The Successes and Failures of Constructing an Audio Crossover

Physics II Honors Project H002

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Idea

The initial idea was to make a very nice yet simple speaker and/or speaker system; however, Dr. Stewart promptly said that that project was too easy. After much consideration, it was decided that an audio crossover would be constructed along with the speakers to be used together. The crossover would split an AC audio stream into three hand-made speakers according to frequency. Although the speakers did not end up working, the crossover worked with decent to success and was therefore available for demonstration.

Theory

In order to reproduce an audio wave, the speakers and crossover need to do their best to speak in the same basic language as sound: the language of waves. Waves through air and other physical materials oscillate at different frequencies which our ears perceive as different tones. These frequencies are represented in a unit called Hertz:

$$Hz \: [=] \frac{1}{s} \: Equation \: (1)$$

The tones are able to be stacked on top of one another and still retain their frequencies, which allows for an almost inexhaustible combination of tones that can be played together to create music. Luckily, electrical circuits contain streams of electrical charge that can be measured in a way that is similar to measuring sound. This stream of electrical charge is called an Electric Current, and is described using the unit Amperes:

$$A \: [=] \frac{C}{s} [=] C \: (Hz) \: Equation \: (2)$$

This shows that there is a direct link that can be made between the waves of alternating current in electrical circuits and audio waves in air and other substances.

To translate between the two waves, we use speakers. Speakers were demonstrated during Activity 19 to work using the Lorentz Force, which describes the effect of a magnetic field on moving charge (Stewart and Stewart 2011):

$$\overrightarrow{F_m} = q\ \vec{v} \times \vec{B} = I\vec{\ell} \times \vec{B}\ Equation\ (3)$$

The magnetic force $\overrightarrow{F_m}$ is determined by the velocity $\vec{v}$ of the charge q in the presence of the magnetic field $\vec{B}$. Alternatively, $q\ \vec{v}$ can be represented by the current I and the distance the charge traveled $\vec{\ell}$. This force is experienced as actual motion of either the current-carrier or the source of magnetic field. In the case of the speakers that were constructed, the magnet was the stationary entity that moved a coil of current-carrying wire t that oscillated at a frequency comparable to the frequency of the audio that it was trying to replicate:

$$f_a = \frac{I}{q} = f_c\ Equation\ (4)$$

Essentially, the audio frequency f_a is comparable with the frequency of the current f_c. This frequency finally is represented by attaching an acoustic object to the coil of wires, which oscillate and move the air, thereby replicated the frequency.

The second part of the project involved the splitting of various different audio frequencies so that they may best be replicated in the most appropriate materials. All materials have a specific range of frequencies that they are best suited for replicating. Large chunks of rubber are good at replicating low frequencies and tiny bits of plastic are good at replicating high frequencies. However, if a material of a

specific frequency range is given a frequency outside that range, there is a loss of power behind the oscillation, and is therefore not an optimum pairing of frequencies and materials.

Although speakers are created such that they try to have as large of a frequency range as possible, it is also a good idea to relegate frequencies to multiple speakers of different frequency ranges to get the most sound out of an audio stream. This can be done by constructing a circuit called a Crossover. A crossover is a circuit that takes the burden off of one speaker with a limited frequency range and distributes the frequencies to many speakers of different ranges (Linkwitz 2012). There are many different ways to construct a crossover, many of which are like Linkwitz's and are quite complicated.

Crossovers often work by combining simple circuits called pass-filters (BSS Audio n.d.). There are low, high, and band-pass filters that allow certain frequencies to go through to the speakers and others to go off somewhere else.
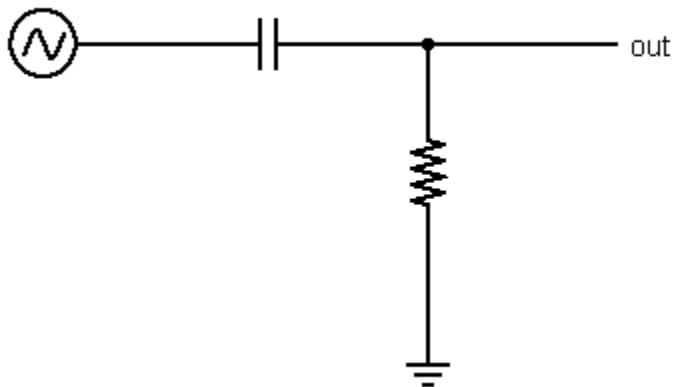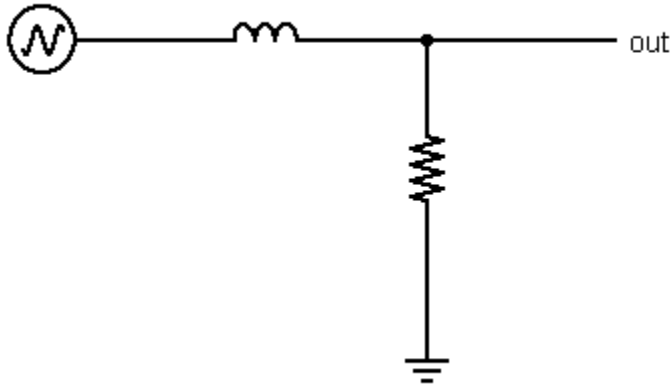
Figure 1: A simple high-pass filter.

Figure 2:A simple low-pass filter.

The capacitors in the circuit allow higher frequencies to pass through easier because a capacitor blocks off current flow as charge is built up in the capacitor. Lower frequencies take more time to fill up the capacitor, so they end up traveling off somewhere else.

$$I(t) = I_0 e^{\frac{-t}{\tau}} \ Equation \ (5)$$

The inverse happens for the low-pass circuit, where the inductor resists fast changes in current due to its own self-induced emf. High frequencies do not stick around long enough to let the inductor let them through, so they go off somewhere else.

$$I(t) = I_f \left(1 - e^{\frac{-t}{\tau}} \right) Equation \ (6)$$

These two basic circuit pieces can be combined to allow any range of frequencies to pass through. When inductors and capacitors are situated to distribute audio frequencies without amplification it is called a passive crossover (Pacific Accessory Corporation 2001). There are other types of crossovers like active crossovers, but they are significantly more complicated and are suited for more powerful systems.

Figure 3: A passive crossover setup. The audio source may be amplified before the crossover splits the audio into different frequencies.
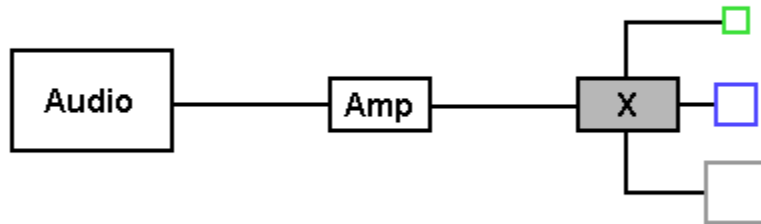

Design and Implementation

For the purposes of this project, it was decided that the easiest type of crossover for the job would be a passive first-order audio crossover in a LRC circuit. This means that the crossover would just take in a single amplified audio stream and split it off into three separate audio streams: a high, a mid, and a bass.

Using the website http://www.diyaudioandvideo.com/Calculator/APCXOver/, it was possible to have a computer determine the specifications for each branch of the crossover (3-Way Crossover Designer / Calculator n.d.). This design was then put into a java program called "Circuit Simulator v1.5n" to make sure that everything would theoretically work (Falstad 2010).

Figure 4: Paul Falstad's Circuit Simulator v1.5n running the design for the crossover.
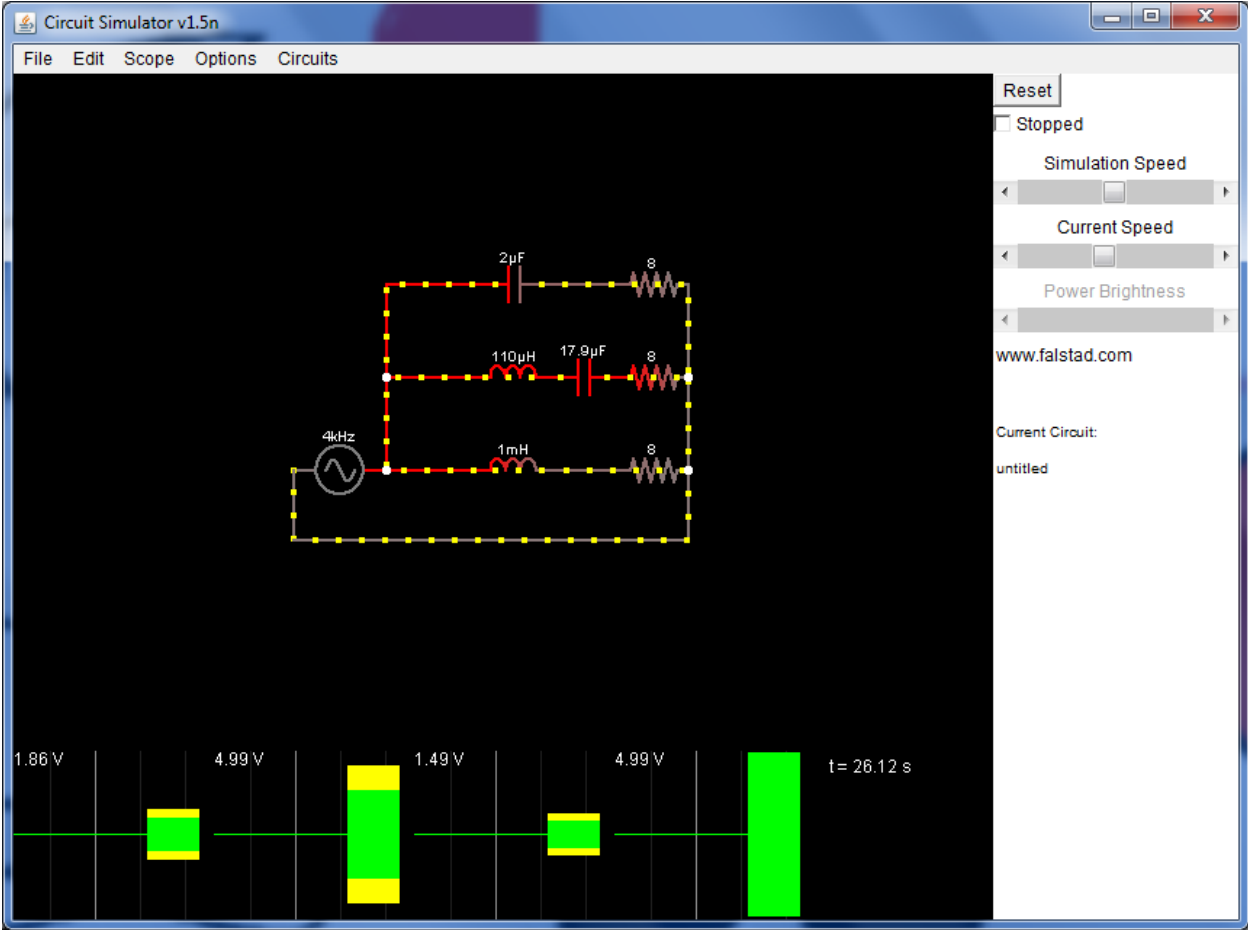

The 8Ω resistors represent the speakers of arbitrary resistance. The circuit should still work fine so long

as the speakers are all of similar resistance.

Figure 5: Breadboard that held the implemented circuit in place.
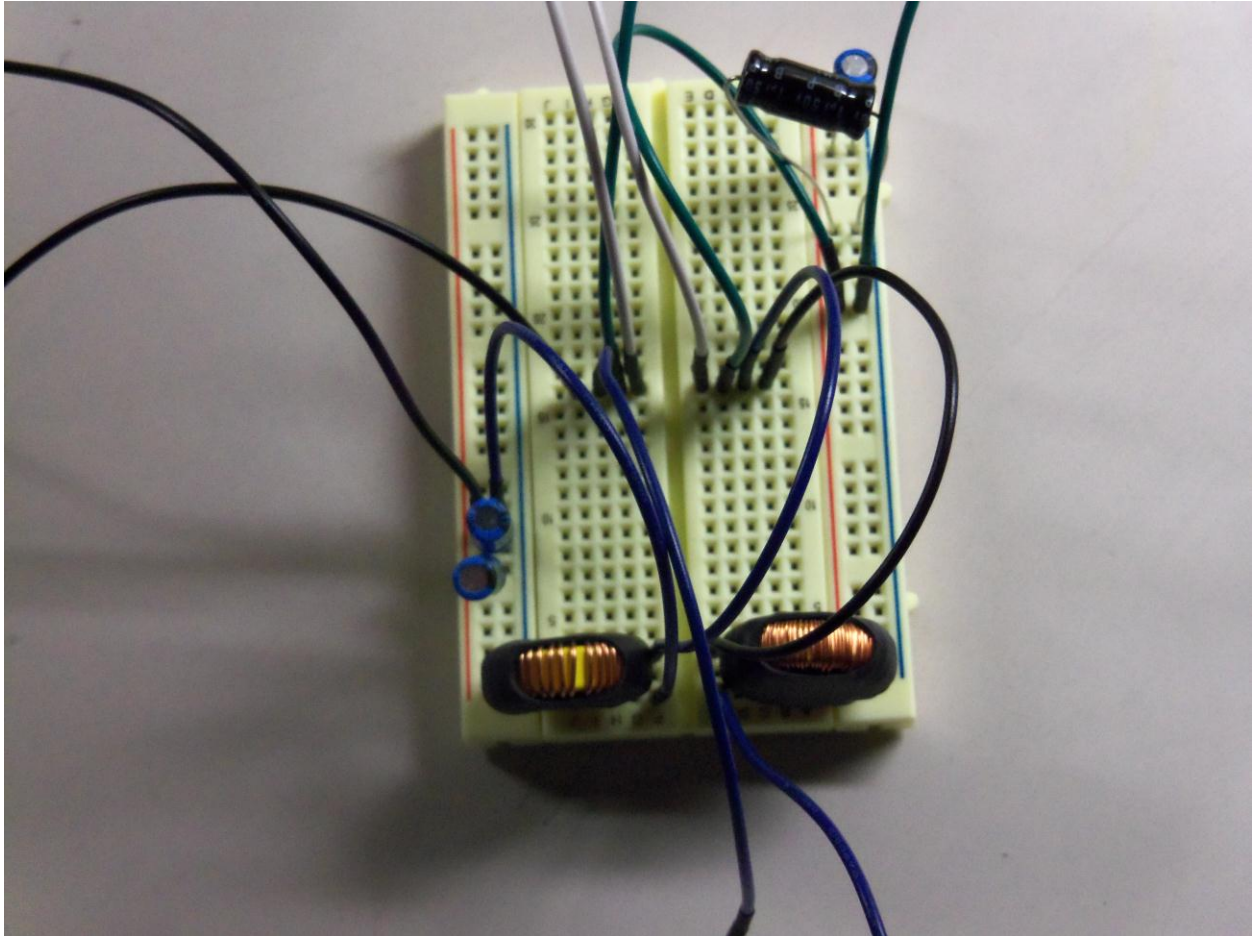
The speakers themselves were designed to fit in to their frequency ranges. The bass "woofer" was made of Styrofoam and duct tape, the mid was a cone made of cardstock, and the high "tweeter" was made from a small circle of paper. The materials and sizes of the speakers were meant to fit them in to their effective ranges. They were powered by rather large ceramic magnets.

Figure 6: The speakers with their magnets and an ID card for reference.
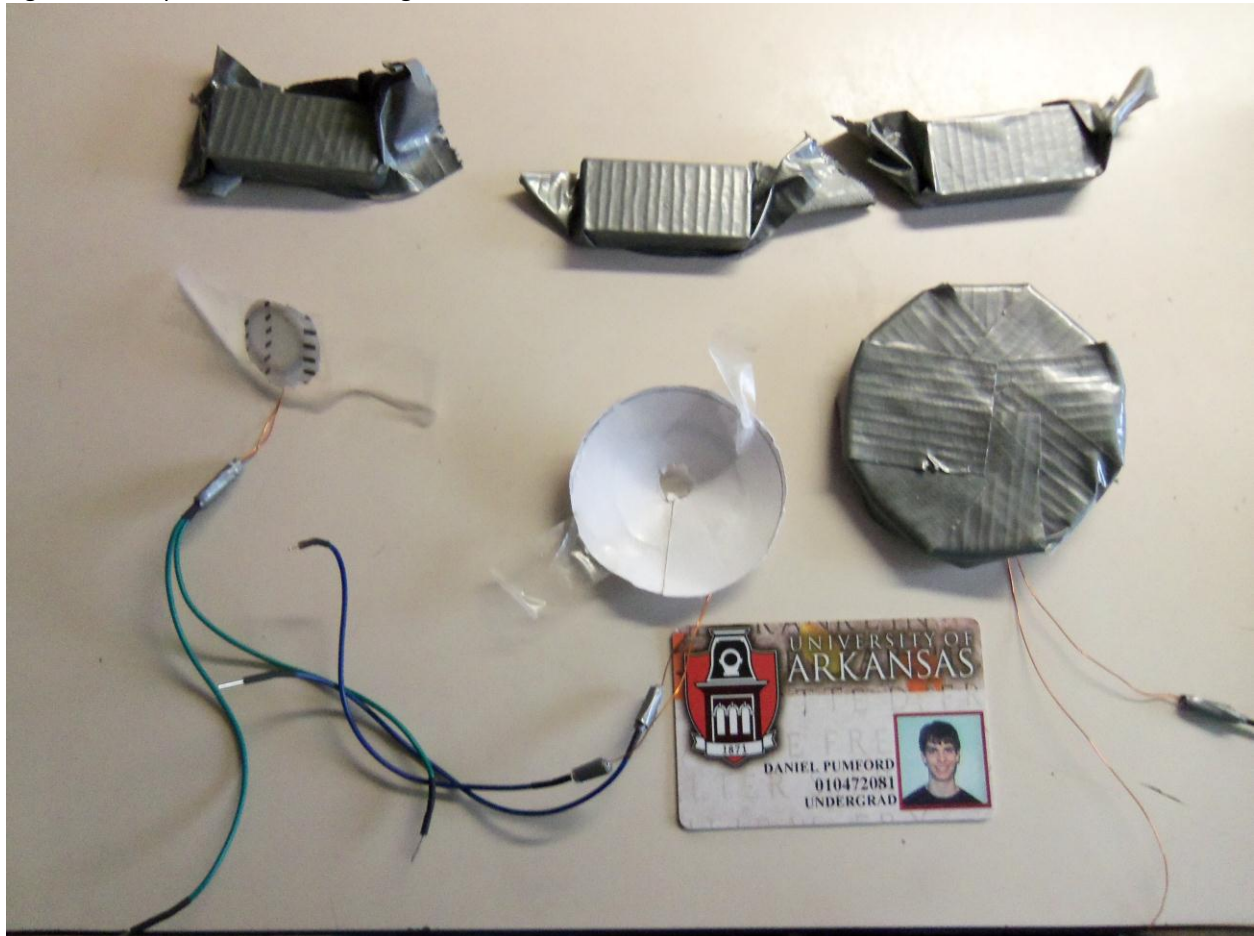
These were all to be combined into one large circuit where the computer would output rather loud

music into the crossover which would split the frequencies into the speakers. The computer did not

provide enough output to power the speakers, so an amplifier was added. The speakers were still

incapable of cooperating and producing demonstrable audio splitting, so they were dropped and

replaced with commercial speakers.

The circuit was also not built to specification. The capacitors were not exactly correct for the

specification because the capacitors were ordered at about ten times the intended capacitance by

accident.

Data

To prove that the crossover was in fact distributing the audio signals, the voltages of various input frequencies were tested. A higher percentage of the input voltage indicated that the crossover was placing more current to the speaker. To do this, alligator clips were place at the input and output of the crossover and at the input and output of the speakers. These alligator clips were easily connected to a voltmeter that was designed to read alternating current. After playing a monotone of four different frequencies, the voltmeter would indicate the peak voltage for the frequency. The audio files were from two different sources and are cited in the bibliography.

Table 1: Shows that the measured resistance of commercial speakers was roughly the same.

	Bass	Mid	High
Resistance (Ω)	3.8	4.1	4.3

Table 2: Shows the peak voltages at various frequencies.

Frequency (Hz)	40	417	1000	10000
System (V)	0.127	0.770	0.551	0.960
Bass (V)	0.043	0.299	0.165	0.004
Mid (V)	0.002	0.130	0.208	0.320
High(V)	0.001	0.077	0.120	0.570
Total Percent	100.00%	100.00%	100.00%	100.00%
Bass	33.86%	38.83%	29.95%	0.42%
Mid	1.57%	16.88%	37.75%	33.33%
High	0.79%	10.00%	21.78%	59.38%
Dissipated	63.78%	34.29%	10.53%	6.88%

Figure7: Shows a pseudo-logarithmic range of frequencies and their extrapolated voltage heights. Note the dissipated voltage.
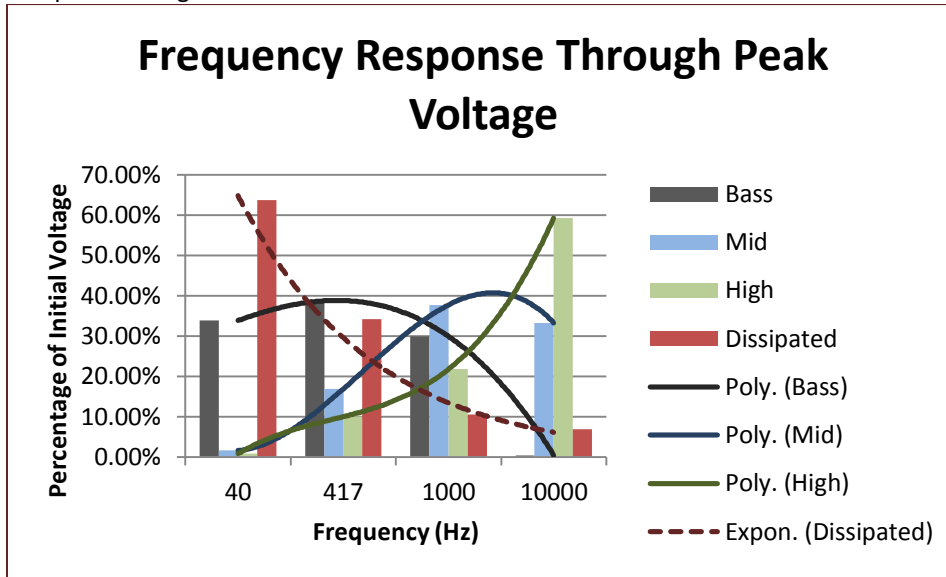
Analysis

As Figure 7 suggests, the crossover appears to be correctly splitting the frequencies between the speakers. Notice the best-fit lines that were drawn on to the graph: they show the rise and fall of frequencies as higher frequencies are tested. The bass is turned up loud at the lower frequencies, but is replaced as dominant speaker somewhere between 417 Hz and 1000 Hz. The high is dominant sometime between 1,000 Hz and 10,000 Hz. The mid is dominant sometime between the other two.

There were not many data points, so the graph is not a definitive indicator of specific frequencies that each speaker was dominant in; however, because the best-fit lines are "crossing-over," it is reasonable to say that the crossover was doing its job and distributing the frequencies in some manner, albeit not a predictable manner.

After the data was gathered, it was worth noting that a certain percentage of the initial voltage was not going to any of the speakers. This was not something that was expressly tested for. This phenomenon is described as "Dissipated Voltage," which appears to have a higher percentage of the initial voltage at

lower frequencies. Theoretically, the voltages of the speakers should all add up to the initial voltage, unless some of the voltage is dropped within the circuit due to the alternating current. No clear hypothesis has emerged to explain this.

Results

Although the speakers did not perform well enough to demonstrate, the crossover was able to split frequencies to three commercial speakers. Because the crossover was the more interesting part of the project, it can be said that the project was a success at demonstrating the usage of RLC circuits to split audio frequencies.

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