ELECTROSTATIC AMPLIFIERS, A SIMPLE MEASURMENT ANALYSIS

Revision	Note	Date
Rev 001	Initial Release	9/7/2020

Nectar Sound Research

Electrostatic Amplifier Measurements

Introduction:

A measurement analysis and evaluation is performed on three amplifiers.

1. The Nectar 1.0 Solid State Amplifier
2. Bottlehead ESTAT headphone amplifier (default with all 12AT7 tubes)
3. STAX SRM1/MK2 amplifier.
4. Bottlehead Re-test with rear tubes replaced with 12BH7

The equipment used is an AP515 (borrowed), a Rigol DS1054 oscilloscope, and a BM4070 RLC meter (to measure headphone capacitance). AP515 was set to 200k Ohm input impedance. No weighting. Balanced input (direct connection).

Headphone capacitance was measured for the following headphones using a BM4070 RLC meter:

1. Nectar Pollinator
2. Nectar Hive
3. R1 Conquest
4. STAX SR407.

In some respects Electrostatics Headphones and Amplifiers are a different animal than traditional driver headphones and amplifiers, so some of the concepts and ideas in this document should not necessarily be applied to the former.

In addition, this is purely a measurement analysis, and a listening test also has its merits which are not discussed here. A broader discussion on design philosophy, distortion, frequency response, what levels can humans perceive or discern, is also not discussed here. The author generally accepts that lower distortion is better, and a flatter frequency response, especially for amps, is desired. The author accepts that designs using tubes typically have higher distortion levels introduced by the tubes (typically second harmonic).

The headphones and amplifiers tested here were chosen based on availability to the author as well as the diversity of the headphones and amps (various harness and types, various amplifier design types of varying complexity).

Conclusions Drawn:

Headphone capacitance is an important factor for electrostatic headphones because the primary load seen by the amplifier is a capacitive load as opposed to an inductive load for traditional drivers. This capacitive load can draw significantly more current at higher frequencies than at lower frequencies. In addition, this capacitance is usually waste (inefficiency). Half or more of the capacitance is caused by the harness and it draws current as leakage. This means that the amplifier is mostly driving a harness, and not the headphones themselves. If you have an amplifier that can handle this (and most probably can) it is not a big issue.

The L+ to L- and R+ to R- capacitance are focused on the most since this is where the primary voltage potentials will be seen across. As an absolute measure, the Nectars had the lowest capacitance, and the R1 Conquest had the most. Relatively the STAX SR407 had the lowest capacitance per inch of harness length. This is expected since the R1 Conquest uses a very thin harness that is tightly packed together, and both the Nectar's and the Stax use a spread out silicone harness. The Stax harness is the widest and has the least capacitance, which allows for a very long harness. Stax also offers harness extension cables. If the amplifier cannot properly handle this kind of load (poor design or amateur design), and the capacitance is too great, the "highs" will become very harsh.

Overall, none of these capacitances are of concern. They are quite low (below 150pF). If the capacitance exceeds 200pF or so then you may want to exclusively use only a very powerful amplifier for the headphones if you want plenty of listening margin. In the amp section we'll see the effect of capacitance on higher frequencies when the amp is pushed to its limits.

In addition, it this is why putting two headphones in parallel on the same amp is not recommended since it will double the load / capacitance on the amplifier.

	Capacitance (pF)							
	L+ to L-	R+ to R-	L+ to R+	L+ to R-	L- to R+	L- to R-	Harness Length (in)	pF/inch
Nectar Hive	81	83	72	96	60	76	67	1.21
Nectar Pollinator	83	83	70	62	102	80	67	1.24
Stax SR407	92	95	66	75	106	114	96	0.96
R1 Conquest	106	103	80	80	81	89	59	1.80

Figure 1: Capacitance Measurements of various ESTAT Headphones

The Nectar 1.0 amplifier, the Bottlehead and the STAX SRM1/MK2 were compared. I consider all of these amplifiers good, powerful, desktop amplifiers that fit certain needs. The Nectar 1.0 is a DIY open source design that can be built for relatively cheap (about $250). The Bottlehead offers a pure 100% tube design operating in open loop for an especially "tuby" sound with the added bonus of a very beautiful design. The SRM1/MK2 is my go to amplifier for a good quality/price used option which can be found for around $450 - $500 on ebay if you're lucky.

All tests were performed with the headphone STAX SR407 connected to the amplifier. This is to give the amplifier a "standard" loading of a "standard" headphone, and therefore capacitance.

Four tests were performed:

1. How high can the output go? Using an oscilloscope, measure a single ended voltage of L+ to GND and crank up the input voltage until BEFORE clipping. From this the differential output can be calculated (L+ to L-).
2. What is the GAIN of the amplifier? The gain can be calculated from above. Take the output Vrms level (differential), divide it by the input vrms level, take the base 10 log of it and multiply it by 20.
3. THD+N measurements at 100Hz, 1kHz, 10kHz, 20kHz. Using the audio analyzer, measure differential (or balanced input) measurement of L+ and L- when the OUTPUT measures 73Vrms. This level is chosen as to not damage my borrowed audio analyzer, and also it is a good average level of sound loudness. The amplifier should easily be able to perform at this level of loudness.
4. Take a frequency response measurement when the output is at 73Vrms.

Overall, all the amplifiers had roughly the same gain (58dB to 59dB) with the SRM1/MK2 having the highest gain. The SRM1/MK2 peaked at about 0.42Vrms input (so try and keep your source volume/voltage low) and the Bottelhead (with standard 12AT7 tubes) had the highest input headroom at around 0.54V. The Nectars were around 0.5V. For reference, the output of an iPhone SE playing a 0dBFS sine wave at max volume was 0.325Vrms (a standard commercial line level output voltage).

Overall, in terms of measurements, I think the STAX SRM1/MK2 performed very well. It had the lowest distortion, about 0.05% THD and had the flattest frequency response between 20Hz and 20kHz when measured at nominal levels (73Vrms differential). It did however perform very poorly on the stress test. At 10kHz and 20kHz driven to around 190Vrms single ended measurement (378Vrms differential) the voltage waveforms looked much more triangular than the Nectar and Bottlehead, and there was clipping at 20kHz.

For music, typically the higher frequency components of musical content are at a much lower amplitude than the lower frequency content therefore this is more of a stress test than a realistic scenario. High frequencies at 10kHz + probably reach nowhere near this high voltage threshold without doing some serious hearing damage. But the preference would be to have an amplifier have plenty of room and margin to swing effortlessly.

The Bottlehead (standard 12AT7 tubes) and Nectar 1.0 had a higher level of distortion at 73Vrms with the Bottlehead at 0.27% at 1kHz and 0.49% at 10kHz while the Nectar 1.0 had 0.11% at 1kHz and 0.20% at 10kHz. The higher distortion form the Bottlehead is somewhat expected as it is a purely tube design so the tubes introduce their own “tuby” distortion. The 3dB rolloff for the Bottlehead is around 20kHz though, (-3dB at 20kHz, -1dB at 10kHz) so the sound will be more warm. Some may prefer for it to “relax” the estat headphones typically sibilant leaning.

The Nectar 1.0 performed relatively well with a distortion of about 0.11% at 1kHz and with only a second and third harmonic observed. The rolloff is also quite flat (-1dB at 20kHz).

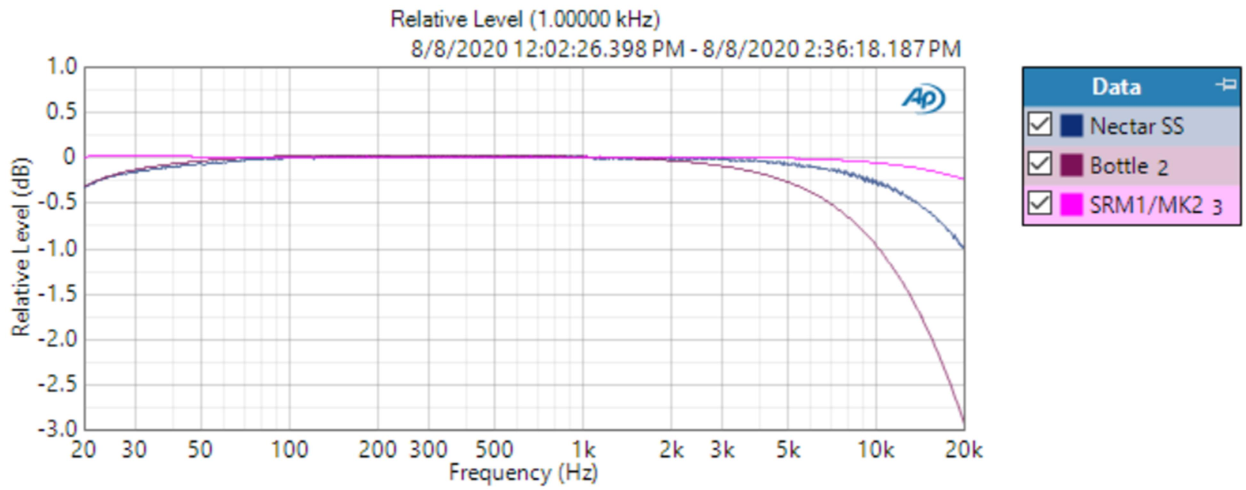


Figure 2: F-response at 73Vrms differential output voltage. Nectar, Bottlehead, and SRM1/MK2.

Bottlehead suggested that the F-response can be flattened out a bit if two 12BH7 tubes replaced the two rear 12AT7 tubers. These are the input tubes to the amplifier. This was performed and the following measurements show a flatter response. Only about -1.5dB at 20kHz and about -1dB at 17kHz. This also improved the THD significantly with only one second and third distortion harmonic observed (see data measurements for more information to compare the distortion FFTs). The drawback is about a 9dB reduction in gain. The amp now only clipped at 1.15V input (versus 0.54V input with the default configuration). Therefore with the 12BH7 configuration, the amplifier could use a Pre-Amp boost. A listening test showed acceptable loudness levels without a Pre-Amp with the 12BH7's.

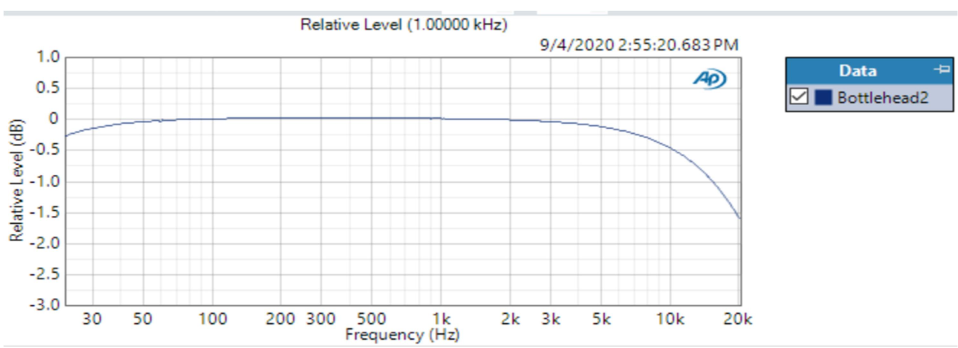


Figure 3: F-response at 73Vrms differential output voltage. Bottlehead with 12BH7 input tubes

THD+N Measurements in %				
	100 Hz	1k Hz	10k Hz	20k Hz
SRM1/MK2	0.05	0.04	0.05	0.05
Nectar 1.0 Amplifier	0.19	0.11	0.2	0.36
Bottlehead (12AT7)	0.19	0.27	0.49	0.72
Bottlehead (12AH7)	0.15	0.15	0.25	0.58

Figure 4: THD+N at various signal levels measured at 73V rms differential

Future Considerations:

Some amplifiers that would be interesting to measure are types that use output transformers. These output transformers improve the amplifier efficiency but they have the disadvantage that comes with transformers such as bass reproduction and the distortion introduced by the transformer. It would be interesting to see how much distortion is introduced if any, and observe the F response. Others to consider are the portable types such as the STAX D10, Kingsound K3, and the low end Stax amplifiers such as the SRM252S.

More on next page

Raw data:

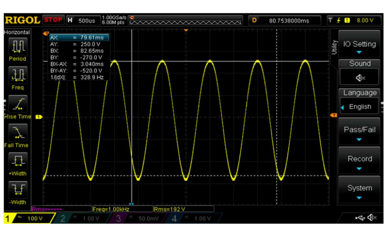
Output Drive Capability Relative to Audio Input						
	Input Voltage	Single Ended Output RMS	Single Ended Output peak	Differential Voltage Peak	Differential Voltage RMS **Output**	Gain dB
Nectar 1.0 Amplifier (Measured @ 1kHz)						
Input @500mV	0.5	190	268.66	537.32	380	58
Input @ which before clipping occurs	0.5	190	268.66	537.32	380	58
Bottlehead Amplifier (default 12AT7 tubes) (Measured @ 1kHz)						
	Volts	Output RMS	Output peak	Balanced Volta	Balanced Volta	Gain dB
Input @500mV	0.5	189	267.246	534.492	378	58
Input @ which before clipping occurs	0.54	199	281.386	562.772	398	57
SRM1/MK2 (Measured @ 1kHz)						
	Volts	Output RMS	Output peak	Balanced Volta	Balanced Volta	Gain dB
Input @500mV	0.5	189	267.246	534.492	378	58
Input @ which before clipping occurs	0.42	189	267.246	534.492	378	59
Bottlehead (rear tubes replaced with 12BH7's) Amplifier (Measured @ 1kHz)						
	Volts	Output RMS	Output peak	Balanced Volta	Balanced Volta	Gain dB
Input @500mV	0.5	84	118.776	237.552	168	51
Input @ which before clipping occurs	1.15	192	271.488	542.976	384	50

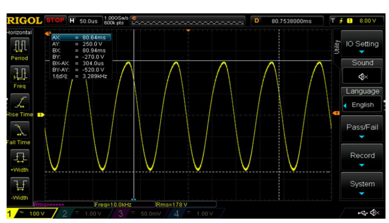
Figure 3: Shows that SRM1/MK2 has the highest gain. Bottlehead has the highest voltage swing capability (without clipping) at 398Vrms.

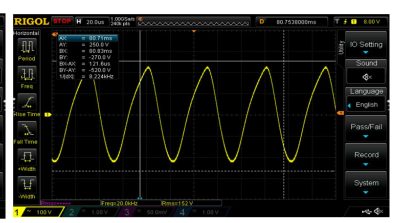
Scope captures at 1kHz, 10kHz, 20kHz with a high output level of ~190V (measured at 1kHz) – This is about a 380V rms output so these measurements are pushed to the limit:

Nectar 1.0:

1kHz / 10kHz / 20kHz. L+ to GND measurement. 0.5V input

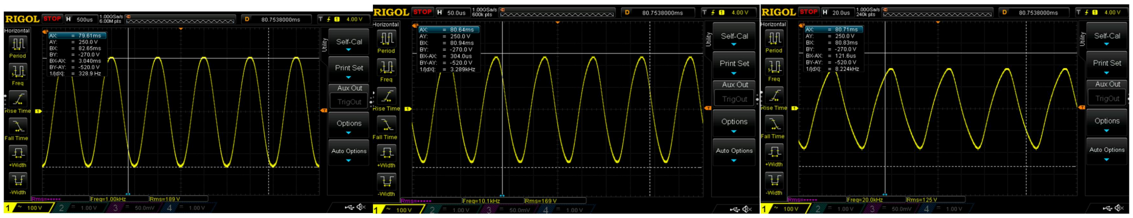






Bottlehead (default 12AT7 input tubes):

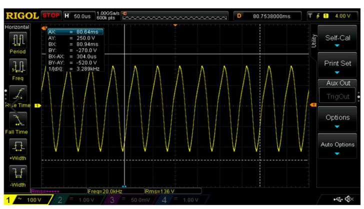
1kHz / 10kHz / 20kHz, L+ to GND measurement. 0.54Vrms input



SRM1/MK2:

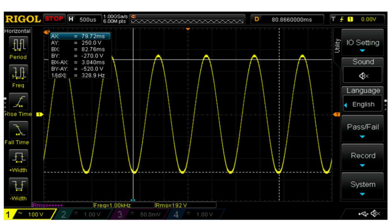
1kHz / 10kHz / 20kHz, L+ to GND measurement, 0.42Vrms input

SRM1/MK2 reduced input to 0.315Vrms until we no longer see clipping @ 20kHz:

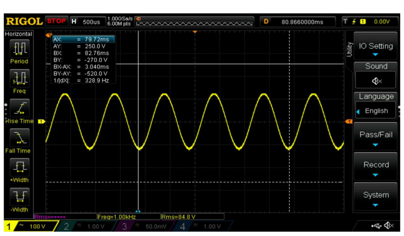


Bottlehead 12BH7 input tubes (plots demonstrate the lower gain with the 12BH7):

1kHz, 1.150Vrms input

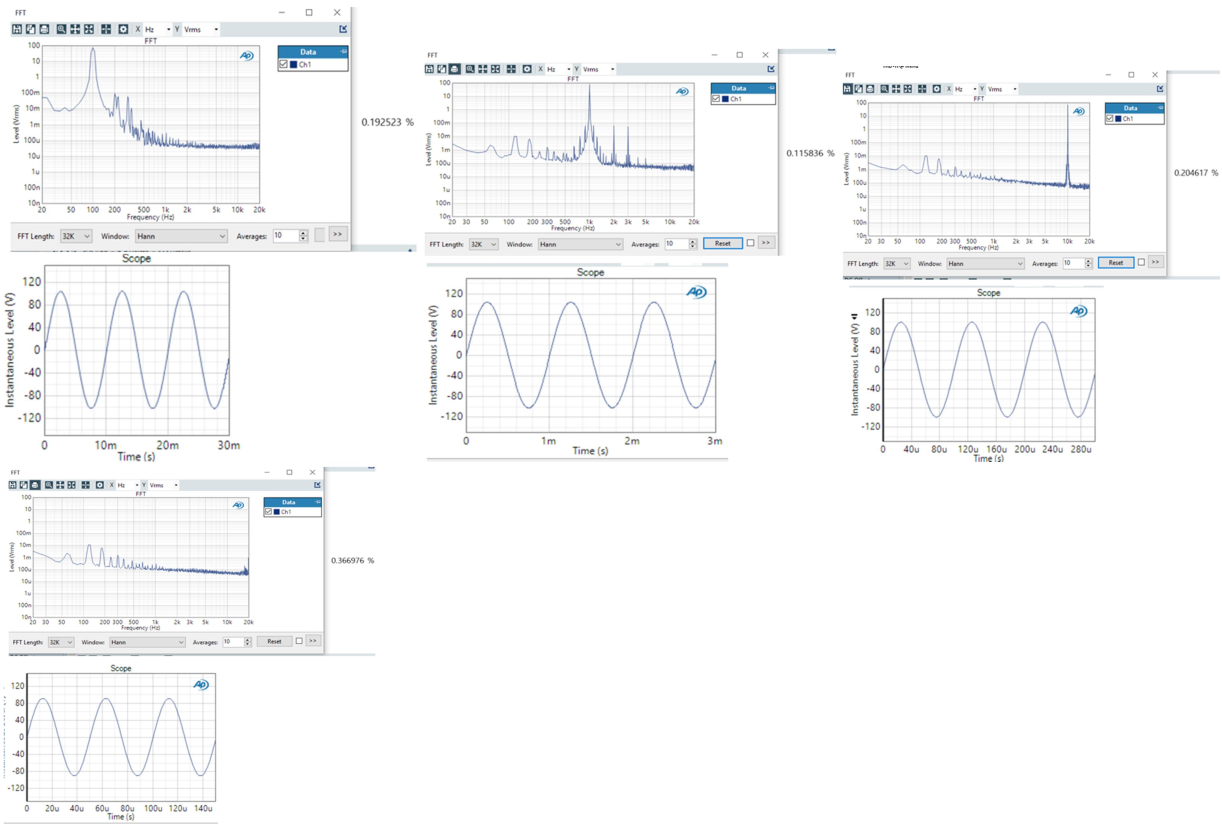


1kHz, 0.5Vrms input

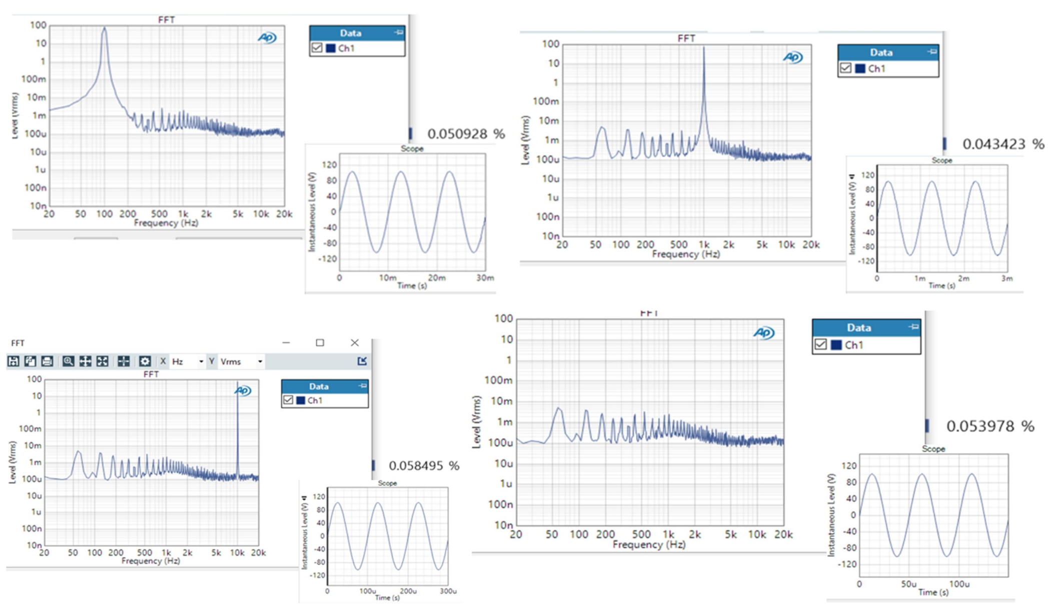


Distortion Measurements (All measured at 73Vrms balanced input):

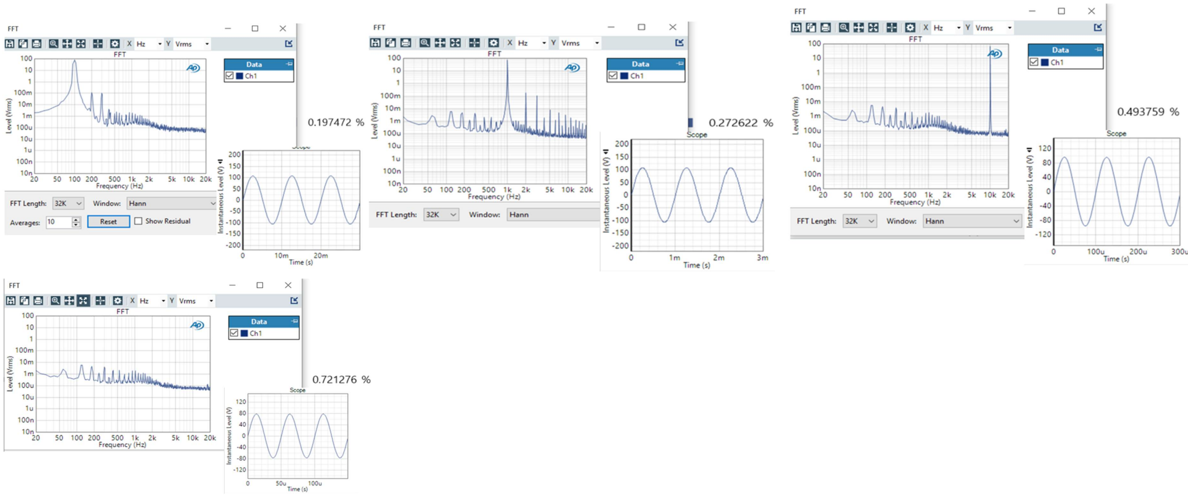
Nectar 1.0, THD+N, 100Hz / 1kHz / 10kHz / 20kHz:



SRM1/MK2 THD+N, 100Hz / 1kHz / 10kHz / 20kHz:



Bottlehead (default 12AT7) THD+N, 100Hz / 1kHz / 10kHz / 20kHz:



Bottlehead (default 12BH7) THD+N, 100Hz / 1kHz / 10kHz / 20kHz: