A Chromatic Chime Set

By: Dan Larson
January – 2011

(A science fair project for a retired engineer)

Why? Just because I could. I have friends who ring bells in church, and I am a closet piano player. When Pablo Casals played a Bach cello sonata VERY fast, someone asked him: why so fast? He answered: Because I can. My son named my creation C Machine, because it plays a C scale.


Figure 1


Figure 2

Figure 1 shows the thing in playing position, figure 2 with the black notes in stowed position. The black and white note frames were built completely separate, and connected as the final stage with ball bearing drawer slides. I used copper for black notes for its contrasting color, and its higher density makes the tubes about three quarters of the length of the aluminum white notes. Figure 3 shows a close up of the black note frame. The frames are made of two pieces of plywood with trapezoidal holes, clamped together to hold all of the 3/8 inch dowels at both ends.


Figure 3


Rear View

The tubes, spacers, and supporting dowels are strung together on 1/32 inch wire. The spacers are little fuzzy pom-poms, bought at a craft shop. I originally planned on using plastic beads, but changed to the fuzzes because the dowels are not perfectly straight, causing uneven spaces, and because I feared that the plastic beads might raffle. The wire is 1/32 inch "aircraft cable" sold at a model shop for control surfaces on RC airplanes and sailboats. It is stainless steel, and gold plated, so it is really easy to solder. I drilled 1/16 holes in the tubes, and the wire was stiff enough to poke through all those holes, like threading needles. I soldered the strands of the cable together so they would not fray as I poked them through all the holes. I poked the wire through the tubes in the same direction as they were drilled, so I did not have to remove the drilling burrs inside the tubes.

The holes in the dowels are sloped to guide the wire through the successively shorter tubes. I used the arctan button on my calculator to calculate the angles for those slopes. I have never previously used the arctan button in my daily life. The wire makes a round trip, through the lower holes and then through the upper holes, and is held under tension a turnbuckle and spring concealed in the plywood frame.

Figure 4

Figure 4 shows my tools for this project: sound lever meter, to explore why the lowest notes are so faint, calculator to calculate multiples of 2-to-the- minus used in tuning process, ruler WITH centimeters. There was no way I could have measured and trimmed tubes using sixteenths and thirty seconds. (Insert metric system lecture for junior high kids here!) Plumbers pipe cutter; with care, I was able to remove strips as short as a couple of millimeters - made a lot of little rings. My wife said the cutter could cut pizzas for really little people. The cutter left neat and safe ends; I only had to do a little mop-up with a file. The "chromatic auto-tuner" came from a music store that sells guitars, etc, My wife uses it to get her flute students to play in tune. I think it was less than $50. Figure 5 is a close up-of that marvelous device. It contains its own microphone, and can be set up, if desired, to be based on other than standard A440 tuning. It has graduations down to 10 cents of pitch, and I could sort of interpolate down to a couple of cents.

TUNING

I would cut the tubing to about 5mm longer than it should be. Then I held it with fingers (before drilling), dinged it, and measured the pitch. measured the length, calculated the needed cutoff, usually in a couple of stages. Only a few times did I have to do mop-up with a file. Then I drilled it.

The 1/16 inch holes did not alter the pitch significantly. Some tubes had the uncertain pitch, "beat notes" that you observed - more often in the copper than in the aluminum. Even in tubes cut from one 8-foot piece of copper pipe there were differences in severity. I have done some plumbing around the house, and never found copper pipe externally out-of-round such that it interfered with fitting and soldering. The pipes may, however, have slightly elliptical or nonconcentric interior bores. I could rotate the tube in my fingers and change where I hit it. In that way I could find orientations with "puree' notes. It as if the tubing had two orthogonal planes with slightly different stiffness. I could also rotate it and hit it 45 degrees between the apparent planes, and get the most pronounced beating. I could have chosen (but didn't) an optimum rotation angle to drill each tube.

Vox Humana

In the world of music, violinists in an orchestra, and vocalists in a choir, never are perfectly in tune, and use (or misuse) varying amounts of vibrato. Some pipe organs have a set of pipes called "vox humana", deliberately mistuned to keep the music from being TOO perfect. My piano tuner deliberately leaves the three strings of each note slightly mistuned for the same reason. Electronic keyboards sometimes provide the same effect. I have a hundred-year-old parlor organ that contains an air-driven rotating baffle to simulate the same effect. The tubes on my machine have varying degrees of the beat notes, and I can rationalize that it is just producing the same kind of deliberately "non-perfect" effect.

Why are my lower notes so weak?

This was a big disappointment. After all, round tubes are not very good sound radiators. The mode diagrams in your write up show that the end sections beyond the 22.4% points have greater vibration amplitudes than the center. Measurement with my Radio Shack level meter confirms that this is really true. Not only that, the ends are in phase opposition with the center, so a listener on a perpendicular with the tube will get a pretty weak sound in the absence of reflections from walls, etc.. In the hi-fi business, at least the sound from the back of the loud speaker could be just dumped, as in "infinite baffle" enclosures, or phase shifted with a bass reflex box or tube structure like a Klipsch horn.

I have not found a way to redirect the wrong-phase sound from the ends of the tubes. However, I can make the sound a bit louder by just blocking the end sound with a piece or plywood. In a wind chime context, if one used three- or four-point ties (so the pipes would not swing) at the 22.4% points and put cylindrical baffles around the end sections, more sound might be available from the center section alone. In the mean time, I have used a somewhat inelegant solution: a microphone close behind the 4 or 5 lowest pipes, and a small amplifier and loudspeaker.

I will welcome your comments, especially dealing the wimpy low note issue.

Dan,

In answer to you question about why the low notes are so weak I will use a couple of references. First the (General Radio [GenRad Inc.] Handbook of Noise measurement" available online here.
http://www.ietlabs.com/pdf/Handbook%20of%20Noise%20Measurment.pdf

and a blog that has some good info here http://blogs.msdn.com/b/audiofool/archive/2007/02/07/louder-sounds-better.aspx

The answer to "Why" is simple. It's not the chimes, it's our ears. They do a poor job at low frequencies. See the Fletcher/Munson "Equal Loudness Curves below. The ear is less sensitive at low frequencies (below about 300-400 Hz) and somewhat at high frequencies (above 4 KHz). A little below C5 it gets tougher to hear well. This also happen to be why "AT&T" originally designed the microphone on the telephone to only transmit between 300 Hz and 3,000 Hz. The ear hears best there. I should also mention that the "vowels" are also contained in that range which was another reason for the selection.

When you said your set was a "C" set, I assume you mean C4? If it is C4 (261 Hz) then yes, that is difficult to say the least, for us to hear as well as at 1500 Hz. This is why amplification is so important at these frequencies (as you learned) i.e. the sounding board on a piano or other sting instruments. For brass instruments we need to move a great deal of air to create a louder sound at the lower frequencies and that is accomplished by an acoustic transformer at the end of the brass instrument. The flair at the end of a trumpet or tuba for example. It's simply matching the impedance of the generator to the impedance of the atmosphere.

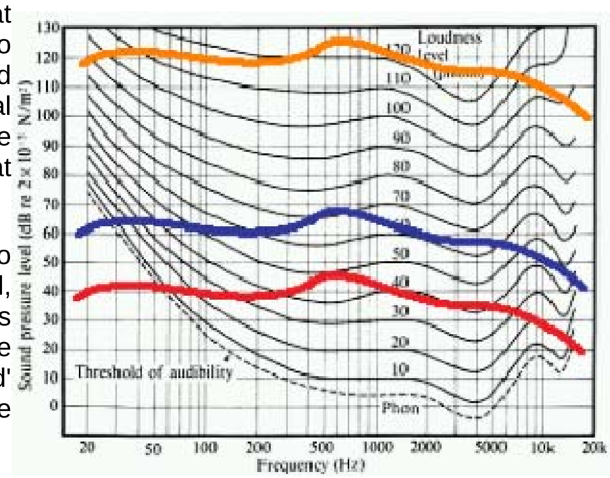
Now, for a chime tube supported in the "free-free" mode, it gets even more difficult when you cannot use a sounding board or an impedance matching transformer. The only way to move more air from a chime tube is to have a larger radiating surface. i.e. a larger tube. That is strike one against loudness. Then as you noted, strike two is caused by the sound pressure wavefront not being in phase all along the tube surface. Strike three is the loudness issue as detailed in the article below.

All in all, there is no good solution except electronic application. If we made the low frequency tubes large enough to be good radiators they would be out of physical proportion to the chimes at C5, C6,and C7. Would probably work but would look funny.

Copied from the web site above

Below is an example of the Fletcher-Munson Equal Loudness Curve. It is one of the most recognized graphics in audio engineering.

The horizontal axis is frequency of tones, and the vertical axis is actual sound pressure in dBSPL. Each point on a curve has about the same subjective "loudness" to the human ear. The low parts of the curves are the frequencies where the ear is more sensitive. Conversely, the high parts are where the ear is less sensitive and it takes more pressure to get the same 'loudness'. The dotted line at the bottom represents the threshold of hearing. Any frequency below that line can't be heard at all by the average human.



Consider an arbitrary waveform coming out of a speaker. That waveform has the frequency response shown in red on the diagram to the right. The blue line is the same waveform amplified by 20dB, and the orange line is amplified by 80dB. Notice that the louder signal aligns better with the flatter Fletcher-Munson curves at the top. There is less variation in sound at different frequencies, and the result is that the louder signal has a richer, fuller sound.

The opposite is also true. For quieter sounds, certain frequencies to which the ear is less-sensitive can seem to drop out of the signal, especially at very high and very low frequencies. The orange line has a very powerful bass, with low frequencies staying close to the same loudness as the middle. The blue line's bass is much less 'loud' than the middle frequencies. Many frequencies on the red line have completely dropped out, below the threshold of hearing.

The Fletcher-Munson curves illustrate an audio engineering example of why, to the human ear, louder sounds better. The higher the signal amplitude, the more frequencies are present, making the signal richer and fuller.

Hope this helps,

Lee