Last Updated: 17 October 2016

Introduction:

The Bottlehead Crack tube amplifier (along with its Speedball upgrade) is a well-known headphone amplifier in the audiophile community. It is an amplifier with an output impedance of about 120 Ω, and it is known for being one of the best amplifier matches for the acclaimed Sennheiser HD600s, HD650s, and HD800s, despite costing a few times less than its competition at $300.

Equipment Used:

- Hakko FX888D Soldering Station
- Hakko CHP-170 Wire Cutter
- Klein Kurve 11055
- 60/40 Rosin Core Solder, 0.062” and 0.032” diameter
- Soldering Wick
- Third Hand Tool
- Tweezers
- Ruler
- Screwdrivers
- BNC Cables
- BNC-F to RCA-M and RCA-F to ¼”-M TRS adapters
- Agilent U3402 DMM
- Keysight InfiniiVision MSO-X 2022A Mixed Signal Oscilloscopes (and Wave Gen)
- Decade Resistor (set at 10 kΩ to discharge capacitors).

List of Current Mods:

- TRS Jack Startup Voltage Mod (T and R pin shorted to ground. Utilizes a switching mechanism when headphones are plugged in)
- Blue Alps pot install (replacing stock pot)

Part 1: The Build and Initial Testing Measurements

Procedure:

There are a few things to note:

1. This product is a product sold by the Bottlehead company.
    a. The instruction / procedure manual is not made available freely and is only sent after an order is placed.
2. The build takes approximately 10 hours total, not including mistakes or cosmetic finishing.

Therefore, the build won't be covered, but (part) of the process can be seen below. Total build time, including painting of the top plate and initial testing, was about 15 hours.

Figure 1.1. Initial Parts.

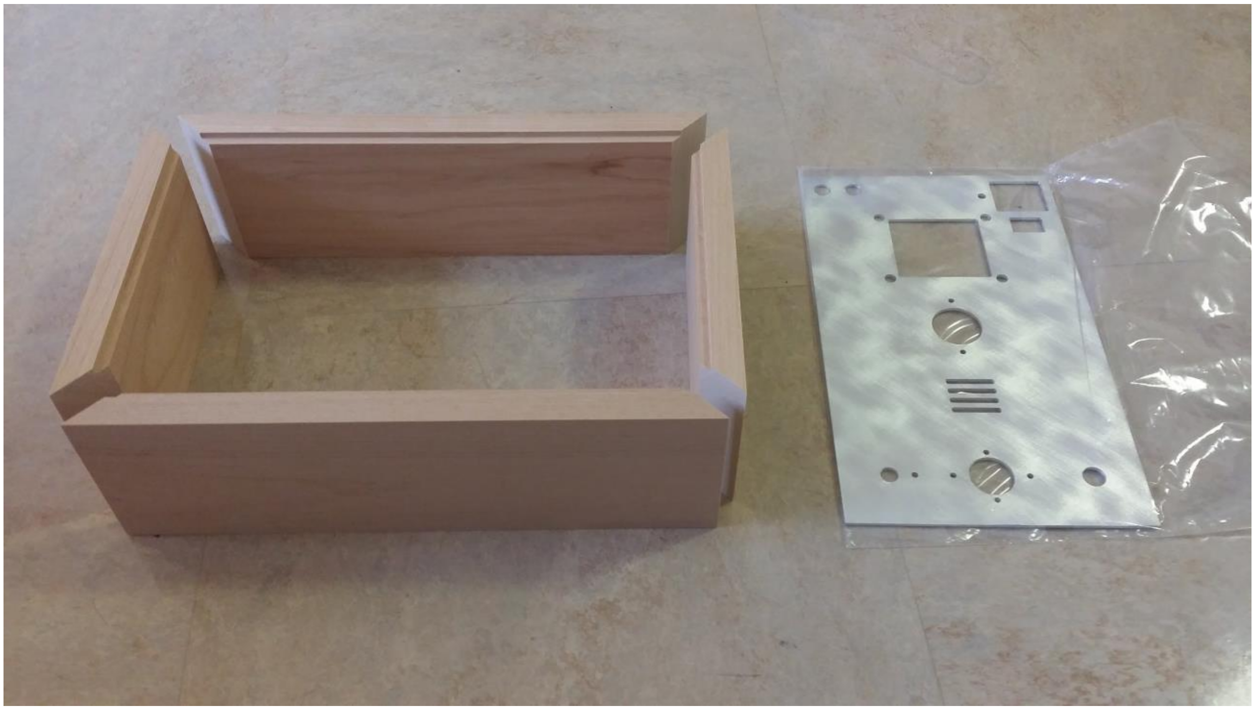


Figure 1.2. Unbuilt Chassis

Figure 1.3. Assembled Chassis and Faceplate


Figure 1.4. Top Side; Fully Assembled with Tubes Installed

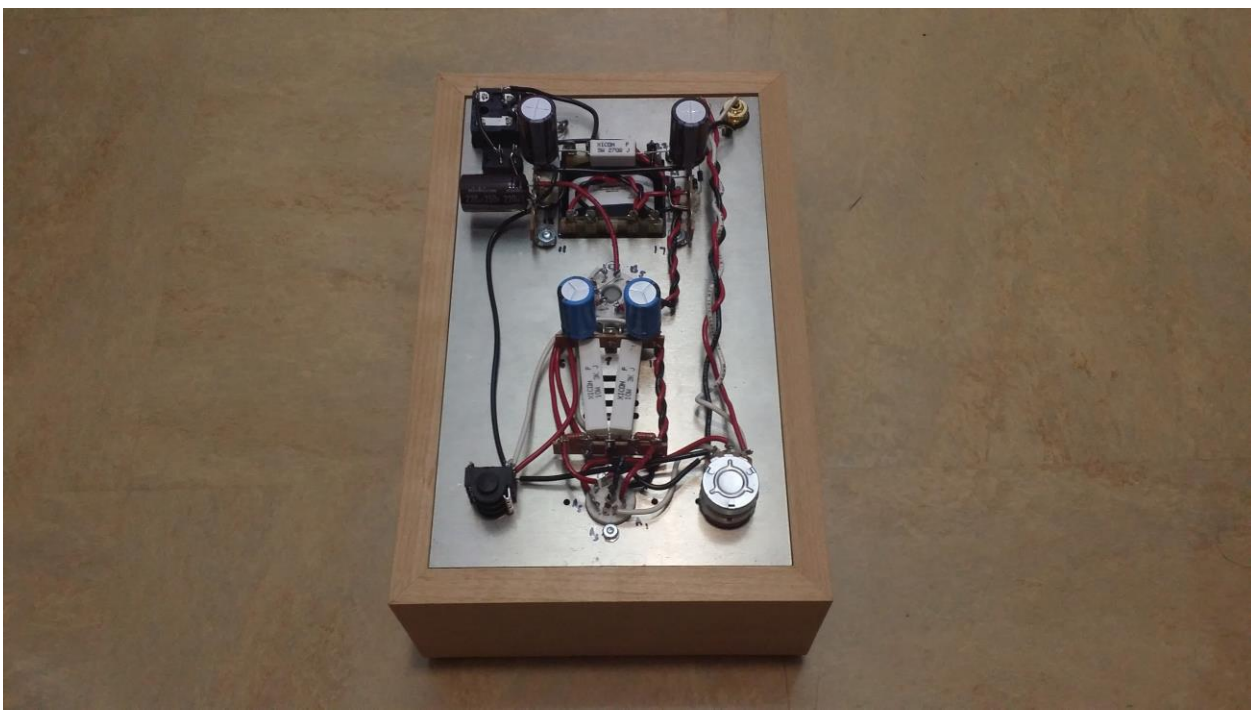


Figure 1.5. Faceplate Bottom Wiring; Full View.

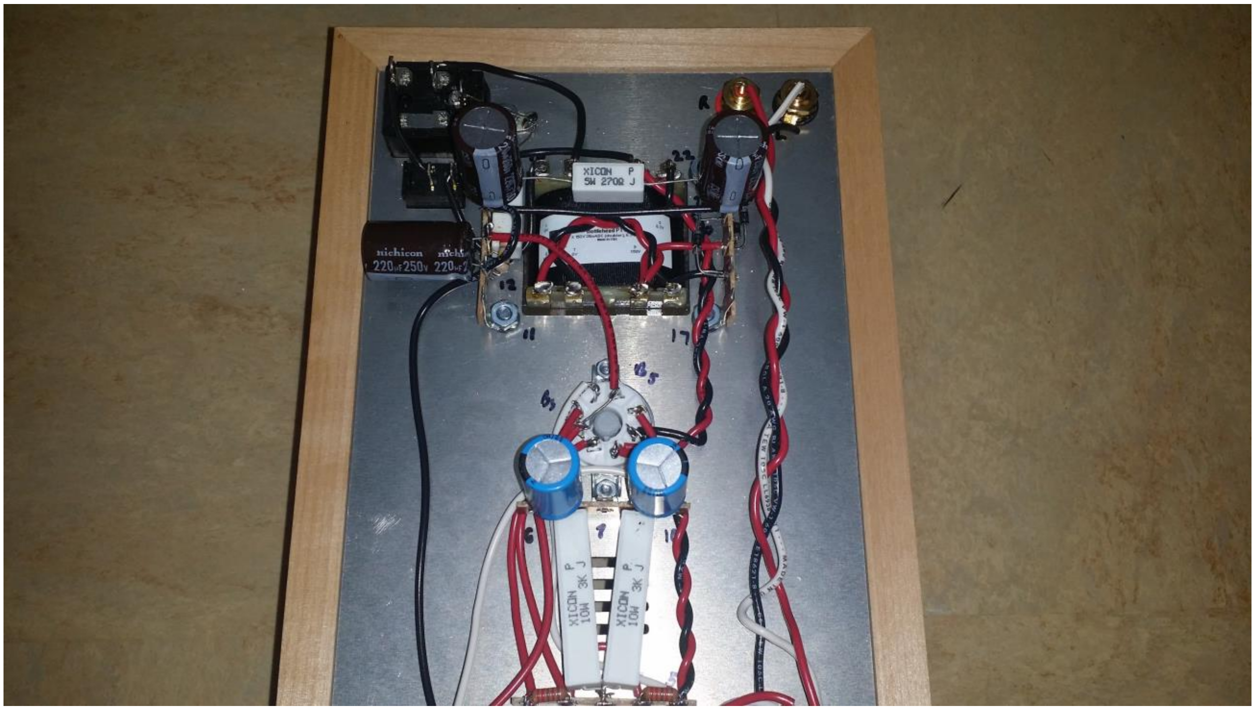


Figure 1.6. Faceplate Bottom Wiring; Top Half View.

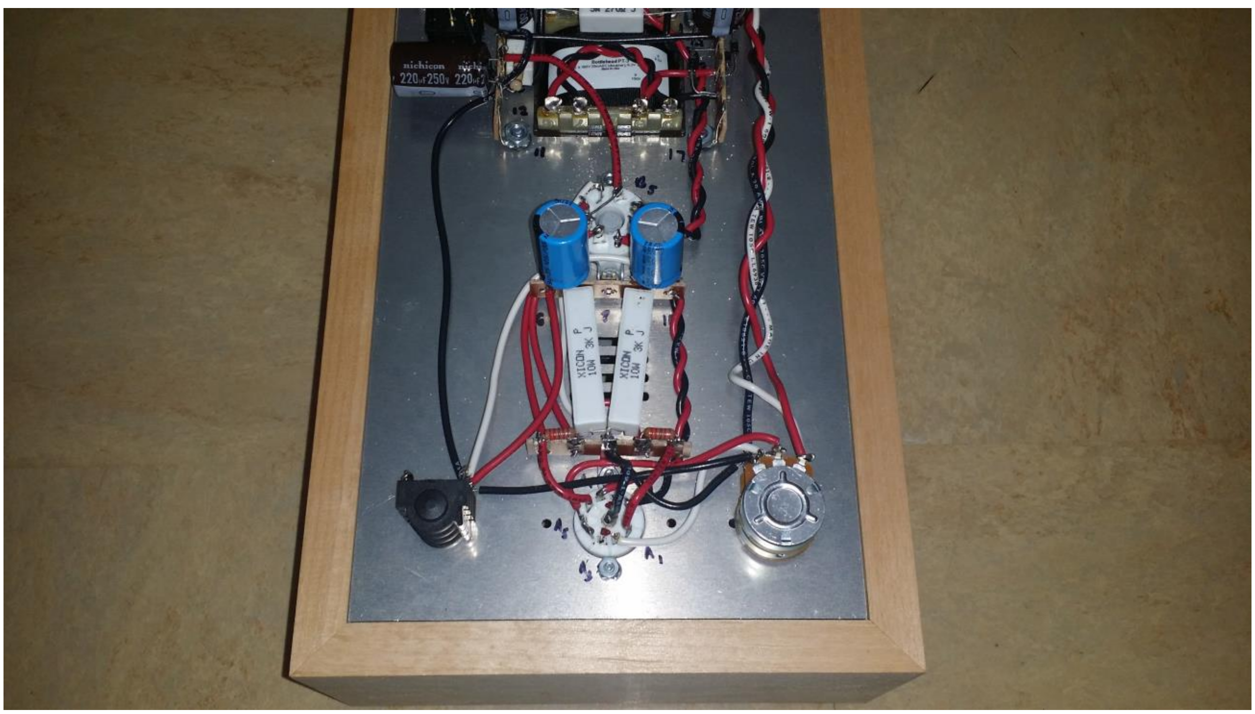


Figure 1.7. Faceplate Bottom Wiring; Bottom Half View.

List of Issues During and Post Build:

1. Crack Assembly
    - Didn't wait long enough for paint to dry (waited 1 day instead of 2 days).
        i. Paint is slightly chipped in some places and dented where I installed components since it was still wet underneath.
    - Melted Power Switch.
    - Shorted a capacitor to ground during voltage tests. No damage, but scary sparks.
    - Lost initial fuse.
2. Channel Imbalance
    - Remedy – replace stock potentiometer with Blue Alps potentiometer.
3. Noise
    - Remedy – check for loose connections using a chopstick and re-solder loose connections.

Data:

Note that a tolerance of 10-15% is acceptable and expected.

Terminal	Measured Resistance (Ω)	Expected Resistance (Ω)	Percent Difference (%)
1	varies	*	null
2	varies	*	null
3	0.085	0	null
4	varies	*	null
5	varies	*	null
6	2.479	2.4k	+3.292%
7	2.9678k	2.9k	+2.338%
8	.09	0	null
9	2.923k	2.9k	+0.793%
10	2.489k	2.4k	3.708%
12	.225	0	null
13	264k (unplugged)	* climbs to 270k	-2.222%
14	.056	0	null
20	.058	0	null
22	.078	0	null
B3	2.9659k	2.9k	+2.272%
B6	2.9240k	2.9k	+0.828%
RCA: Ground Lug	.08	0	null
RCA: Center Pin	103.83k (l) 105.89k (r)	90k-100k	~+9.3% (l) ~+11.463% (r)

Table 1.1. Resistance Measurements of Build (Stock)

Terminal	Measured Voltage (V)	Expected Voltage (V)	Percent Difference (%)
1	87.8	75-90	~+6.42%
2	168.8	170	-0.706%
3	0.000668	0	null
4	168.8	170	-0.706%
5	81.25	75-90	-1.52%
6	0.000420	0	null
7	109.23	100	+9.23%
8	0.000863	0	null
9	103.95	100	+3.95%
10	0.000395	0	null
11	0.000962	0	null
12	0.000043	0	null
13	168.85	170	-0.676%
14	0.0003452	0	null
15	190.17	185	+2.80%
20	0.000427	0	null
21	211.26	206	+2.55%

Table 1.2. Voltage Measurements of Build (Stock)

Terminal	Measured Voltage (V)	Expected Voltage (V)	Percent Difference (%)
A1	80.63	90	-0.10%
A2	0.000506	0	null
A4	0.000406	0	null
A5	0.000406	0	null
A6	87.08	90	-3.2%
A7	0.000407	0	null
A9	0.000744	0	null
B1	87.205	90	-2.8%
B2	168.71	170	-0.759%
B3	109.33	100	+9.33%
B4	80.54	90	-11.0%
B5	168.73	170	-0.747%
B6	103.924	100	+3.92%
B7	0.00080	0	null
B8	0.000554	0	null

Table 1.3. Voltage Measurements of Build Cont. (Tube Sockets) (Stock).

Discussion:

The percent differences from the expected are calculated as follows:

$$Percent\ Difference = \frac{Measured - Expected}{Expected} \times 100$$

All the percent differences were below 10%. Therefore, all the measurements checked out since they all fell within the specified 15% tolerance range. Also, all resistances and voltages that were supposed to be 0 were measured below a [mV]/[mΩ], which is essentially 0.

Since all the voltages and resistances checked out, we then proceed to turn on and test the amplifier.

For power, researching tells us that the Bottlehead Crack consumes about 30 W per hour.[1] The calculation below calculates how much power would be used in a month when it's on for 8 hours a day.

Calculation 1.1: Power Usage

$$[\frac{kWh}{month}] = \frac{30\ [W]}{[hr]} \times \frac{8\ [hr]}{1\ [day]} \times \frac{30\ [days]}{1\ [month]} = 7200\ [\frac{Wh}{month}] = 7.2\ [\frac{kWh}{month}]$$

Further research shows that the average American household uses 911 [kWh/month].[2] The calculation below determines how much of that would be attributed to the amplifier.

Calculation 1.2: Power Usage with Respect to Average per Household per Month

$$Percent\ of\ Average = \frac{7.2}{911} \times 100 = 0.8\%$$

The usage of this amplifier should therefore be very sustainable since its power usage is only 1% of the average American household when used 8 hours per day. Most people would likely listen to music with headphones for much less than 8 hours daily, making the cost of operating the Bottlehead Crack negligible.

Part 2: Distortion

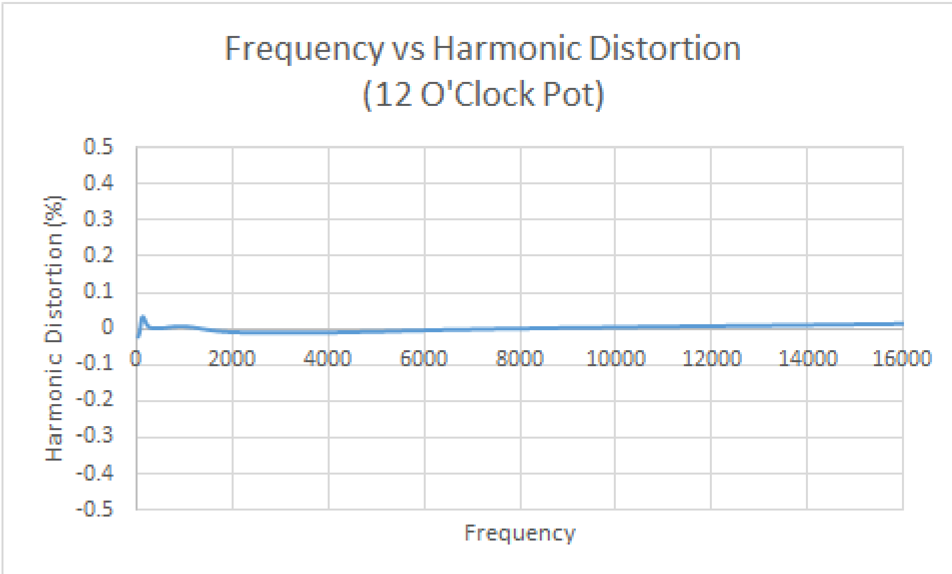
Procedure:

To measure the distortion, connect the input RCAs to the waveform generator and the output ¼” TRS (stereo) jack to the inputs of the Scope. Set the pot to its 12 o’clock position. Set the waveform to a $1V_{pp}$ sine wave with no DC offset. Starting at a 31.25Hz input frequency, take as many measurements of the output frequency as possible and record them. Then average them to get the approximate output frequency corresponding to the respective input frequency. Then increase the frequency by 2x every time and perform the same measurements. Stop at 16 kHz. Perform the measurements again with the pot at its maximum position.

Data:

Input Frequency (Hz)	Output Frequency (Avg) (Hz)	Distortion (%)
31.3	31.29296	-0.0225
62.5	62.49424	-0.0092
125	125.042	0.0336
250	250.014	0.0056
500	500.0076	0.0015
1000	1000.066	0.0066
2000	1999.712	-0.0094
4000	3999.588	-0.0103
8000	8000.06	0.0008
16000	16002.2	0.0138

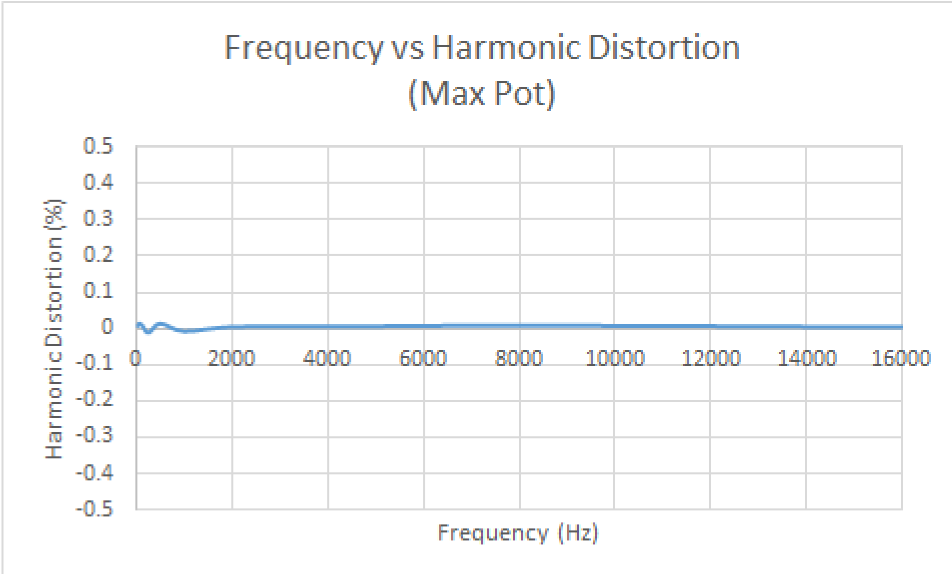
Table 2.1: Harmonic Distortion Data, 12 O’Clock Pot



Graph 2.1: Plot of Table 4 (Harmonic Distortion Relative to Frequency with Pot at 12 O'Clock).

Input Frequency (Hz)	**Output Frequency (Avg) (Hz)**	**THD (%)**
31.3	31.30236	0.0075
62.5	62.50876	0.0140
125	125.0104	0.0083
250	249.9708	-0.0117
500	500.0692	0.0138
1000	999.924	-0.0076
2000	2000.088	0.0044
4000	4000.2	0.0050
8000	8000.68	0.0085
16000	16000.6	0.0038

Table 2.2: Harmonic Distortion Data, Maximum Pot



Graph 2.2: Plot of Table 5 (Harmonic Distortion Relative to Frequency with Pot at Max).

Discussion:

Both graphs, and by extension tables, show that the distortion is very close to 0% for all frequencies, which is ideal. Generally, total harmonic distortion is reported as the harmonic distortion at the 1 kHz frequency, but it was unclear how to actually measure the THD with an Oscilloscope. Regardless, in this case, the distortion would be at about 0.007% with respect to the pot in its 12 o’clock position. The overall distortion, with respect to all the recorded frequencies and the pot configuration, is calculated as follows:

Calculation Set 2.1: Overall Distortion

$$D_{12\ o'clock\ pot} = \frac{\sum\ D\ @\ all\ Frequencies}{\#\ of\ Frequencies} = 0.00105\%$$

$$D_{max\ pot} = \frac{\sum\ D\ @\ all\ Frequencies}{\#\ of\ Frequencies} = 0.0046\%$$

$$Percent\ Difference = \frac{0.0046-0.00105}{0.00105} \times 100 = +338.1\%$$

Calculation set 2.1 shows that the average distortion at 12 o’clock (generally the optimal listening position for most headphone amplifiers) is about 0.001%. This is inaudible. The distortion at its maximum pot position increases to 0.0046%, which is a 300% increase relative to the distortion at the 12 o’clock position. This demonstrates that an amplifier adds distortion to a signal the more it tries to amplify it, but in this case, it is still insignificant since a distortion of 0.0046% is not audible nor is it dangerous to audio equipment.

Part 3: Frequency Response

Procedure:

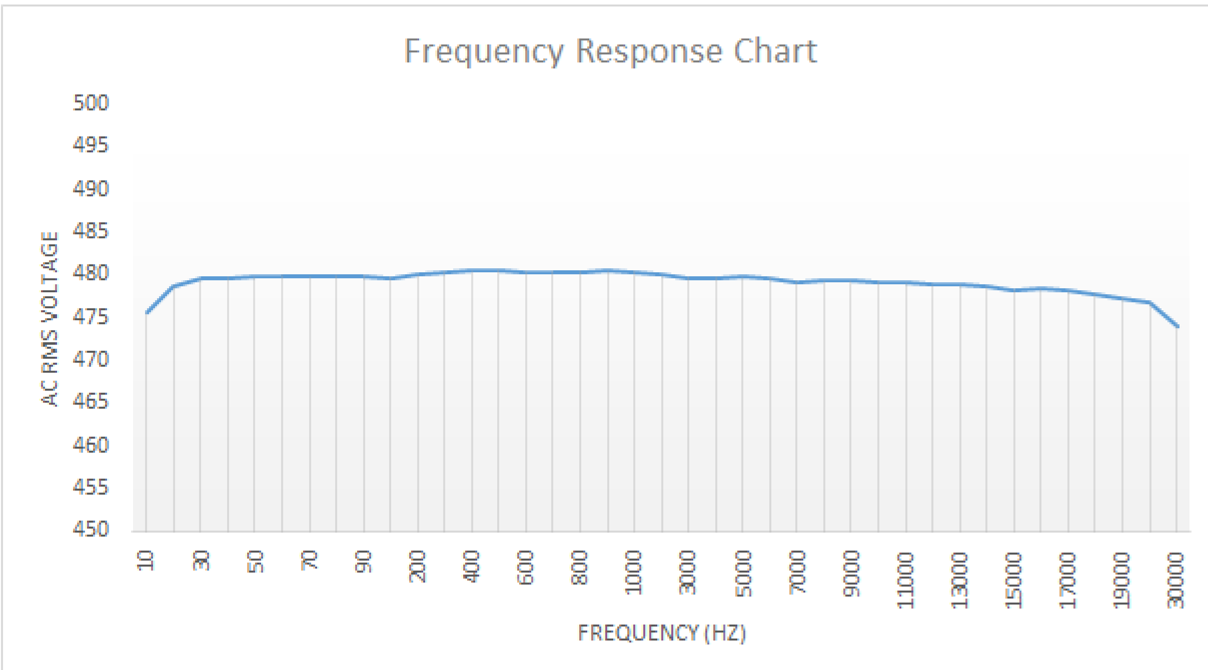
The best way to measure frequency response would be to graph how the amplifier responds to a frequency sweep. Without a frequency sweep function, each individual frequency needs to be measured instead. In this case, and using the same wiring configuration, set a 1 V_{pp} sine wave with no DC offset, and set the pot to its 12 o'clock position. Starting at a waveform with a 10 Hz frequency, measure the output AC RMS voltage multiple times and then take their average. Then increase the frequency as follows and perform the same measurements: 10 Hz - 100 Hz in increments of 10 Hz, 100 Hz - 1000 Hz in increments of 100 Hz, 1000 Hz to 20000 Hz in increments of 1000 Hz, and 20000 Hz - 30000 Hz in increments of 10000 Hz.

Data:

Frequency (Hz)	AC RMS, ~2 Cycles (V) (Average of 10)	Frequency (Hz)	AC RMS, ~2 Cycles (Average of 10) (V)
10	475.575	2000	480.063
20	478.767	3000	479.702
30	479.53	4000	479.706
40	479.621	5000	479.769
50	479.73	6000	479.643
60	479.839	7000	479.223
70	479.827	8000	479.309
80	479.853	9000	479.331
90	479.9	10000	479.19
100	479.708	11000	479.095
200	480.053	12000	478.831
300	480.375	13000	478.785
400	480.481	14000	478.657
500	480.581	15000	478.313
600	480.387	16000	478.38
700	480.33	17000	478.09

800	480.398	18000	477.79
900	480.443	19000	477.353
1000	480.362	20000	476.776
		30000	474.01

Table 3.1. Frequency Response Data.



Graph 3.1. Plot of Table 6.

Discussion:

Graph 3.1 reveals that the response of the amplifier is relatively flat, especially when considering the actual audible human range (20 Hz - 20 kHz). It begins to roll off significantly past the audible human range, but fortunately, this does not matter for listeners of the amplifier. It is therefore a rather ideal amplifier since, theoretically, the frequency response chart of any amplifier should be as flat as possible since its main purpose (disregarding the music enthusiast / audiophile world) is to simply amplify the original input source such that the amplified source is the same as the original input source except louder. Theoretically, no distortion, noise, or “color” (change in any output frequency) should be added. In the case of the Crack, we can see that the frequency response indicates a “warm” sound-signature, as described in the audio world, and this also agrees with the consensus of this amplifier’s perceived characteristics.

The largest percent difference between the lowest and highest value measured and within the audible range is:

$$Percent\ Difference = \frac{480.581\ (900\ Hz) - 476.776\ (20\ kHz)}{476.776} \times 100 = 0.798\%$$

This means that at any frequency, the output voltage relative to two different frequencies is, at most, 1% different. Noting that this amplifier has a maximum V_{rms} output of 10 V into a 300 Ω load, this means that the output voltage between two frequencies is, at most, 0.1 V with respect the load at which it is considered to perform its best at. This is essentially inaudible, and this will also be seen in the next section, where channel imbalance is approximately measured to be audible at greater than a 25% voltage difference. A 1% difference between frequencies is clearly far less than a 25% difference.

Part 4: Channel Imbalance

Procedure:

Measuring channel imbalance will depend on the wave generator used. In the case of a single output waveform generator, each channel's AC RMS voltage will have to be measured separately. Set the scope to measure the AC RMS value over its full cycle. Then connect either channel of the scope's input RCA to the waveform generator. On the waveform generator, set a 1 V_{pp} sine wave with no DC offset at a frequency of 1 kHz. Then measure the AC RMS voltage at pot positions of: off, 7:30, 9 o'clock, 10:30, 12 o'clock, 1:30, 3 o'clock, 4:30, and max. Switch the input channel before moving onto the next pot position for maximum accuracy. Also take multiple measurements at each position and average them for maximum accuracy.

Data:

Left Channel		***Right Channel***		**Percent Difference Between Left and Right Channel**
Pot Position	**AC RMS - Full Cycle (V)**	**Pot Position**	**AC RMS - Full Cycle (V)**	
Off	0.002	Off	0.003	-39.394
7:30	0.0195	7:30	0.007	+167.156
9:00	0.174	9:00	0.131	+33.039
10:30	0.335	10:30	0.243	+38.284
12:00	0.488	12:00	0.357	+36.605
1:30	0.860	1:30	0.680	+26.319
3:00	2.105	3:00	1.788	+17.770
4:30	2.910	4:30	2.453	+18.633
Max	2.924	Max	2.475	+18.157

Table 4.1. Channel Imbalance Data

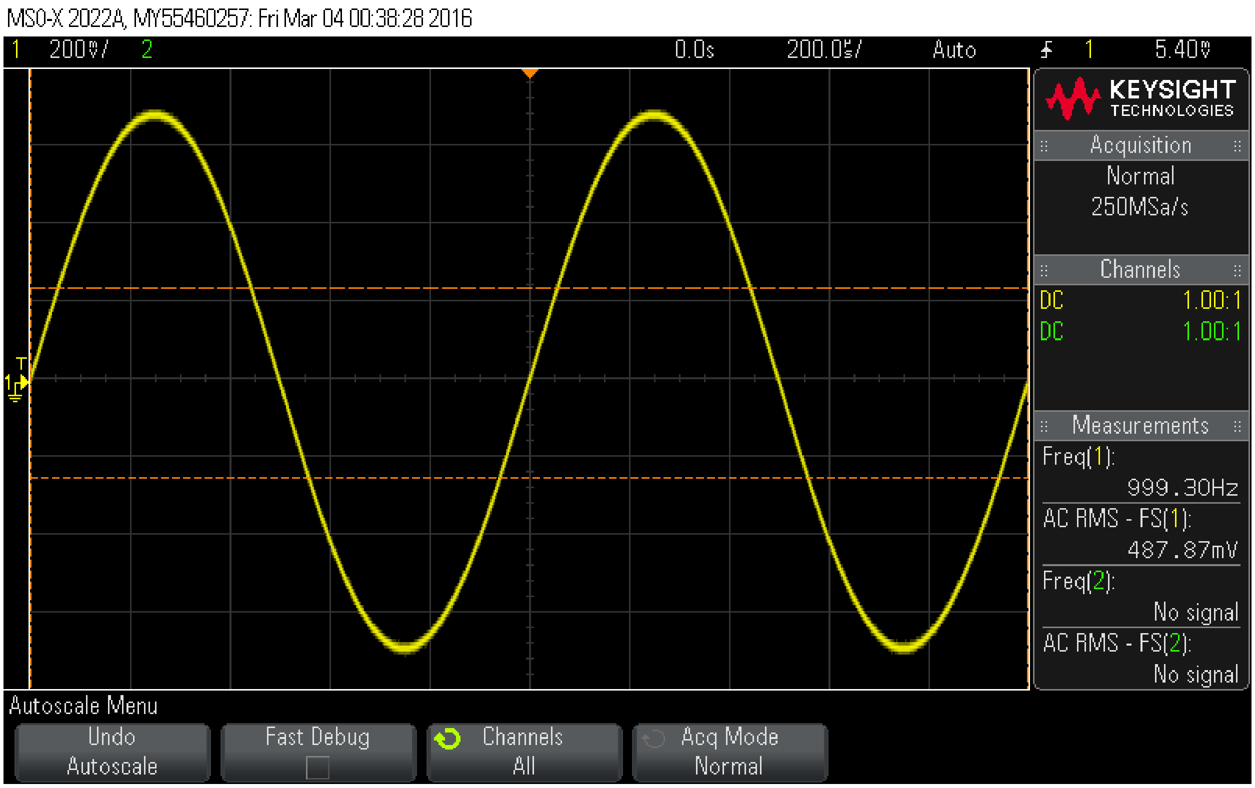


Figure 4.1. Left Channel Response at 12 O'Clock Position (Example Picture).

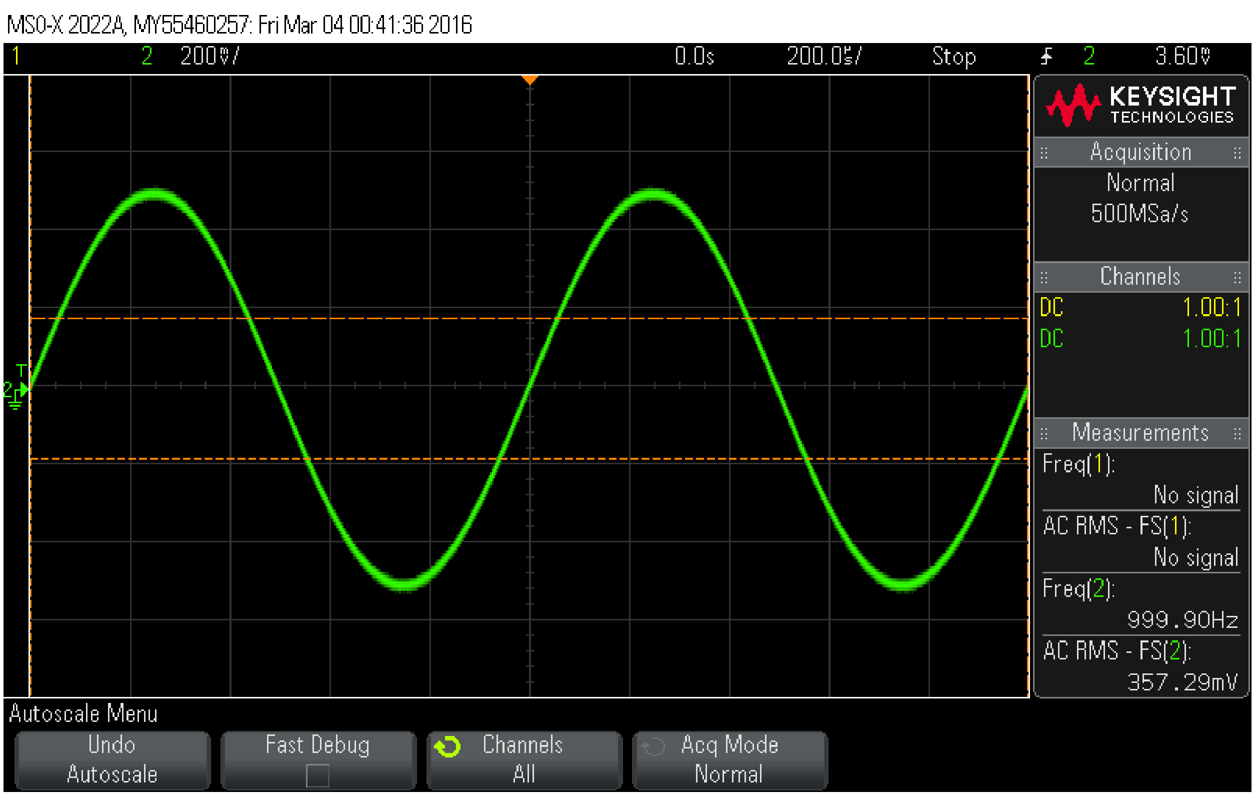


Figure 4.2. Right Channel Response at 12 O'Clock Position (Example Picture).

Discussion:

Note that Table 4.1 shows that the pot is logarithmic rather than linear. This is because human hearing is logarithmic rather than linear.

The percent difference between the left and right channel is calculated as follows:

$$Percent\ Difference = \frac{V_{left} - V_{right}}{V_{right}} \times 100$$

Listening to the amplifier with headphones reveals a left channel bias up until about the 1:30 pot position. According to the data, this is when the voltages begin to drop below a 30% difference. Furthermore, as the pot is increased to its max, the difference between the two channels begin to drop to about an 18% difference with the left channel still having more voltage. Tying it with the experience of listening to the amplifier, it appears that about a 25% difference between the voltage of two channels at sufficient loudness is when it becomes harder to discern whether or not there actually is a channel imbalance. For reference, we'll calculate the relative dB difference when the pot is at its maximum position.

Calculation Set 4.1. dB Difference Between Left and Right Channel at Max Pot Position

$$.\Delta dB = dB_{left,\max} - dB_{right,max} = 20\log(2.924) - 20\log(2.475) = 1.45\ [dB]$$

The relative difference between the two dB values is 1.45 [dB]. The agreed upon value at which perceived loudness is twice as loud as the previous volume is when there is a 10 [dB] increase. Noting that dB is on a logarithmic scale, 1.45 [dB] is therefore hardly an increase in perceived loudness.

The data also confirms other users' (of the Bottlehead Crack) suspicions of the stock potentiometer having an imbalance at lower volumes / pot positions. This is shown in table 4.1 with the pot at the 7:30 position. The left channel's voltage is 167% greater than the right channels voltage at this position. On the other hand, this pot batch appears to be one of the worst ones since most users report hearing an audible channel imbalance up to about the 9:30 position, rather than the 1:30 position in this case (which is about ¼ a turn increase in volume).

Part 5: Add-ons

Figure 5.1. Post-Build Staining (8 coats oil-based stain, 3 coats varnish).

Bibliography

[1]B, D. (2014, July 30). Watt usage Crack Bottlehead amp. Retrieved March 10, 2016, from http://bottlehead.com/smf/index.php?topic=6586.0

[2]U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. (n.d.). Retrieved March 09, 2016, from https://www.eia.gov/tools/faqs/faq.cfm?id=97