HP-1 R1.1

User's Guide

Contents

Revision History

HP-1 R1.1 Design Documentation

Revision	Date	Notes
0.1	07 JAN 2017	Document created.

HP-1 Circuit Board

Revision	Date	Notes
1.0	12 SEP 2016	First prototype layout.
1.1	20 NOV 2016	Final production layout. Improved protection circuit. Mechanical tweaks.

Disclaimer

While the risk of mishaps during use is minimal, it is not zero. The operator of the HP-1 assumes all risk associated with operation of the HP-1.

Key Specifications

The HP-1 is truly a state-of-the-art headphone amplifier. It is intended as a high-performance, turnkey analog subsystem. It has been optimized to provide the highest possible performance with readily available parts. The key specifications are tabulated below. Enjoy.

Parameter	Value	Notes
Output Power (20 Ω)	3.0 W	THD+N < 0.005 % @ 1 kHz
Output Power (32 Ω)	3.0 W	THD+N < 0.005 % @ 1 kHz
Output Power (300 Ω)	450 mW	THD+N < 0.001 % @ 1 kHz
Output Power (600 Ω)	230 mW	THD+N < 0.001 % @ 1 kHz
Total Harmonic Distortion	0.000017%	1 kHz, 200 mW, 600 Ω
Total Harmonic Distortion	0.000032%	1 kHz, 200 mW, 300 Ω
Total Harmonic Distortion	0.000050%	1 kHz, 200 mW, 32 Ω
Total Harmonic Distortion + Noise	0.00061%	1 kHz, 200 mW, 300 Ω
IMD (SMPTE: 60 Hz + 7 kHz, 4:1)	0.00063%	200 mW, 300 Ω
IMD (DFD: 18 kHz + 19 kHz, 1:1)	0.00013%	200 mW, 300 Ω
Multi-Tone IMD residual	< -127 dBV	AP 32-tone, 200 mW, 300 Ω
Channel Separation	115 dB	1 kHz
Channel Separation	> 105 dB	20 Hz - 20 kHz
Gain	+6/+12/+20 dB	Switch selectable
Gain Variation	±0.02 dB	20 Hz - 20 kHz
Input Sensitivity	3.7/1.9/0.74 V RMS	200 mW, 300 Ω
Bandwidth	0.10 Hz – 290 kHz	
Full-Power Bandwidth	71 kHz	

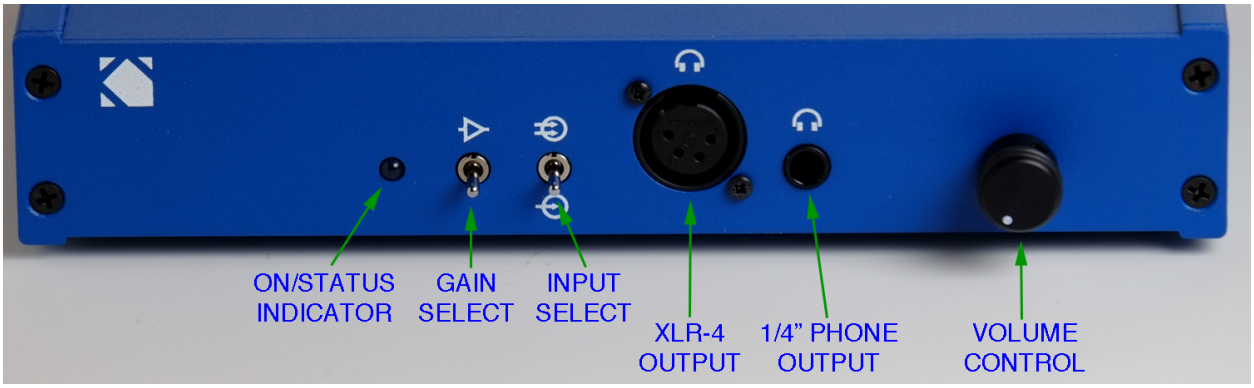
Parameter	Value	Notes
Slew Rate	7.6 V/µs	300 Ω || 220 pF load
Total Integrated Output Noise and Residual Mains Hum	1.00 µV RMS	A-weighted, 20 Hz - 20 kHz, +6 dB gain, min. volume
Total Integrated Output Noise and Residual Mains Hum	1.26 µV RMS	Unweighted, 20 Hz - 20 kHz, +6 dB gain, min. volume
Output Impedance	0.5 Ω	20 - 20 kHz
Residual Mains Hum	< -136 dBV	
Dynamic Range (AES17)	128 dB	1 kHz
Common-Mode Rejection Ratio	> 80 dB	Typ., 1 kHz
Mains Voltage	85 – 264 VAC	47 – 440 Hz

All parameters are measured at +6 dB gain and using the balanced input unless otherwise noted.

The Two-Page User's Guide

To prevent damage to your headphones, always power off the HP-1 before connecting or disconnecting signal sources to the HP-1.

Front Panel



ON/STATUS Indicator

LED	Status
OFF	HP-1 is turned off.
SOLID ON	HP-1 is turned on and ready for use.
BLINKING	Output is disabled. Occurs during the first ten seconds after power-up. Also occurs if the protection circuit has detected an error.

Gain Selector Switch

Switch Position	Gain	Intended Use
DOWN	+6 dB (low)	High-end and professional sources.
CENTRE	+12 dB (mid)	Most consumer sources.
UP	+20 dB (high)	Phones, tablets, and small DACs.

The best performance is obtained at the lower gain settings. Therefore, only increase the gain if satisfactory loudness is not achieved at the maximum setting of the volume control. The HP-1 is a very powerful amplifier. Be mindful of you hearing!

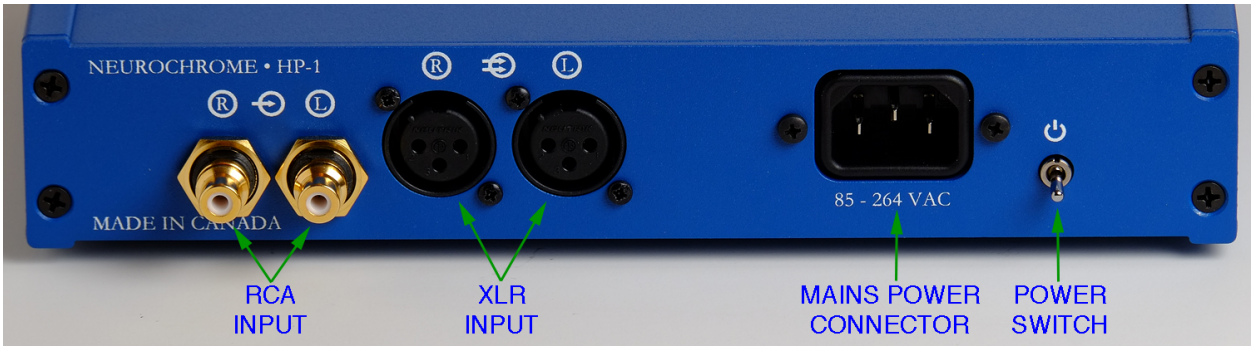
Input Selector Switch

Switch Position	Selected Input
DOWN	Single-ended (RCA)
UP	Differential (XLR)

Output Connectors & Volume Control

The 1/4" headphone jack and the volume control should not require introduction. The 4-pin XLR connector is provided as some high-end headphones use this connector to separate the ground connections of the two transducers.

Rear Panel



Inputs

Unbalanced RCA inputs are provided for single-ended sources. Balanced XLR inputs are available for use with professional audio gear as well as high-end sources.

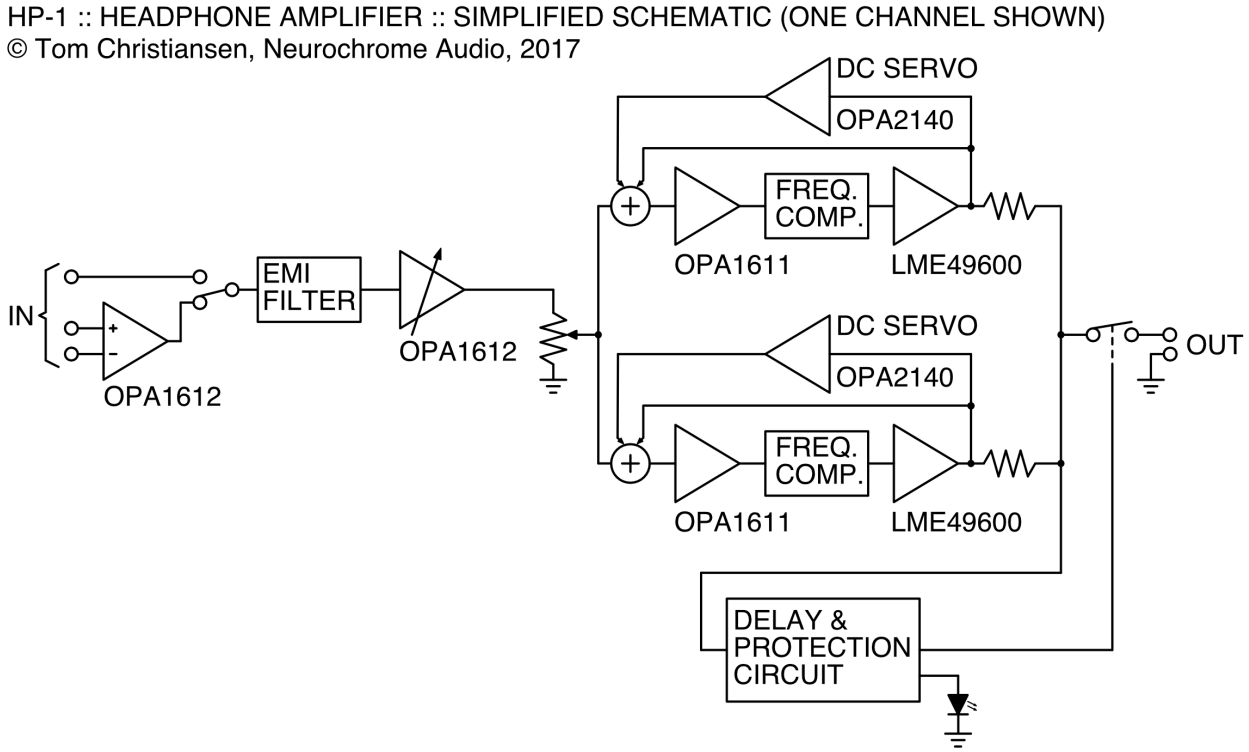
Mains Power & Power Switch

The mains connector uses a standard grounded IEC connector. These are commonly found on hifi and computer equipment.

Switch Position	Function
DOWN	Power OFF
UP	Power ON

Circuit Description

A simplified schematic of one channel of the HP-1 is shown below.



Input Circuits, EMI filter, and ESD protection

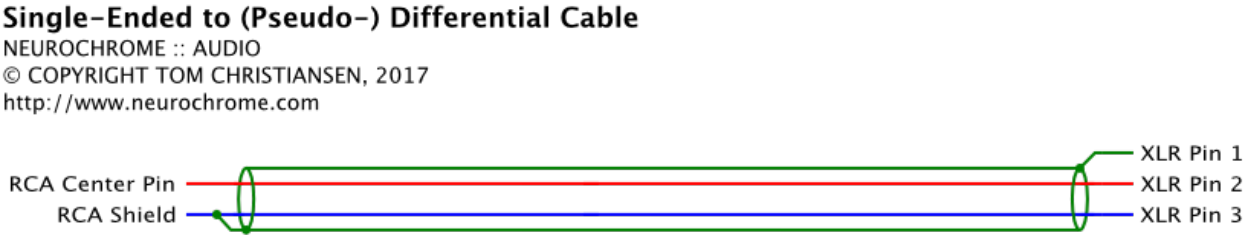
In addition to the common single-ended (RCA) inputs, the HP-1 is equipped with differential (XLR) inputs. There are two reasons for this:

1. Differential signalling generally sounds better.
2. Differential signalling measures better.

The differential inputs of the HP-1 offers transformer-like performance with a common-mode rejection ratio of 85 dB for a typical build. This means that any noise injected on the input cables is rejected by a factor of nearly 20000. The result is complete silence during quiet parts of the music, good separation between instruments, and a wider and deeper sound stage. Hence, the optimal connection to the HP-1 is a differential connection.

While differential connections are standard on professional audio equipment, many consumer and prosumer sources do not offer a differential output. To accommodate those sources, the HP-1 features a single-ended (RCA) input as well.

It is possible to get most of the advantages of the differential input by using a pseudo-differential interconnect to the single-ended source output. Such an interconnect cable can be constructed by following the diagram below.



These types of cables are also available commercially. The conventional configuration is to use a male RCA connector and a male XLR connector on the interconnect cable.

Both the differential and the single-ended inputs feature an electromagnetic interference (EMI) filter to prevent any RF pickup from interfering with the amplifier. This filter ensures that RF energy present from cell phone signals, WiFi, motor control switch transients, etc. as well as interference sources within the chassis, such as micro controllers, will not interfere with the music reproduction. In addition, the differential input is protected against ESD discharge and allows for hot-plugging of the amplifier. To prevent damage to your headphones, please do turn the volume control all the way to its minimum setting while hot-plugging the XLR input cables.

Gain Stage

The inputs have unity gain. To allow the overall amplifier gain to be increased, the HP-1 features a gain stage with switch-selectable gain. Three gain settings are provided by the gain stage: +0, +6, and +14 dB. In addition, the output stage of the HP-1 provides +6 dB gain. The total system gain for the three gain settings are tabulated below along with the maximum input voltage that can be applied without overloading the HP-1.

Gain (dB)	Gain (lin.)	Max. input voltage @ min. volume	Max. input voltage @ max. volume	Intended use
+6	2×	11.28 V RMS	4.61 V RMS	Pro and high-end audio sources
+12	4×	5.64 V RMS	2.31 V RMS	Consumer sources

Gain (dB)	Gain (lin.)	Max. input voltage @ min. volume	Max. input voltage @ max. volume	Intended use
+20	10×	1.13 V RMS	0.92 V RMS	Phones, tablets, etc.

The best performance is obtained on the lower gain settings. Thus, it is recommended to use the lowest gain setting that allows for satisfactory sound pressure level in the headphones.

Output Stage

Each channel of the HP-1 is comprised of two output stages operating in parallel. This provides the output current that allows the HP-1 to drive a 32 Ω load with ease. Each output stage is a composite amplifier. An LME49600 headphone driver IC provides the output drive while an OPA1611 precision audio opamp performs error correction on the output stage. This topology linearizes the output stage and is responsible for the stellar performance of the HP-1.

The main challenge with composite amplifiers is stability. In the HP-1, this is further complicated by the use of the OPA1611 as its internal compensation causes a phase shift in the loop response. Therefore a frequency compensation network is employed within the loop. This ensures that the HP-1 remains stable even when driving heavy capacitive loads. The frequency compensation network was designed to cause minimum reduction of the loop gain at 20 kHz, thereby, optimizing the performance of the HP-1 within the audio band.

The HP-1 is capable of driving in excess of 10 nF of capacitive load. This corresponds to approximately 300 m of headphone cable.

The output stage has a gain of +6 dB which is the lowest gain possible on the HP-1.

DC servo

Each output stage is equipped with a precision DC servo. The DC servo in the HP-1 combines an integrator and a multiple-feedback lowpass filter to provide third order filtering. This ensures that the output offset voltage settles to below 100 µV within the first 10-15 seconds after power-up. The DC servo architecture was selected to ensure

that the DC servo caused no measurable or perceptible degradation of performance within the audio band while also providing a fast settling time.
The HP-1 needs no further warmup than the 10-15 seconds it takes for the DC servo to settle.

Protection & Delay Circuit

Turn-on and turn-off thumps can destroy sensitive headphones. To prevent this from happening, the HP-1 features a delay circuit. This circuit enables the output approximately ten seconds after the amplifier is powered on. When the power is turned off, the circuit will automatically disable the output when the power supply rails collapse. This prevents all turn on/off thumps.
In addition to the delay circuit, the HP-1 features a protection circuit guarding against excessive DC voltage on the amplifier output. Should the DC voltage ever exceed 1.4 V, the output is immediately disabled.

Output Connectors

The output of the amplifier is provided on two connectors: A standard 1/4" headphone jack and a 4-pin XLR connector. The pinout of the two connectors is as follows.

4-pin XLR connector

XLR Pin	Function
1	LEFT channel (+)
2	LEFT channel (-)
3	RIGHT channel (+)
4	RIGHT channel (-)

3-pin 1/4" phone (TRS) connector

TRS Pin	Function
Tip	LEFT channel (+)
Ring	RIGHT channel (+)
Sleve	Common ground (-)

Modifications

A sizeable part of the DIY community enjoys tweaking circuits. Note, however, that performing arbitrary modifications of the HP-1 is much more likely to degrade performance than to improve it. In particular modification of the frequency compensation networks is likely to result in instability. For these reasons, modifications to the HP-1 are not recommended.

