Initial Plasma Loudspeaker Analysis

An interactive report on the acoustical qualities of a plasma loudspeaker

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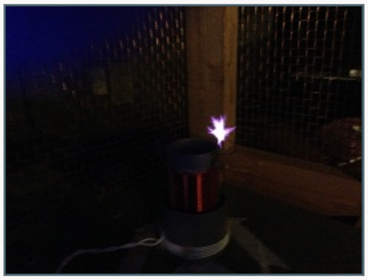
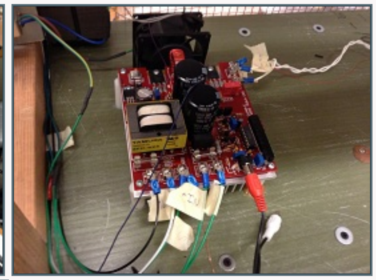
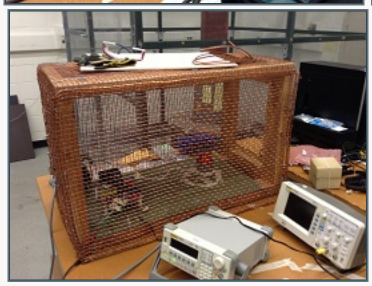
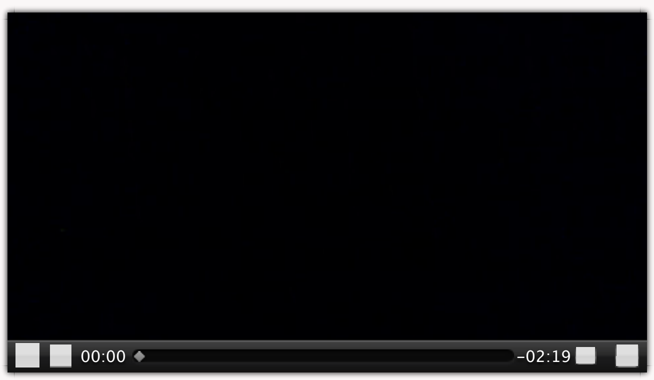
Frequency Response | Impulse Response | Distortion | Directivity | Sensitivity
Spectroscopy | High Speed Video | Conclusions | Further Work



Plasma speakers use atomic-scale particles as the main driver of sound pressure waves as opposed to traditional speaker drivers such as paper cones. The plasma discharge excites the surrounding particles and ions, causing them to collide with neutral air particles. These collisions are what is responsible for the creation of pressure waves that we perceive as sound. Because of this, the plasma speaker possesses some relatively unique properties. The following data and experiments were performed with a Dayton EMM-6 microphone mounted on a ring stand 10cm away from the speaker driver in a non-anechoic chamber. The measurements may suffer from background noise levels but should hold relative to other speakers tested. Unless otherwise noted, YMEC RealTime Analyzer was used to obtain measurements.

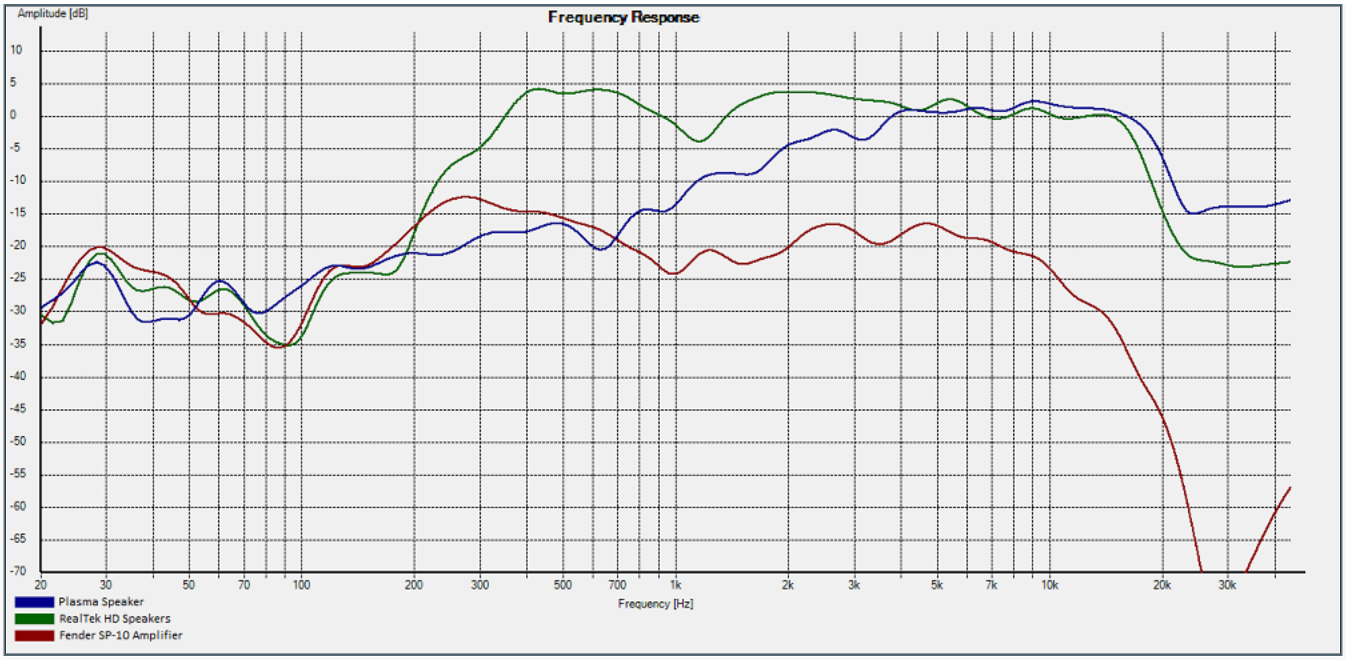


Our plasma speaker plays "Breezeblocks" by Alt-J (An Awesome Wave, 2012) off of an Apple iPod Nano 5g

Frequency Response

The frequency response of a system is generally defined as the measure of amplitude (volume) over frequency. The frequency response curve is typically smoothed over 1/3 octave for viewability. The ideal speaker's frequency response is characterized as a flat line; indicating that the speaker reproduces all frequencies evenly and at a consistent volume.

Using a program called HOLMAcoustics, the frequency response was measured using a logarithmic sweep signal from 20Hz to 20kHz over 20 seconds. A 22W Fender Squire SP-10 guitar amplifier and a set of computer RealTekHD Audio speakers were tested as well for comparison.



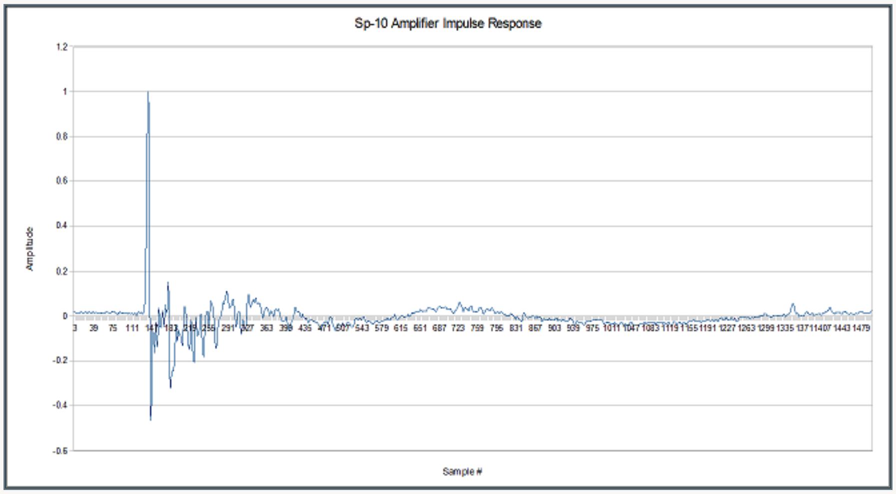
Due to mic and background noise limitations, I suggest that only the data in the range of 100-18000Hz be considered.

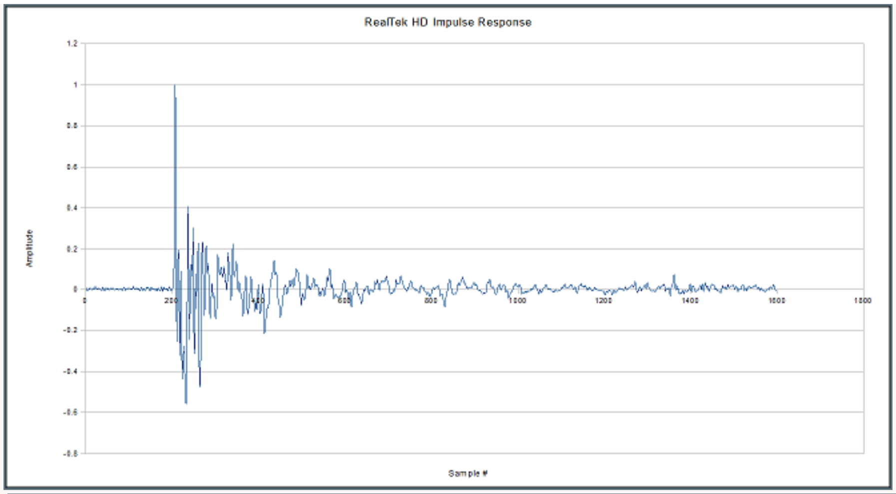
The frequency response of the plasma speaker shows a consistent, logarithmic increase in amplitude with increase in frequency (a trendline regression shows a logarithmic coefficient (base 10) of 13.47 or a natural log coefficient of 5.85). Because the speaker driver is "massless," it is capable of producing very high frequencies due to its ability to move very small quantities of air. To contrast, the Fender SP-10 stays flat from about 200-10,000Hz (with a peak in the low-mid range around 270Hz). Starting at 10kHz, however, its response deteriorates quickly. The RealTekHD computer speakers perform flatly (with the exception of a drop in the 1-2kHz area) and only begin to deteriorate at about 18kHz

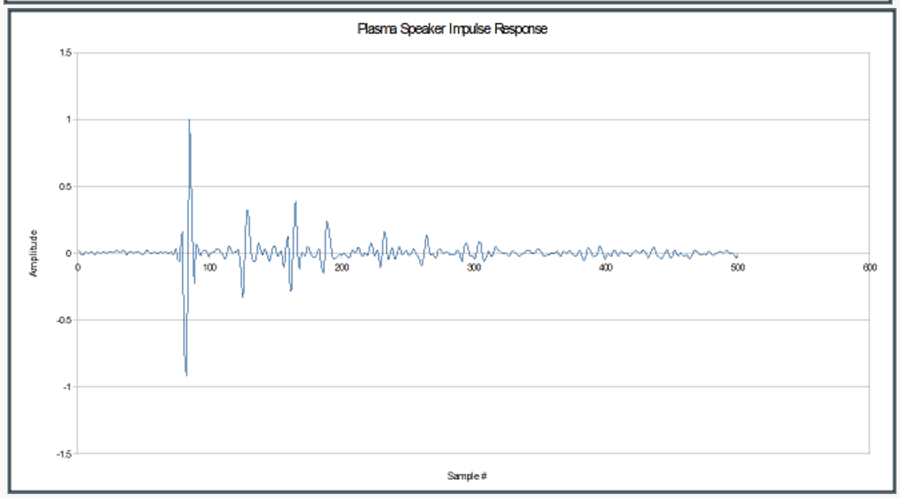
Impulse Response

Impulse response (in this sense) will be used to measure colouration; or how much the speaker adds to the sound through excess vibration. A short impulse of pink noise was applied to the system and the waveform recorded at a sample rate of 88.2kHz. The impulse response of an ideal speaker shows as little residual noise as possible, simply reproducing the signal and then ceasing to cause vibrations.

Click to enlarge





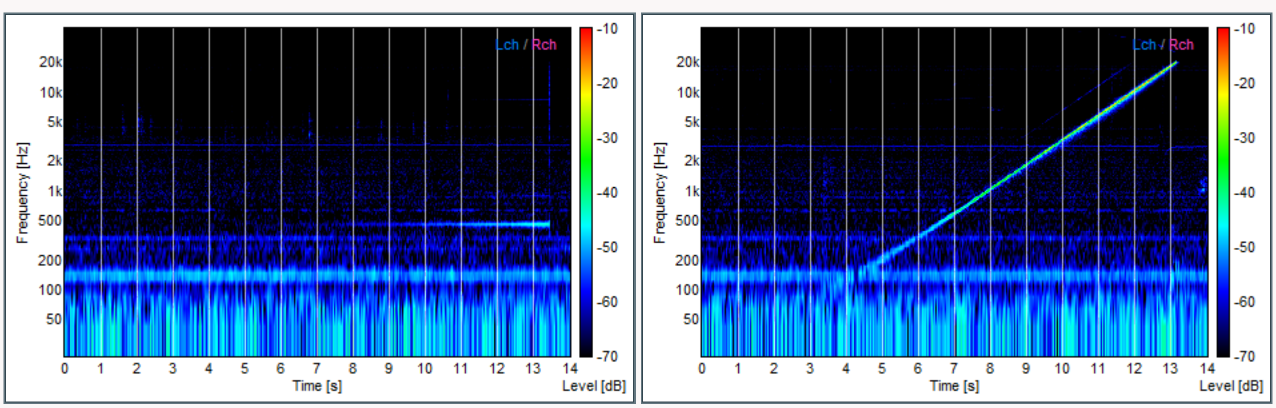


The plasma speaker enjoys a clean, noiseless impulse response. The room reflections are clearly visible in the response, each appearing and ending at a specific point in time while the original impulse has already stopped sounding. The plasma speaker stops sounding completely by sample 500 (5.7ms), whereas the SP-10 and the computer speakers continue to suffer from residual vibration at approximately 10ms and 15ms respectively.

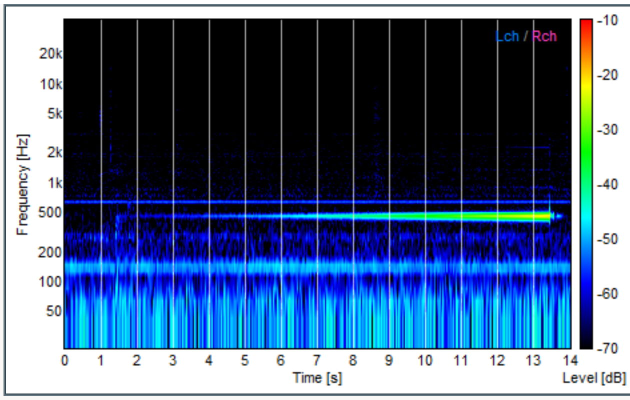
Distortion

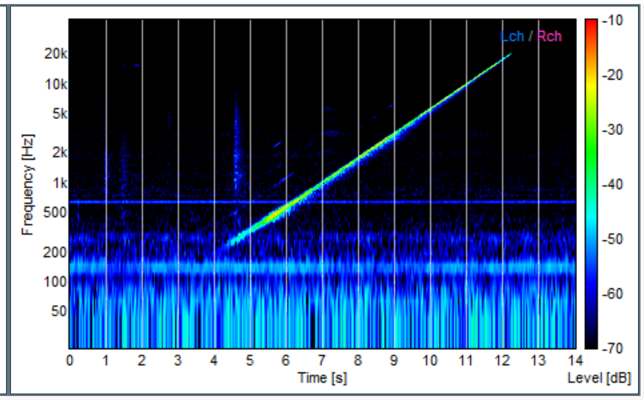
Another measure of speaker quality is the measure of distortion. There are two ways to measure distortion, one measuring against amplitude, the other against frequency. Harmonic distortions can also be spotted in spectrograms by examining any other frequencies that appear when a pure control tone or sweep is being played.

Spectrograms of the plasma speaker: -40-0dB sweep (left) @440 Hz, and 20-20000Hz sweep (right) @ 0dB



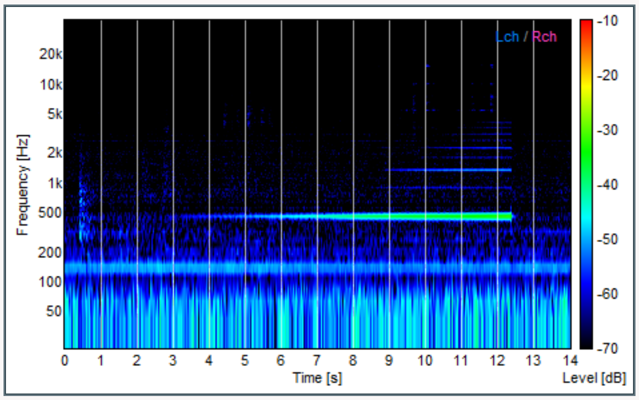
RealTekHD speakers

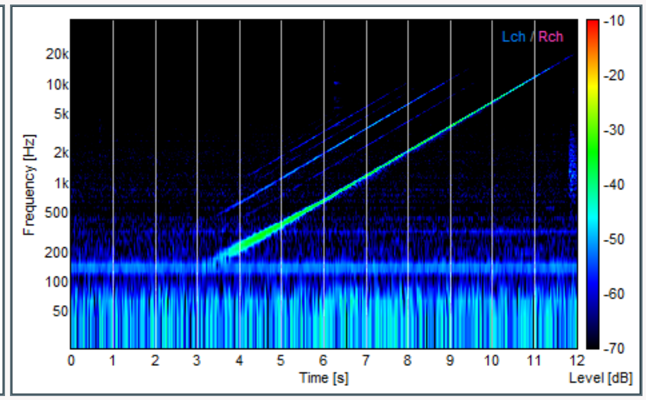




Note the noise just before 5s was caused by outside interference.

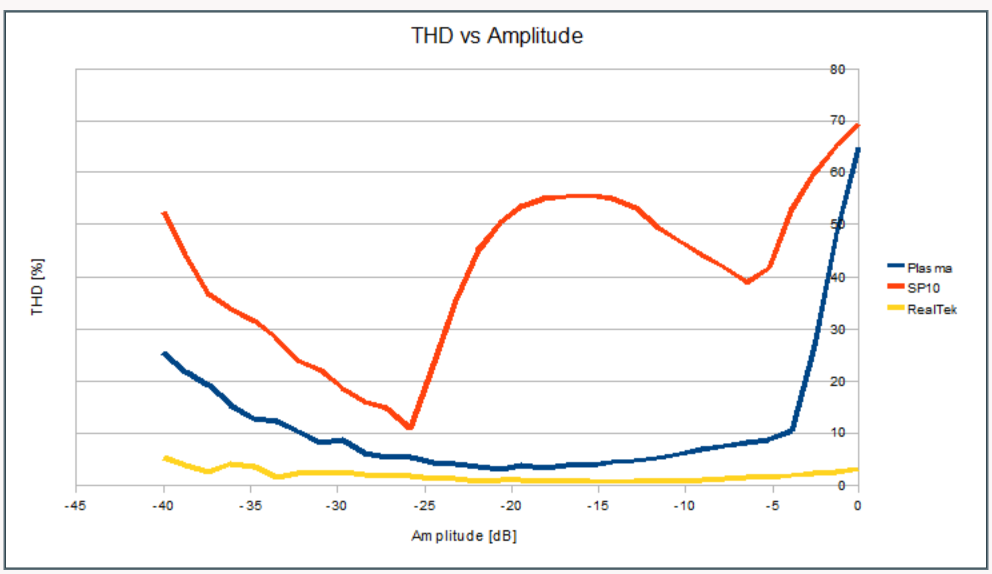
Fender SP-10 Amplifier

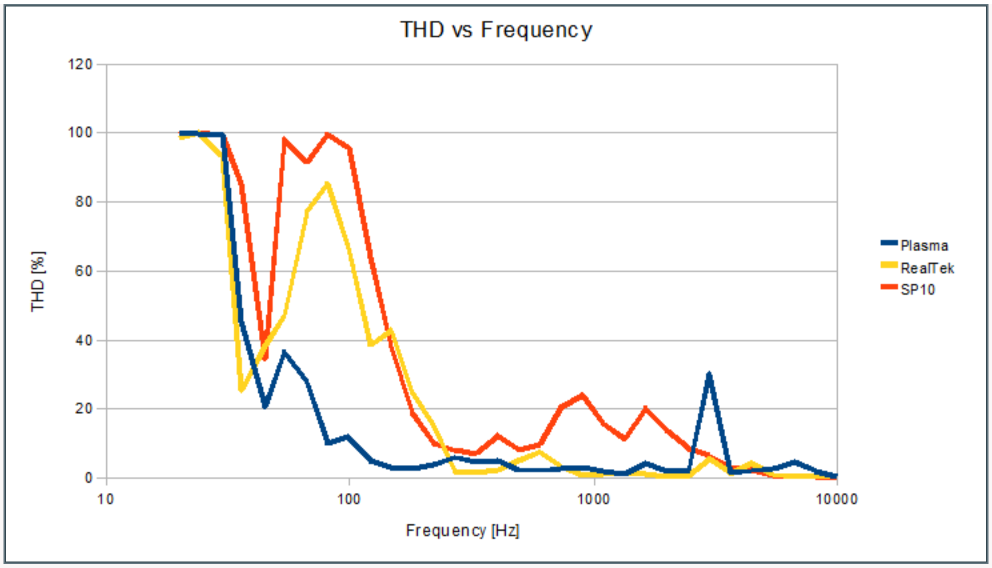




These spectrograms offer a simple visual of the audio systems. The plasma speaker appears to generate a very soft tone around 3kHz while operating, and suffers from little distortion until the end of the frequency sweep at the loudest setting. The computer speakers' spectrograph shows a similar tone, this time around 600Hz. A very small amount of distortion can be detected at the end of the 440Hz amplitude sweep. Meanwhile, harmonic distortion is rampant and obvious in the SP-10 amplifier as volume increased (starting at about 9s), and in the mid frequency range (500-5000Hz). Examine the thickness and texture of the spectrographic lines. Notice the icnreasing thickness of all the systems as amplitude increases. Thicker lines signify that additional frequencies are being detected close to, but not exactly at, the original. This is another kind of distortion; the ideal system would show a straight, perfectly thin line changing in color (in the amplitude sweep) and height (in the frequency sweep). Note the added thickness and fuzz of the RealTek computer speakers throughout the frequency sweep, and the tapering form of the SP-10 in the lower frequencies below 500Hz. This suggests additional distortion in those ranges, while the plasma speaker enjoys and less textured and consistently thin output.

Objective measurements of THD can also be taken, revealing the plasma speaker to suffer from distortion at high volumes and low frequencies. While the Fender measurements disagre slightly witht he spectrograms, the plasma speaker's measurements are observed to maintain our previous findings.

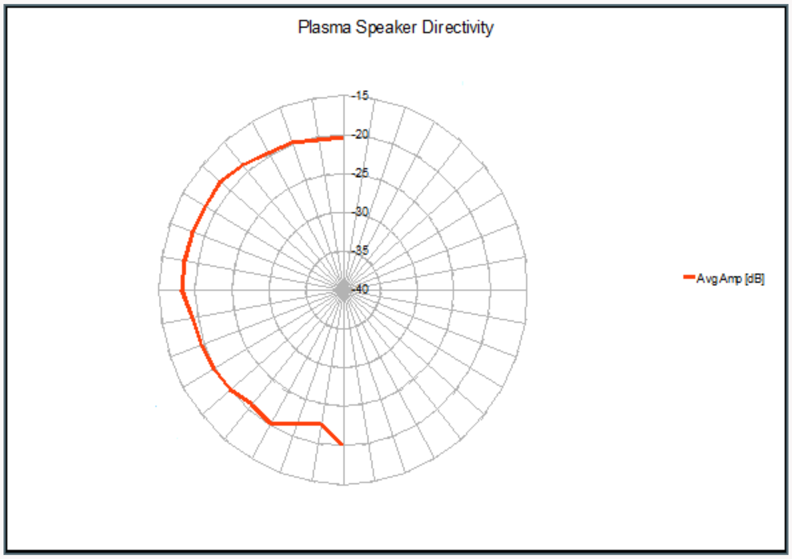




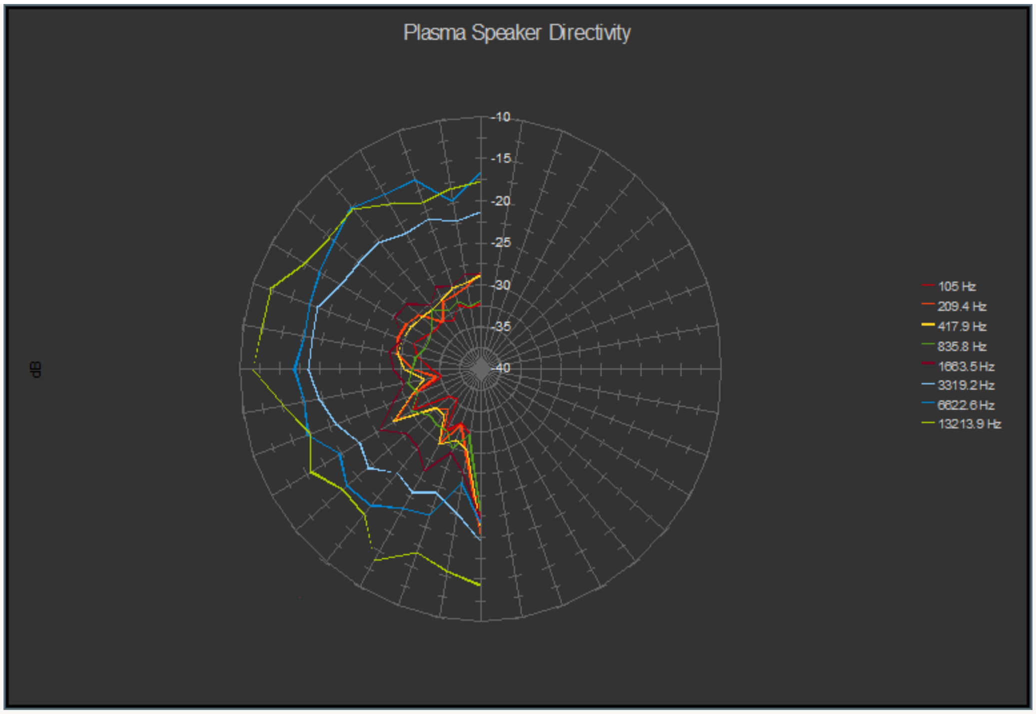
Directivity

Directivity measures how 'directional' a speaker is; that is, how the position of a listener may change the perceived or measured frequency response or volume. To measure directivity, a frequency response sweep was taken at 10 degree intervals at a 30cm radial distance over a period of 180 degrees (from directly on-axis to directly behind the unit).

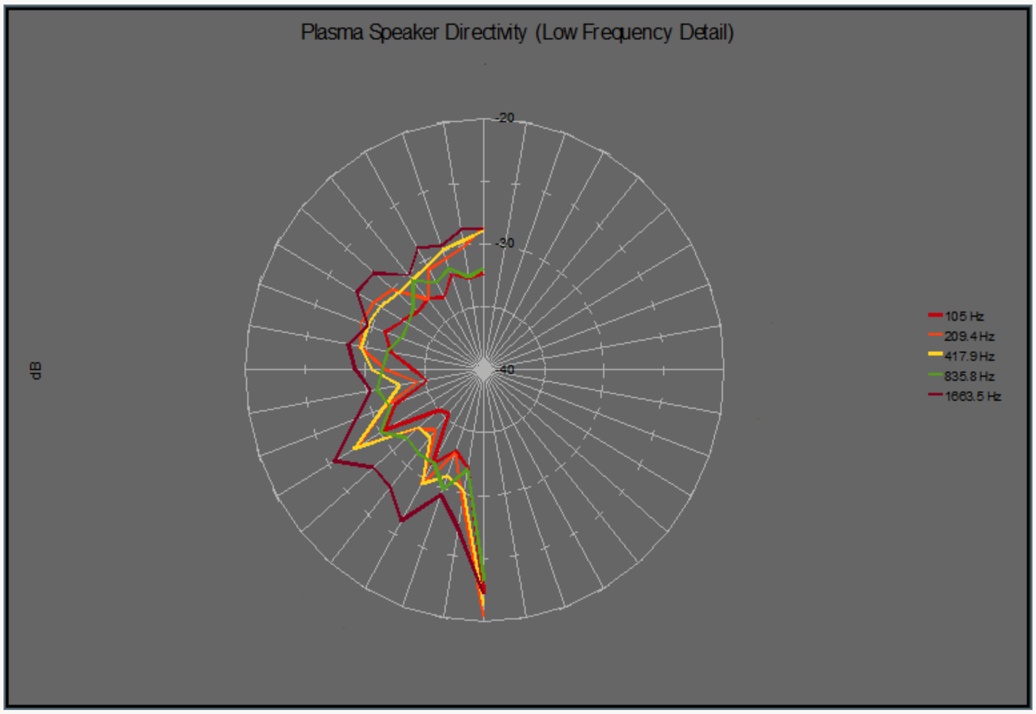
Directivity polar plot of the integration of all frequencies



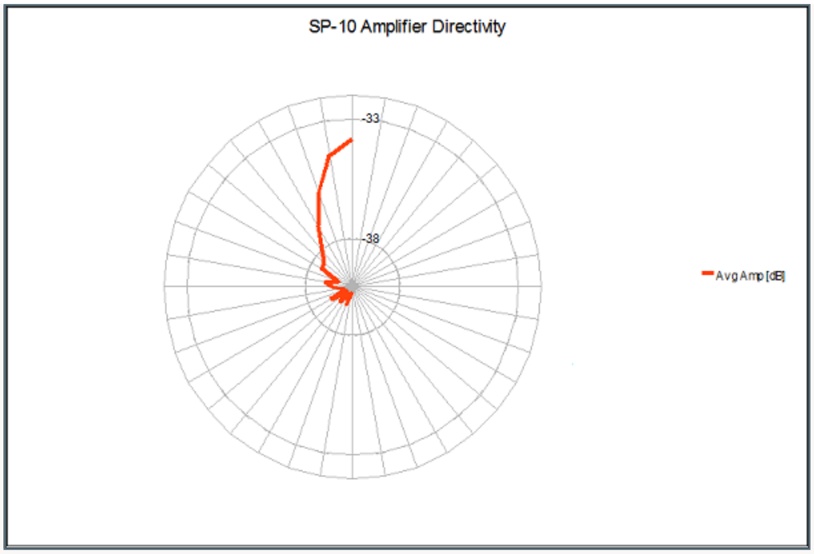
Range of frequencies

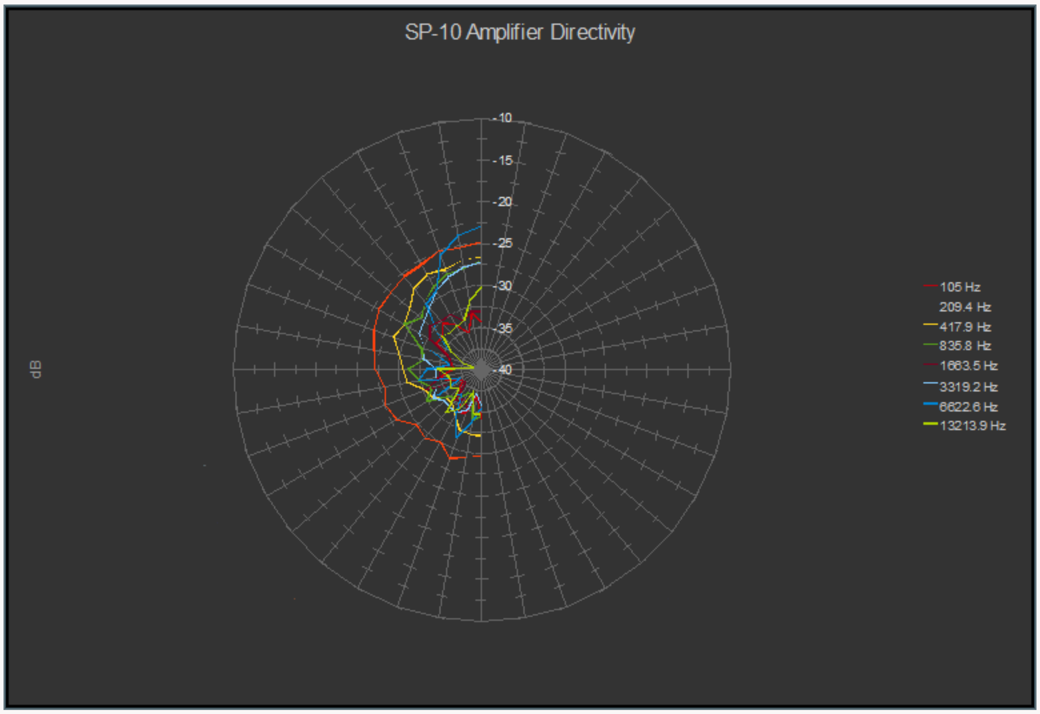


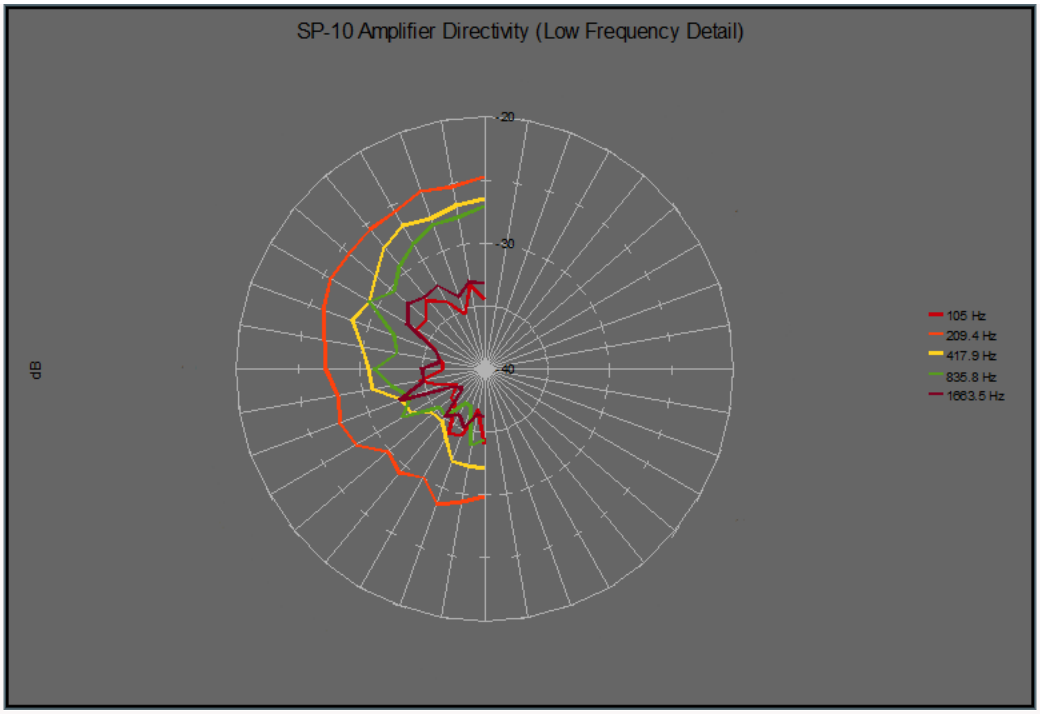
Detail of low frequencies



The plasma loudspeaker is nearly omnidirectional, with total volume dropping slightly past the 90 degree mark. Note the amplitude actually grows as we move from on axis (0 degrees) to the 90 degree mark-- the peak is actually to the side of the unit. In the individual frequency tests, the low frequencies all share a strong increase in amplitude at 180 degrees while the higher frequencies' curves remain more or less circular in shape. In fact, the intensity of the spike at 180 degrees seems inversely proportional to the frequency: the lower frequencies have the largest spike This effect is expected.


SP-10 Amplifier Directivity
-33
-38
Avg Amp [dB]


SP-10 Amplifier Directivity
-10
-15
-20
-25
-30
-35
-40
dB
105 Hz
209.4 Hz
417.9 Hz
835.8 Hz
1663.5 Hz
3319.2 Hz
6622.6 Hz
13213.9 Hz



The Fender is very directional. Its performance degrades sharply as the listener moves off axis. Higher frequencies begin to disappear while lower ones remain (this time the effect is much more pronounced), messing up the frequency response, while the total integrated volume continues to drop as a whole.

Sensitivity

Sensititivity is defined as the relationship between input power and peak Sound Pressure level, typically measured in decibels per watt per meter.

Fender SP-10

We provided a constant pink noise signal to the Fender using the YMEC signal generator and adjusted the volume control to finally read an average output of 85.0dB SPL at a distance of 1 meter at .60V with an 8 ohm impedance. After calculation, we obtained a value of 97.6dB/W/m for the sensitivity of the SP-10. A second iteration of the measurements was done with the Decibel 10 noise meter, this time yielding a sensitivity of 99.32dB

Show Calculations

Plasma Speaker

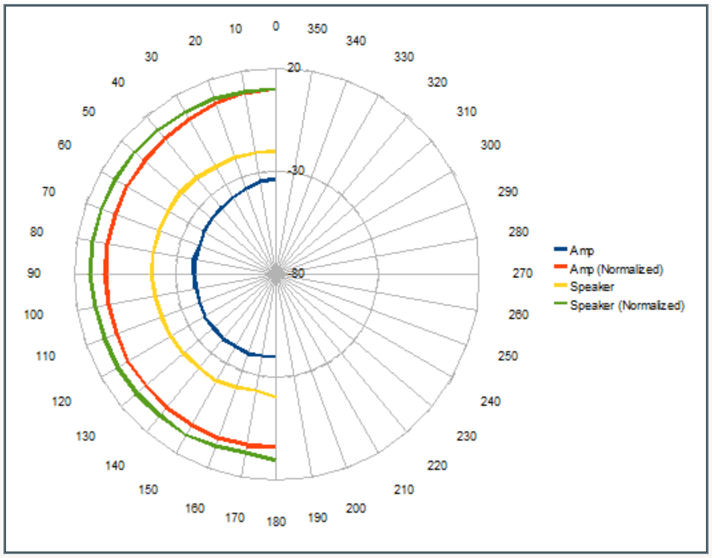
For the plasma speaker, we measured the input current and voltage to obtain a power reading of 2.4A * 79V = 190W used to output 70.7dB at 10cm. After calclucation we obtained a value of 21.6 dB/W/m for the sensitivity of the plasma speaker (driven at 3.769MHz with the long-cable+cage setup). A second iteration of the measurements was repeated using the Decibel 10 measurement software, giving a result of 48.84 dB/W/m using the short cable setup at 3.99MHz and 24.5cm.

Show Calculations

One might be tempted to say the plasma speaker's sensitivity is only about 5 times as bad as the Fender amplifier. However, we must remember that decibels are logarithmic units; an extra 3 dB increase in sensitivity means half the power is needed for the same pressure output. The Fender SP-10 is 70 decibles, or 7 orders of magnitude more sensitive than the plasma speaker (42,276,000:1). However, the second set of measurements, usng the Decibel 10 noise meter and the plasma speaker in its original orientation (short cable) at 3.99 MHz finds a difference of only 50dB.

Normalizing to Directivity

The one flaw with this method of measuring is that the conventional speaker is **intended** to be fairly uni-directional. The plasma speaker is sounding in all directions, but our on-axis sensitivity measurement is only picking up a small portion of it, where the SP-10's strongest signal is on-axis. To make a proper comparison, we must make a calculation of the average sensitivity over the 0-180degree space.

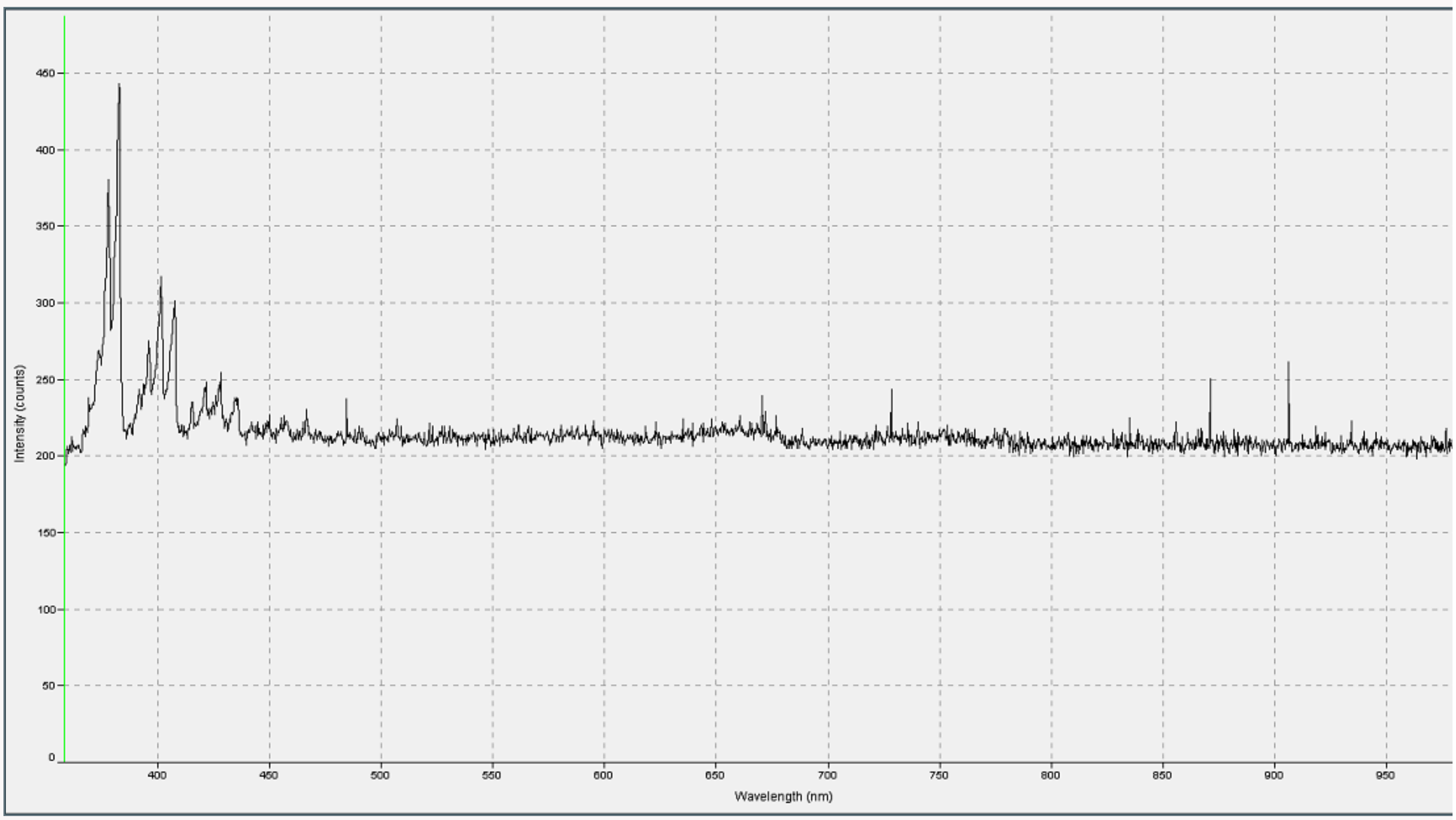


Normalizing the directivity curves to 10dB

After integrating over the directivity space and dividing by (18 intervals*10dB) to find the average value, the plasma speaker's sensitivity (over the 180 degree range) is only about 20dB lower than the amplifier's. (69.64dB/W/m vs 49.21dB/W/m).

Spectroscopy

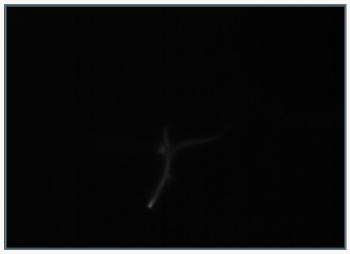
Using OceanOptics spectroscopy software and low light conditions a visual spectroscopy (as opposed to audio) of the plasma discharge was obtained.



The large spikes in the lower end of the spectrum match our visual observations of purple/blue light emnating from the discharge

The spectroscopy's strongest emissions are in the lower wavelengths (<450nm), with a few small spikes here and there (670.9, 728.4, 871.6, and 906.4nm). Many of the lower end lines match the emission spectrum of oxygen and nitrogen-3. There is one instance of a possible copper emission (407.5nm), though it is also possible that it is just another nitrogen emission.

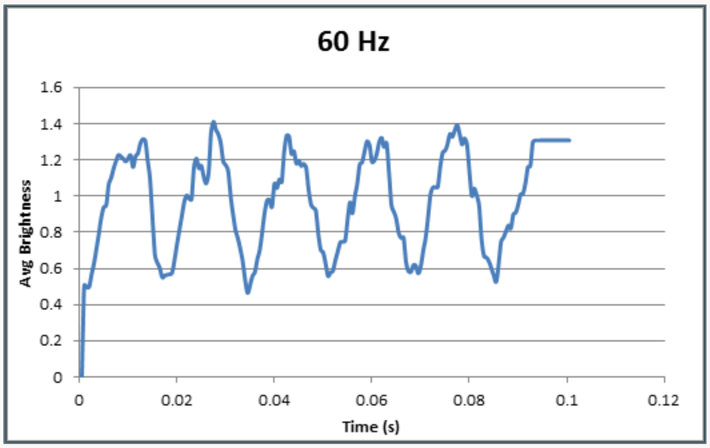
High Speed Video Analysis



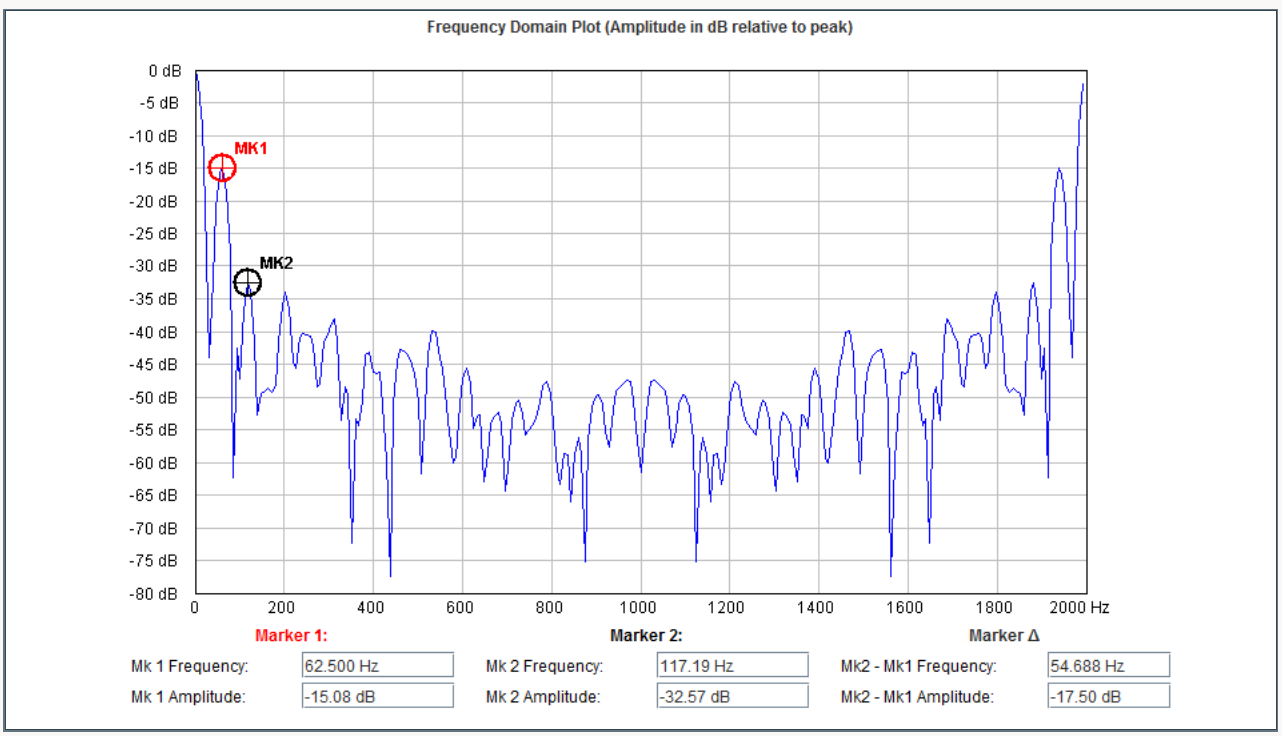
The plasma speaker plays a 200Hz tone, filmed at 2000fps. Played back at 10fps.

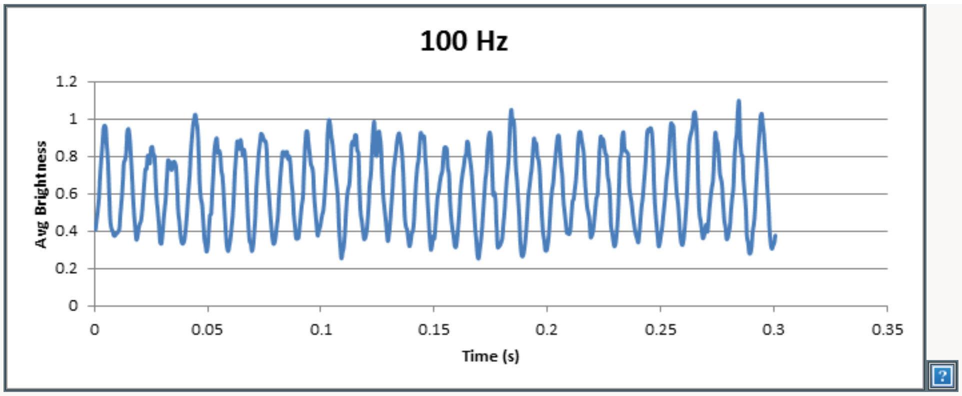
We filmed the plasma discharge at 2000fps for varying input signals to attempt to analyze the relation between the visual appearance of the discharge and the audio output. The video shows visually that the streamer appears to pulse with a regular period. The next step was to quantify this period by measuring the average brightness using a freeware image analysis program called ImageJ.

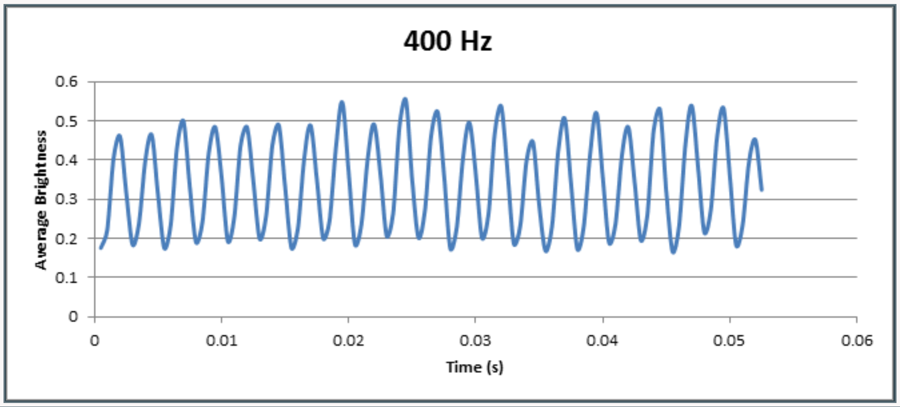
Below, raw plot of mean brightness for a 60Hz input tone

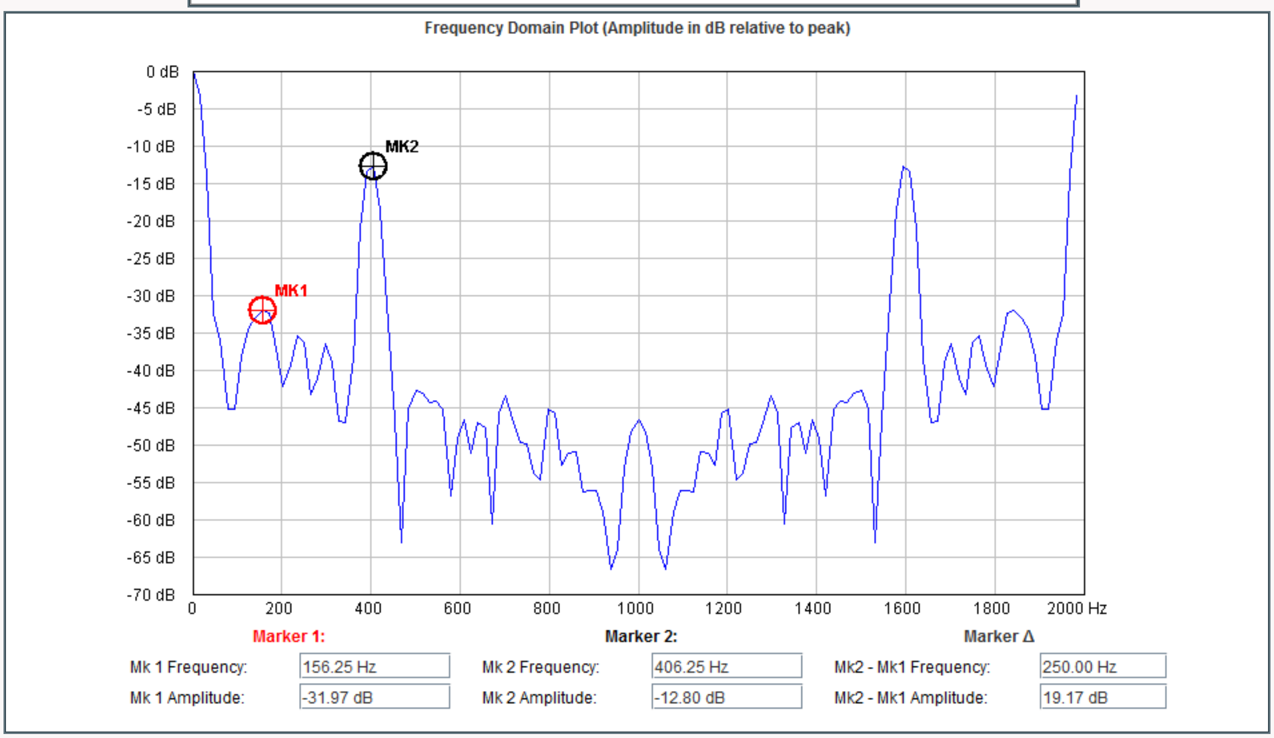


FFT power spectrum of the same

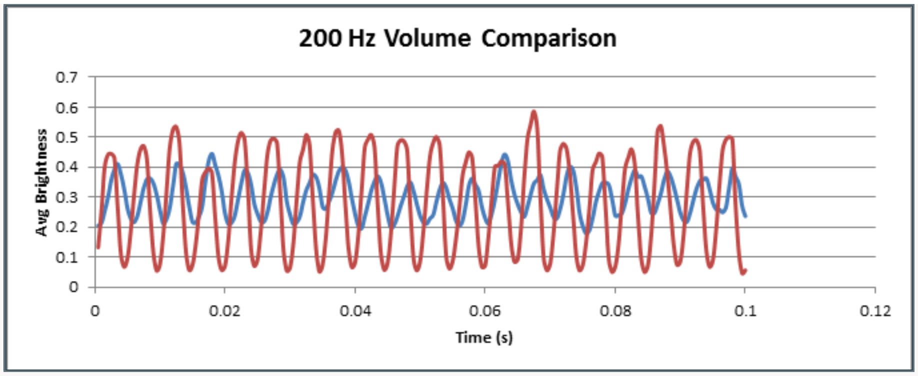


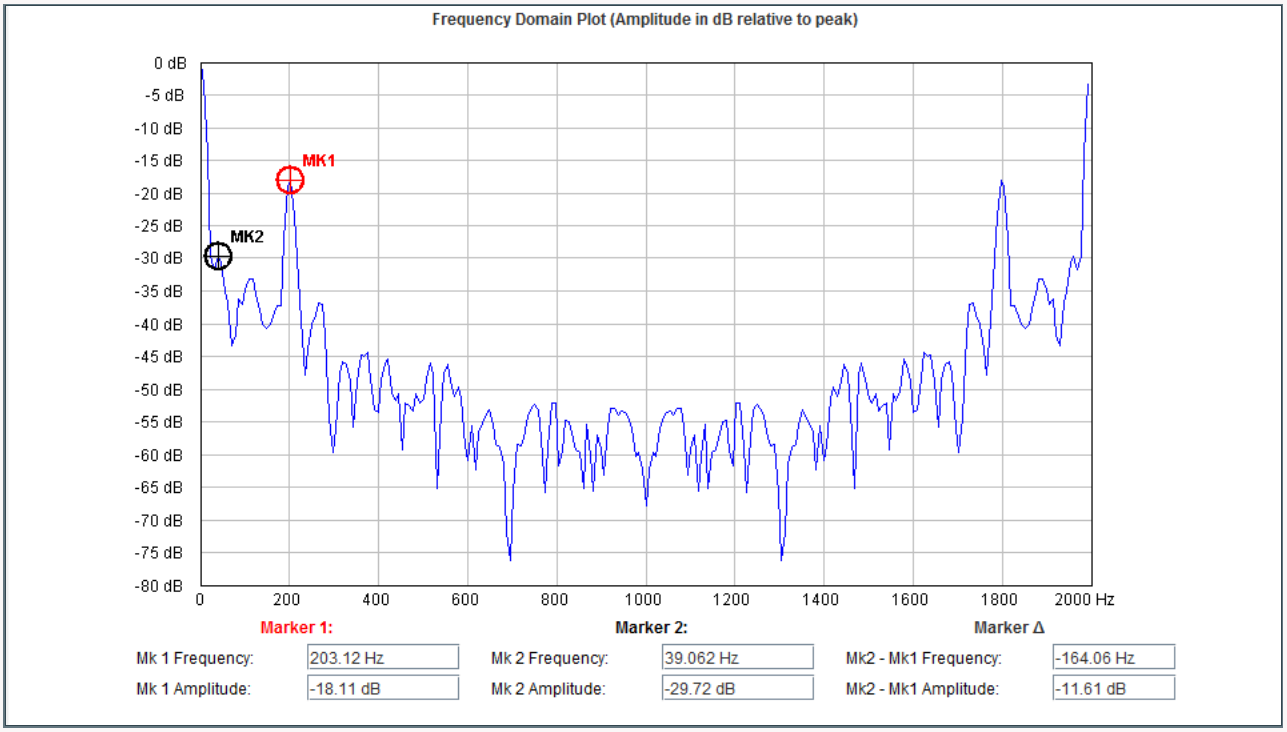


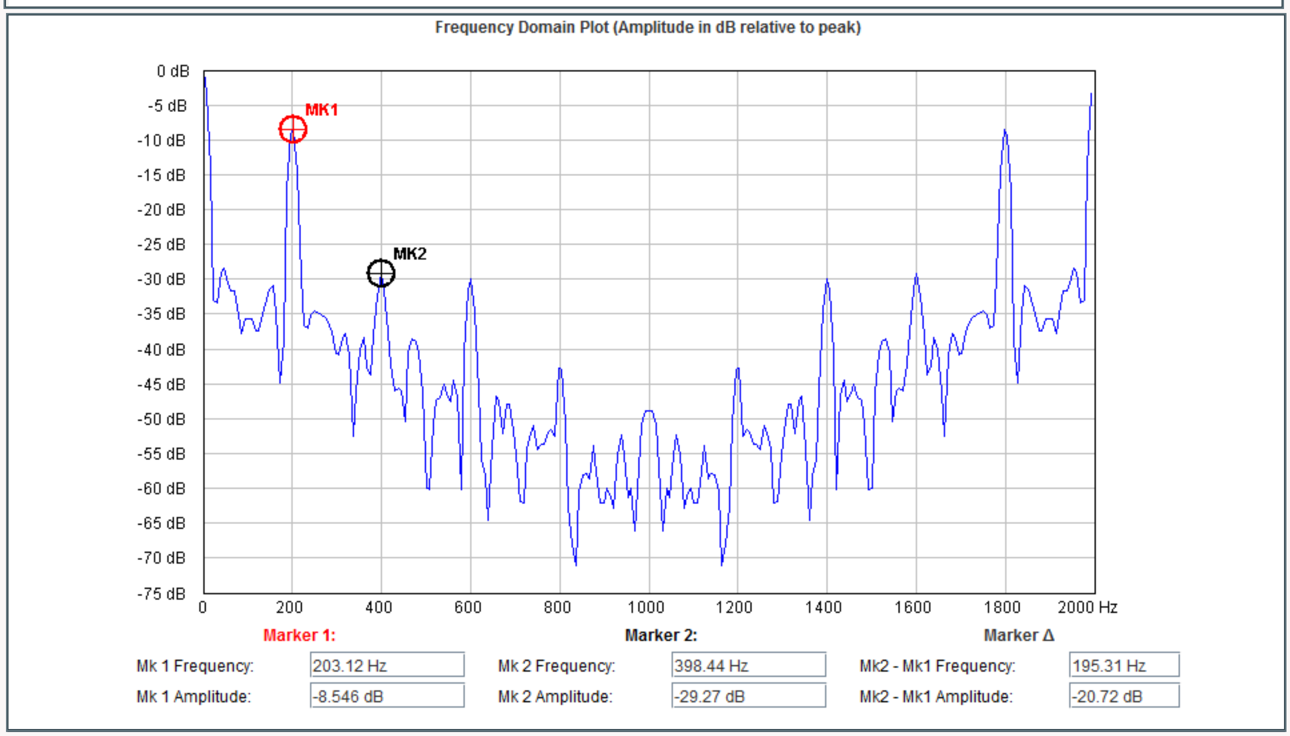




The data shows that the brightness does indeed oscillate (with an error of about 1%) to the frequency of the input signal. Next, we began some analysis on volume.


200 Hz Volume Comparison
Avg Brightness
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
0.02
0.04
0.06
0.08
0.1
0.12
Time (s)


Frequency Domain Plot (Amplitude in dB relative to peak)
0 dB
-5 dB
-10 dB
-15 dB
-20 dB
-25 dB
-30 dB
-35 dB
-40 dB
-45 dB
-50 dB
-55 dB
-60 dB
-65 dB
-70 dB
-75 dB
-80 dB
0
200
400
600
800
1000
1200
1400
1600
1800
2000 Hz
MK1
MK2
Marker 1:
Marker 2:
Marker Δ
Mk 1 Frequency: 203.12 Hz
Mk 1 Amplitude: -18.11 dB
Mk 2 Frequency: 39.062 Hz
Mk 2 Amplitude: -29.72 dB
Mk2 - Mk1 Frequency: -164.06 Hz
Mk2 - Mk1 Amplitude: -11.61 dB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-30 dB
-35 dB
-40 dB
-45 dB
-50 dB
-55 dB
-60 dB
-65 dB
-70 dB
-75 dB
0
200
400
600
800
1000
1200
1400
1600
1800
2000 Hz
MK1
MK2
Marker 1:
Marker 2:
Marker Δ
Mk 1 Frequency: 203.12 Hz
Mk 1 Amplitude: -8.546 dB
Mk 2 Frequency: 398.44 Hz
Mk 2 Amplitude: -29.27 dB
Mk2 - Mk1 Frequency: 195.31 Hz
Mk2 - Mk1 Amplitude: -20.72 dB

The graphs above represent two different video samples: both of a 200hz input tone, but with different volume levels (one at output level 30, the other at 100). The amplitude of the brightness oscillation increased by a sizable amount--approximately by a factor of 2. A more interesting note is that the FFT revealed the louder input to exhibit frequencies of approx. 400 and 600Hz in addition to the original input of 200Hz. These are harmonic distortions, which matches our auditory and objective distortion evidence.

Conclusions

The plasma speaker has unparalleled performance and fidelity in the higher ranges. However, it is countered by a weakness and increase in distortion at low levels. The unique nature of its "massless" driver gives it very low colouration, but again is offset by an extremely insensitive, inefficient performance. Its omnidirectional ability is potentially very valuable. While its poor frequency response renders it useess as a high quality standalone speaker, as a specialized tweeter it may do very well in combination with a subwoofer or other low-mid system. Low frequencies are naturally less directional than high frequencies, so a conventional subwoofer in combination with a plasma tweeter could theoretically show an even frequency response while keeping omnidirectionality.

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