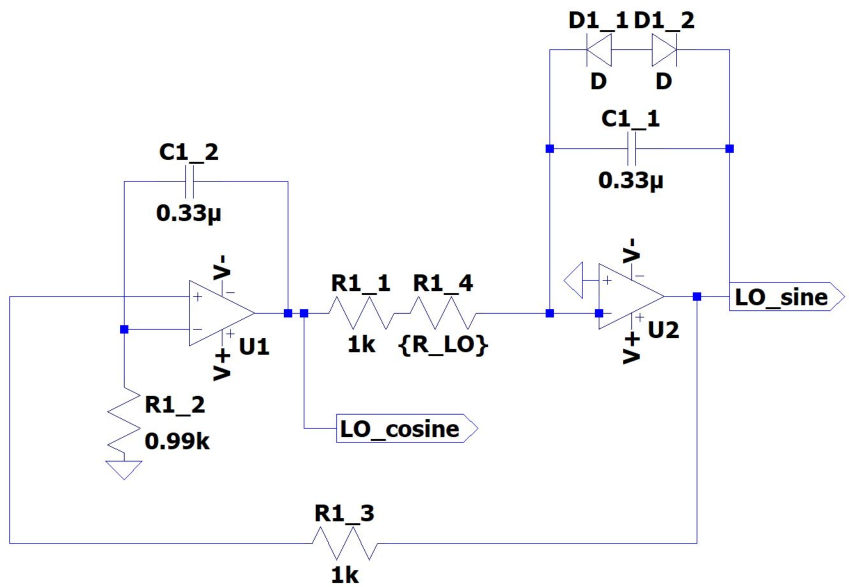
However, even after creating the circuit for the topology above, our single-sideband mixer was unsuccessful and both the sum and difference of the two frequencies still propagated to the output. Therefore, to avoid this program and narrow the scope of our project, we decided to focus on pure tone frequency doubling. Effectively, this shifts an incoming audio up by an octave. When multiplying a frequency by itself, you end up with the sum (so double the frequency) and the difference which has a frequency of 0. Therefore, you only hear the summed frequencies.

To do this, we repurposed two main modules from the single sideband mixer: the local oscillator (as the incoming audio source) and the multiplier. The block diagram of our new pitch shifter is shown below.



Local Oscillator: Wein Bridge Oscillator

To create the local oscillator, we decided to build the Wein Bridge Oscillator. This gives us the benefit of creating both the sine and cosine of a frequency at the same time.

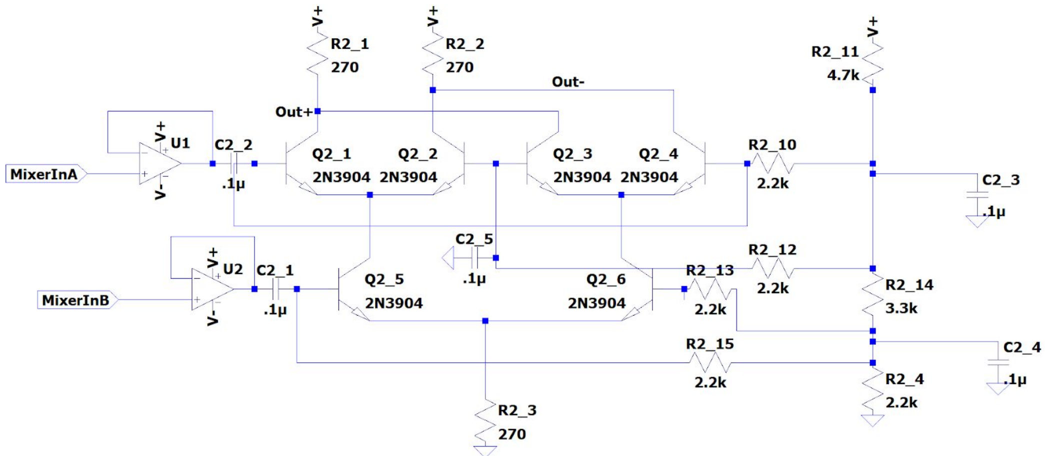


The frequency is determined by the capacitors and resistors in the circuit. Since we wanted to have the ability to change the incoming audio's frequency easily, we implemented a 10kΩ potentiometer (denoted as R1_4) in series with R1_1. With these values, the local oscillator was capable of creating sine waves from 5 kHz to 200 Hz. However, by tweaking the resistor and capacitor values, we can achieve the full range of audio frequencies.

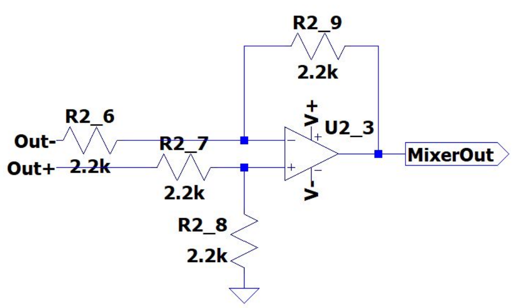
The sine output was 5 Vpp while the osine output was 390 mVpp. The multiplier created worked best at input values of 200 mVpp. Therefore, we implemented inverting gain op-amp to decrease the outputs to roughly 200 mVpp.

Multiplier: Gilbert Cell

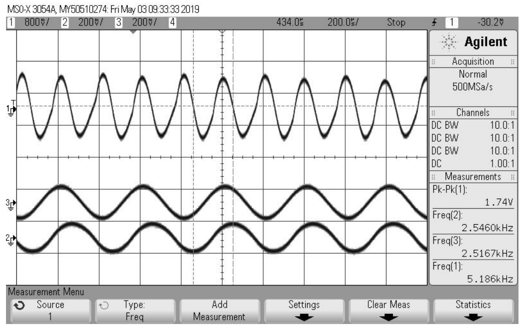
The multiplier used was a gilbert cell. However, we had to figure out the correct bias for the transistors in the Gilbert cell (which was done in simulation).



The Gilbert Cell creates two outputs (denoted as Out+ and Out-), and the difference between the two is the multiplied output. In order to obtain the proper output, we created a differential op-amp circuit shown below.



The figure below is a oscilloscope shot demonstrating the mixer's functionality. The two 2.5 kHz sine wave at the bottom is the incoming inputs to the mixer. The 5 kHz waveform is our output. Looking at the final waveform, the peaks of the sine wave are not uniform and tend to oscillate slightly. This is due to the transistors in the mixer circuit. When choosing the transistors, we attempted to find transistors with similar $\square_{FE}$ values. By doing so, we were able to make the difference much smaller. However, to further eliminate this variation, we could use super-matched transistor pairs.

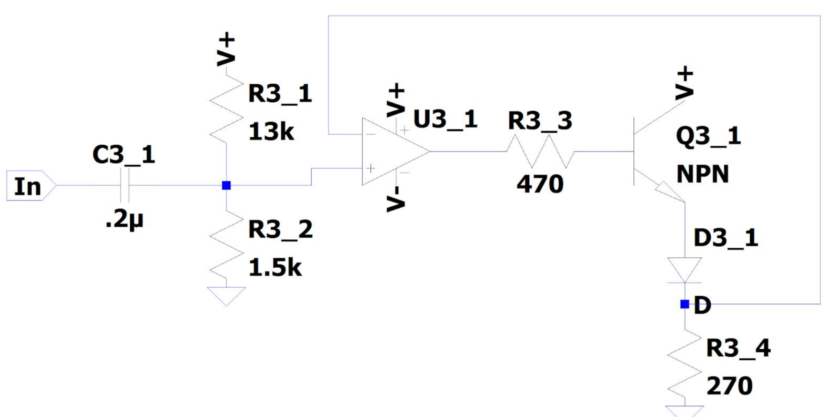


When testing, this multiplier works when mixing 20 kHz to 200 Hz signals with itself. However, there is a decay in the output waveform at 2kHz. This is due to the multiple capacitors and resistors in the Gilbert cell, which could have caused a high pass filter, therefore attenuating signals with a lower frequencies. In addition, the mixer also works when mixing two different frequencies.

Optical Components (Emmanuel)

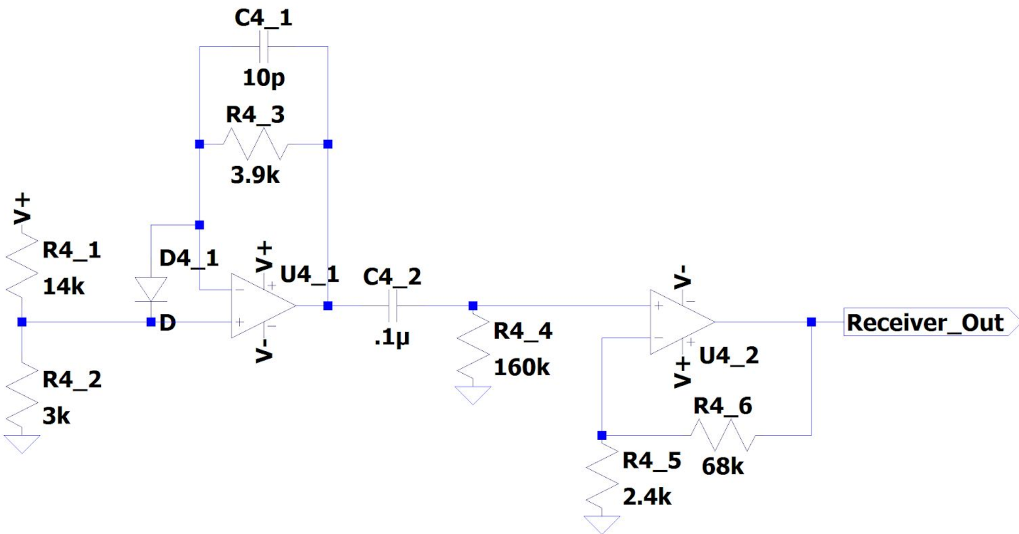
Transmitter

The optical transmitter was modeled as an LED. Unlike previous teams who have worked with the transmitter in the past, we chose to send baseband signals instead of first frequency modulating our signal. This greatly simplified our design from other teams, and even when doing so, we did not perceive distortion when simply sending the baseband signal over the optical transmission medium. Previous team have worked with optical fibers before, so we were able to use their work and made an optical transmitter. [5 , P.15]



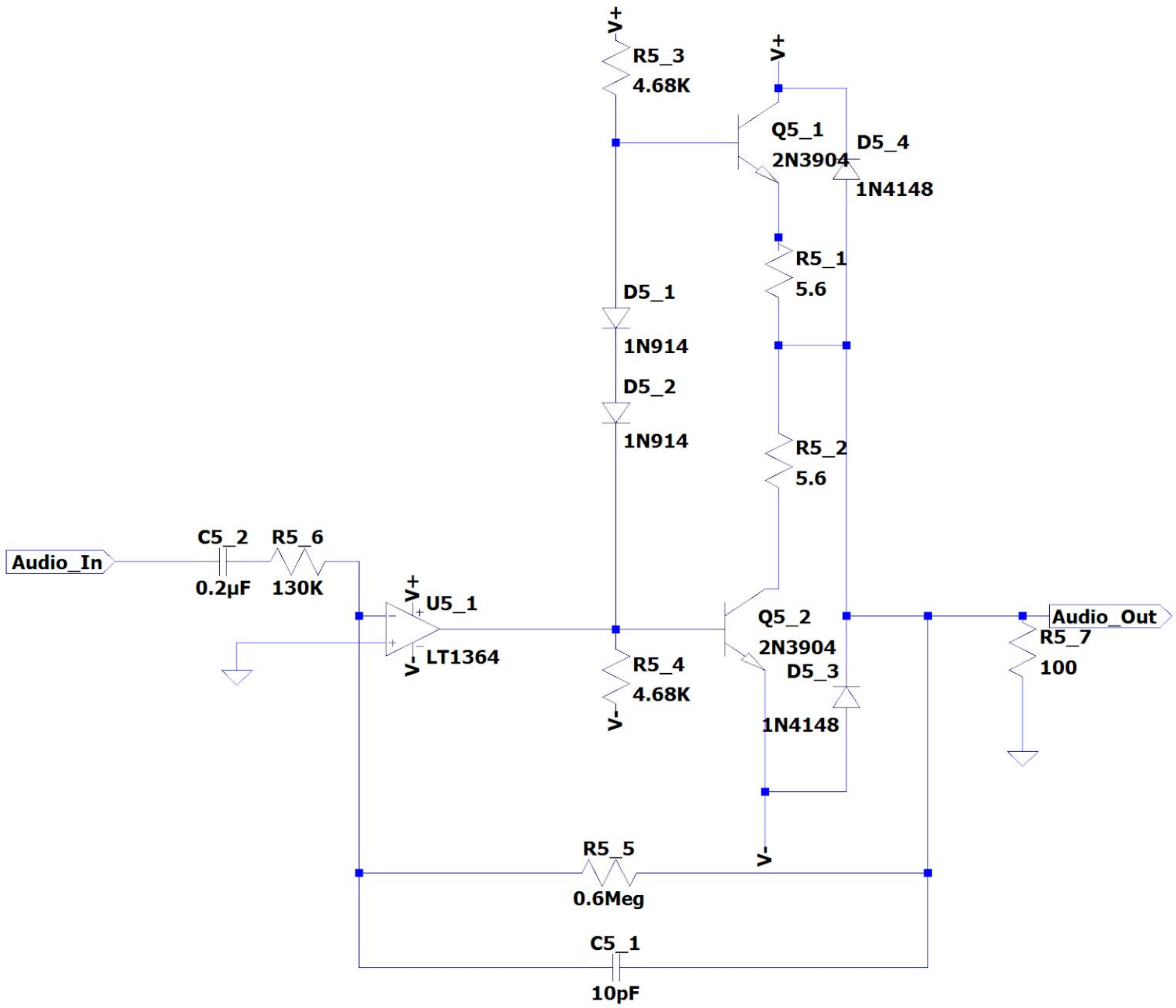
Optical Receiver (Emmanuel)

The optical receiver can be modeled as a photodiode, and we build a transimpedance amplifier. After the optical receiver, we added a high pass filter to get rid of the DC signal offset and a gain stage to level up the output voltage to replicate the magnitude of the input voltage to the optical transmitter. By doing so, we are able to approximate the optical transmitter and receiver as a wire. Therefore, adding the optical components in between the pitch shifter and the speaker driver negligibly alters the output. [ref 5, Page 16-17]



Speaker driver (Emmanuel)

We used lab 5 speaker driver to test our pitch shifting circuit. We did almost no innovation on this as we deemed it good for the purpose. The speaker driver operates as an AB amplifier. The biasing make the crossover distortion small.



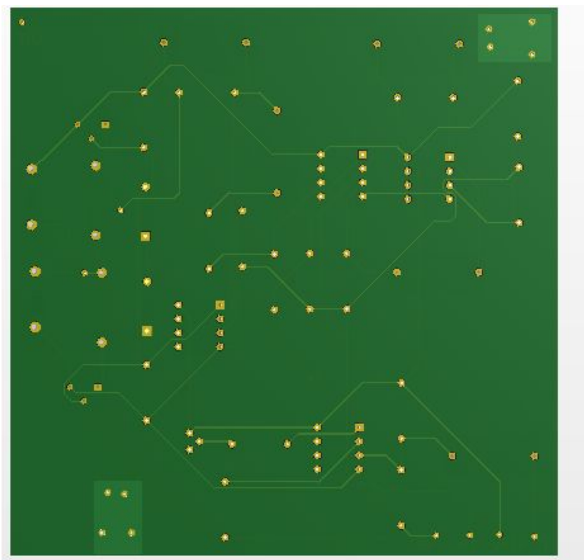
PCB Design and Ordering (Emmanuel and Wings)

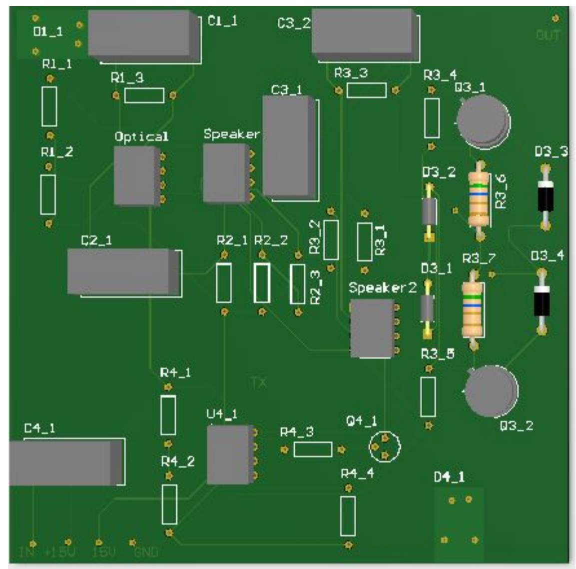
We were able to make and order PCB for optical transmitter, receiver and speaker driver subsystems, but we were not able to get it in time for class presentations. We currently attribute the lateness of PCB to both our limited experience with PCB design and ordering, and it seems like the **May day holiday in China** shaved away 3 days from our expected delivery time. When ordering the PCB design, the gerber files we created and sent were not complete, and therefore, we had to redo it. While this further delayed our PCB arrival date, it was a good learning experience. The PCB was not critical to the functionality of our design and the goal was to learn how to design the pcb board and ordering. We think that we were able to achieve that.

Companies we worked with are **Smart Prototyping** [2]and **JLCPCB(Shenzhen JLC Electronics Co., Ltd.) [3]**. The later was after working with smart prototyping and trying out a different company. Currently we would recommend JLCPCB as it had more help on its website on how to get gerber file formats for circuitMaker that our team was using, and had good first order discounts. But Smart prototyping had good help on email as we just had an incomplete gerber file package and almost told them to find the files.

Approximate time : 5-10 days (5 business days for JLCPCB with our fastest shipping that we got DHL, and no file issues)
Cost: production cost + shipping cost (variable)

The PCB design is shown below.





Conclusion

We realized that the original idea of doing any audio pitch shift was fundamentally flawed, but was ok for pure tones or sounds with main pitches. The multiplication of two pure tones creates two tones with sums and difference, but for more than two tones, the terms are a result of convolution in frequency domain which is not a pitch shift at all for each pitch, but a mix of all possible combinations of pitches. This may still be okay for sound with main tones as other components may not matter, but for a normal sound, the audio will be very noisy. However, we were able to make our system work for simple tones.

In retrospect, we should have ordered our PCB earlier, since the PCB lead time was inaccurate due to their holiday schedules and our limited experience with ordering PCBs.

References

1. JLCPCB(Shenzhen JLC Electronics Co., Ltd.), https://jlcpcb.com/

2. Smart-prototyping , https://www.smart-prototyping.com/
3. JLCPCB support on gerber files
https://support.jlcpcb.com/article/48-how-to-export-altium-circuitmaker-pcb-to-gerber-files
4. https://www.travelchinaguide.com/essential/public-holiday.htm, accessed 12 May 2019
5. NTSC Transmission through Optic Fiber by Hugo Malpica, Germain Martinez, Khaled Moharam, [May 2015]