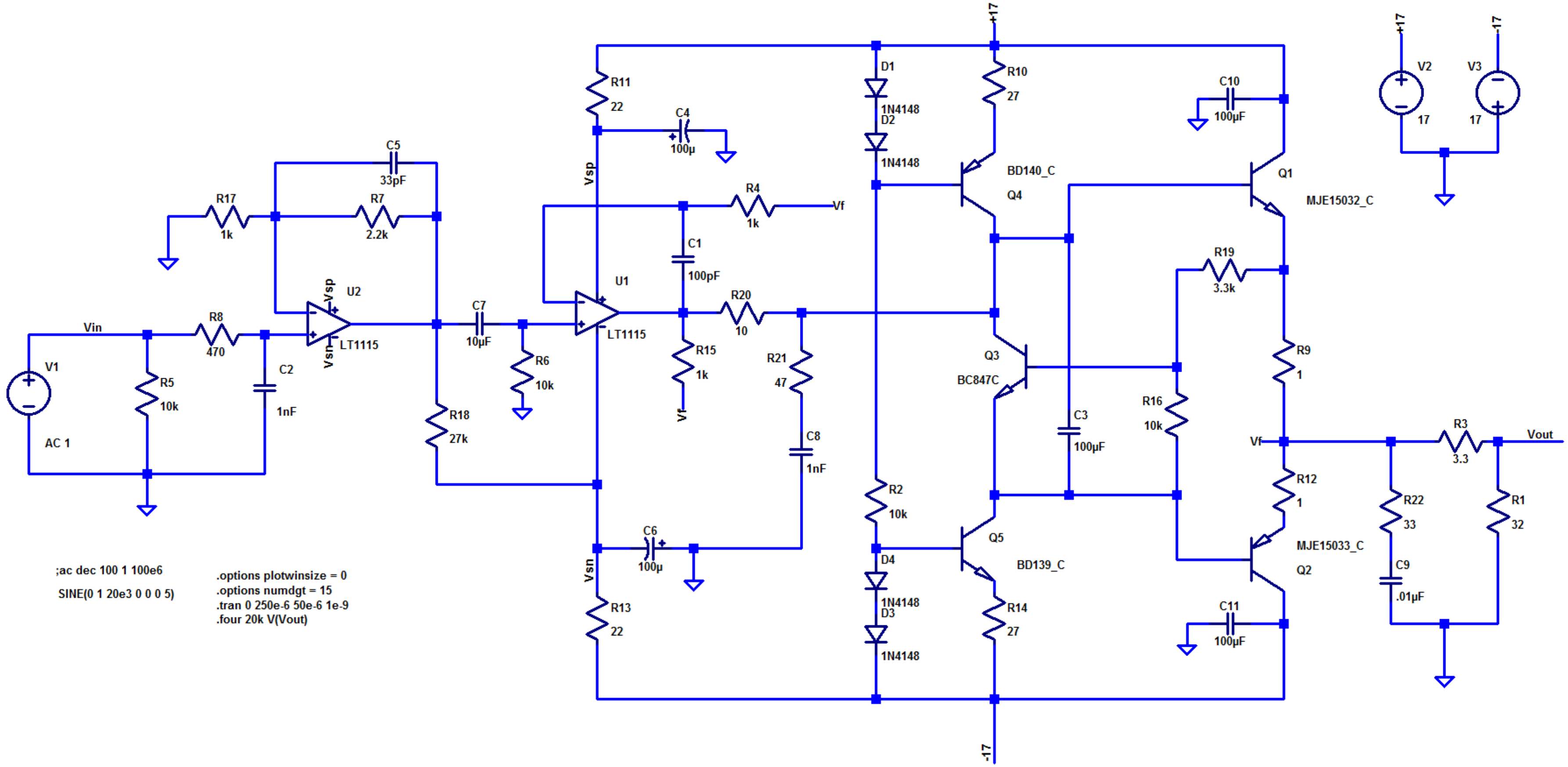


Hifisonix HPA-1 – A Very High Performance Class A Headphone Amplifier

A good pair of headphones demands the very best amplifier performance because if there are any shortfalls in the amplification (or DAC/source for that matter), you will hear it immediately – and this is especially so with those designs that employ low voltage IC headphone amps. The class AB LME49600 + LM47910 can offer sterling performance with low distortion and great dynamic range if powered off +-15 V rails – I used this combo on my SCA-1 preamplifier in 2010. However, for the most effortless sound and micro detail, a good class A amp design is hard to beat. The HPA-1 headphone amp described here employs a class A output stage, that at 3V peak output will deliver ~400 ppb distortion at 20 kHz. On 90 dBm (32 Ω) headphones, this corresponds to about 115 dB SPL – i.e. rock concert levels. Even at 8V peak into 32 Ωs, the distortion is less than 2 ppm (20 kHz).

A slightly simpler version of this circuit has been used in my top of the range 'Symphony' preamplifier and I can attest to its superb sound – I used an OPPO BD103 CD player, a QNKTC DAC and a HiFimeDIY ESS 9023 DAC to assess the performance, along with an assortment of CD's.

Circuit Description. The input signal is bandwidth limited to 340 kHz by R8 (470 Ωs) and C2 (1nF) , with R5 (10k) providing input bias to U1, the buffer/amplifier front end stage. You can increase the gain by reducing the value of R17, which is nominally 1k and with R7 at 2.2 k sets the gain at 3.2 x. C5 provides some basic response shaping, ensuring U2's output is well behaved with no peaking. The output of U2 couples to the main output buffer stage built around U1 through C7 (10uF film) and R6, setting the lower -3 dB response at 1.6 Hz. Since the front end is DC coupled to the source, we do not want any DC offset accumulation appearing at the headphone socket – this will affect the sound. R28 is an optional class A bias resistor – it forces U2's output stage to operate in class A for signals of up to about 3V peak ensuring that everything in the signal chain is operating in class A.

U1 's output stage is biased ~700uA into class A by 1 k bootstrapping resistor R15 before driving the OPS. Q1 and Q2 are configured as a conventional push pull output stage, with Q3 setting the output standing current at ~200mA. The output current is sensed across R9 and R12 by R19 and R16, causing Q3 to adjust its collector-emitter voltage such that at the junction of R19 and R16, the voltage equals its Vbe. Further, if Q3 is coupled to the heatsink of the output devices, it compensates for thermal drift and the output device standing current is remarkably stable – just 10-15 mA in 200mA over the full operating temperature. C3 simply decouples Q3, ensuring the bias voltage source impedance remains low all the way through to HF.

Q4 and Q5 are configured as constant current source loads and offer high PSRR, and importantly fix the middle stage bias current. These can be replaced with resistors, but the distortion is then 4~5 x higher, and especially so at high outputs. I have used commonly available BD139/140 devices since they will be dissipating about 330mW – a bit too much for a TO-92 device. The peak current into the middle and output stage at 12V peak out into 32 Ohms is about 3mA. For a modern opamp, this is a light load. At 3V peak output, it is about 1mA.

R21 and C8 provide the loop compensation by means of some phase lag (see later slide for loop gain plots and an explanation of the compensation design process), while C1 shapes the overall loop response. This design is unconditionally stable with capacitive loads from 0 to 100nF – it will drive any type of headphone and its associated cable capacitance.

A simple 3.3 Ohm resistor (R3) couples the amplifier to the headphone. This approach reduces cable ringing, while the Zobel network (R22 and C9) compensate for headphone cable inductance.

The total power draw is around 6 W per channel, 12 W for a stereo set-up - for reliable cool operation I would suggest a 20 to 25W power supply.

Parts Selection and Construction. **The output devices will each dissipate 3 W on +-15 V rails so they need to be on decent heat sinks – a single 5C per Watt or greater heatsink for both devices will suffice - you can expect a temperature rise of about 30C above ambient with this arrangement.**

For Q3 use BC547C (NPN) through hole device - I used the SMD types for the modelling but the parametric specifications are the same.

Locate R7, R17 and C5 as close as feasible to inverting input of U1.

For U1 and U2, use LM4562 dual opamp for best performance – however, any decent, *unity gain stable opamp* will work well in this circuit. Of the available duals, the LM4562 will offer the lowest distortion however.

Keep R4 and C1 as close to the inverting input of U2 as possible.

Couple Q3 to the output device heatsink. Locate Q1 in close proximity to Q3. C9 and C8 must be placed close to the output devices

Use a god quality film capacitor for C7 – do not use an electrolytic and keep in mind, this will be a big device with 22.5mm pin spacing – you will need a lot of PCB space.

All resistors are 0.5W metal film.

Make sure that the decoupling capacitors (C4, C6 and C10 and C11) have their own power ground return back to the star ground – do not use the same ground as the signal ground. Make sure that C4 and C6 are located close to the dual opamp. C10 and C11 must be located close to the collectors of their respective output devices.

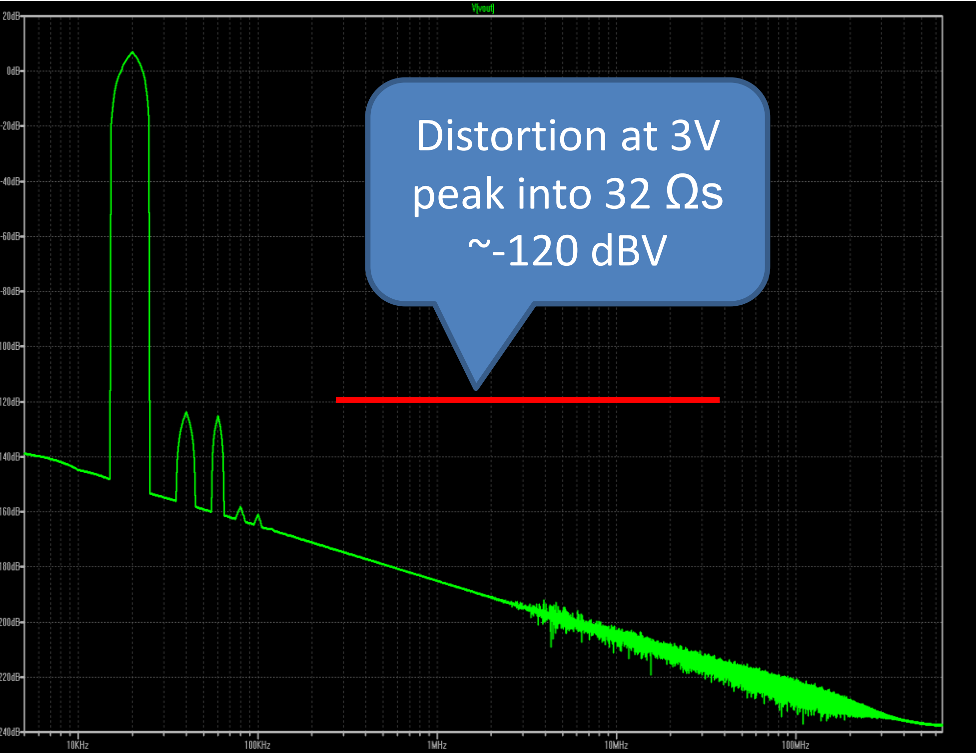
When assembling the HPA-1, the input phono sockets and the headphone out put socket must not make electrical contact with the chassis – if they do, the amplifier will hum. All ground connections to the output socket, and to the input sockets must go onto the PCB, and from there to the star ground.

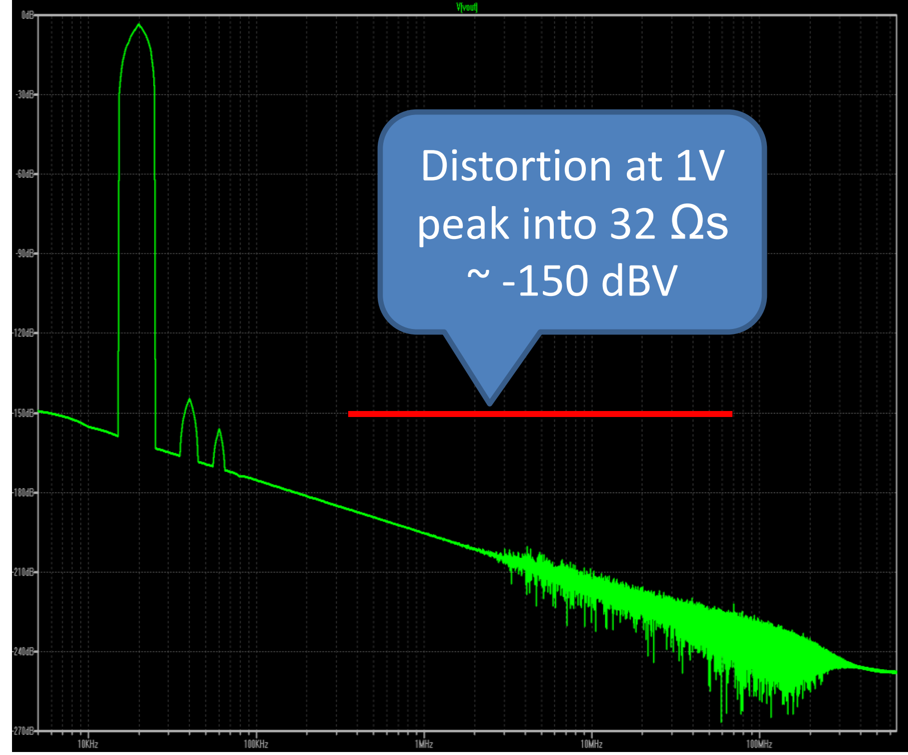
There should be one, and only one, connection from the star ground to the chassis through the ground lifter (see the PSU circuit diagram for details) . The incoming mains ground must also connect to this single bonding point.

Use a regulated power supply of +-15V.

Hifisonix HPA-1 Headphone Amplifier Specifications

General Description:	Push Pull class A headphone amplifier featuring ultra low distortion and very wide bandwidth
Gain	3x – can easily be changed to accommodate varying headphone sensitivity
Input	1V peak for 3V peak output into 32 Ohms; 10k Input impedance
Output:	12V peak class A into 32 Ωs ~2.5 W class A
Slew Rate:	20 V/us
Output Impedance:	3.3 Ω resistive
Signal to noise:	better than -110 dB ref 1 V output
Stability:	Unconditionally stable for capacitive loads of 0 pF to 100 nF
Peak output current:	~400 mA class A; OPS standing current 200 mA
Distortion (simulated):	~60 ppb (0.000006%) at 1 V peak into 32 Ω at 20 kHz
	330 ppb (0.000033%) at 3 V peak into 32 Ωs at 20 kHz
	<2 ppm at 8 V peak into 32 Ωs
	<5 ppm at 12V peak into 32 Ohms
Frequency Response:	2 Hz to 340 KHz -3 dB; 20 Hz to 20 KHz +0 dB -0.1 dB
DC Output Offset:	typically 100 uV; 700 uV max
Build Cost:	approx $100 including power supply (excl. housing).

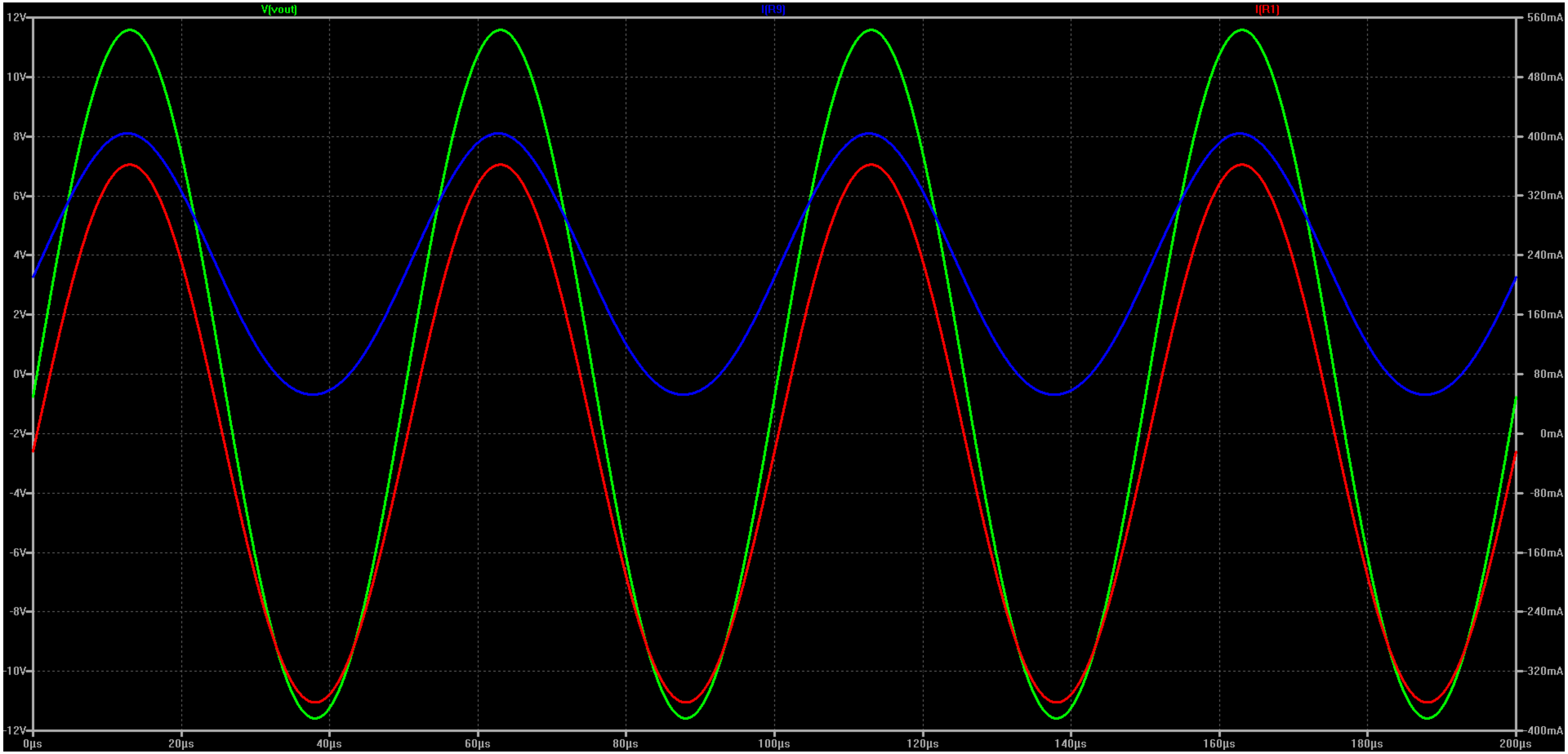




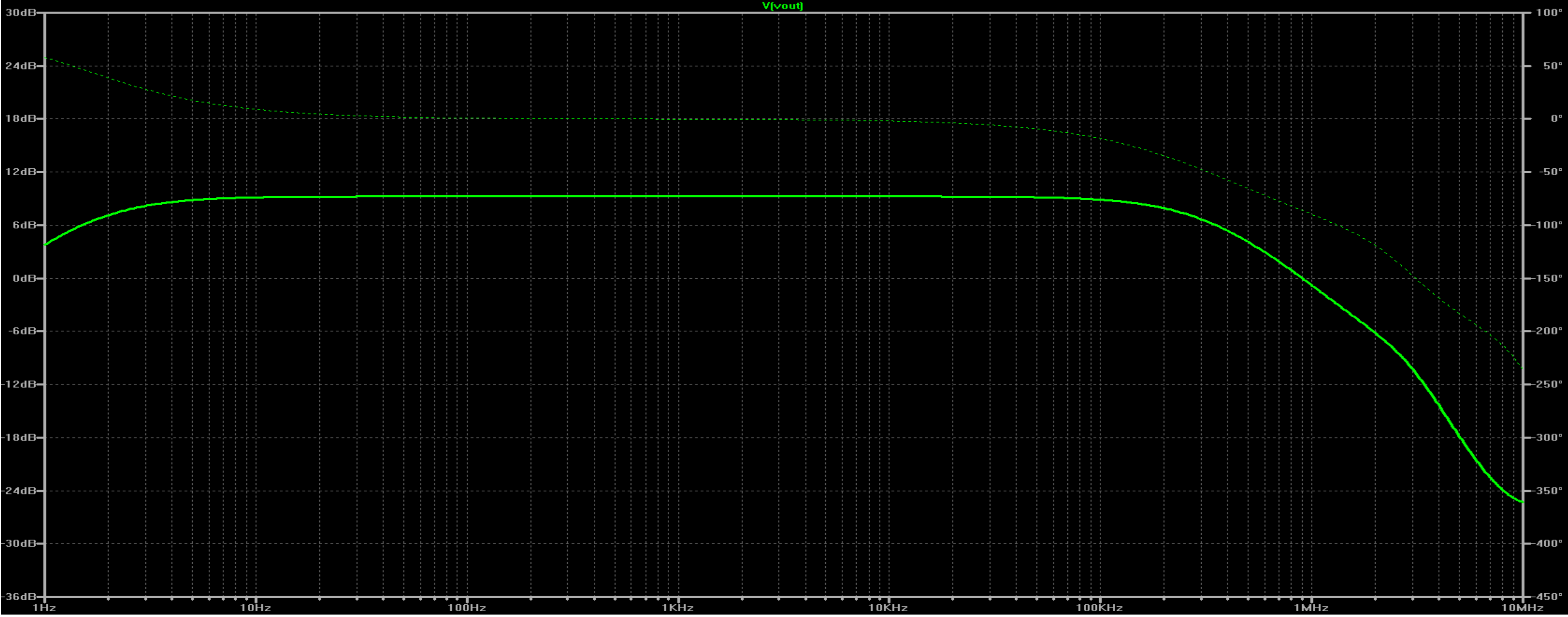
These plots give some indication of the distortion performance potential of the HPA-1.
In the LHS panel is the FFT at 20 KHz at 3V pk into 32 Ωs and on the RHS the FFT at 1 V out into 32 Ωs. Both plots for a 20 KHz input.

At 3V peak into 32 Ωs, the distortion is about 500 ppb and at 1V into 32 Ωs it is about 60 ppb. This is extremely low but Importantly, *it is low order*.

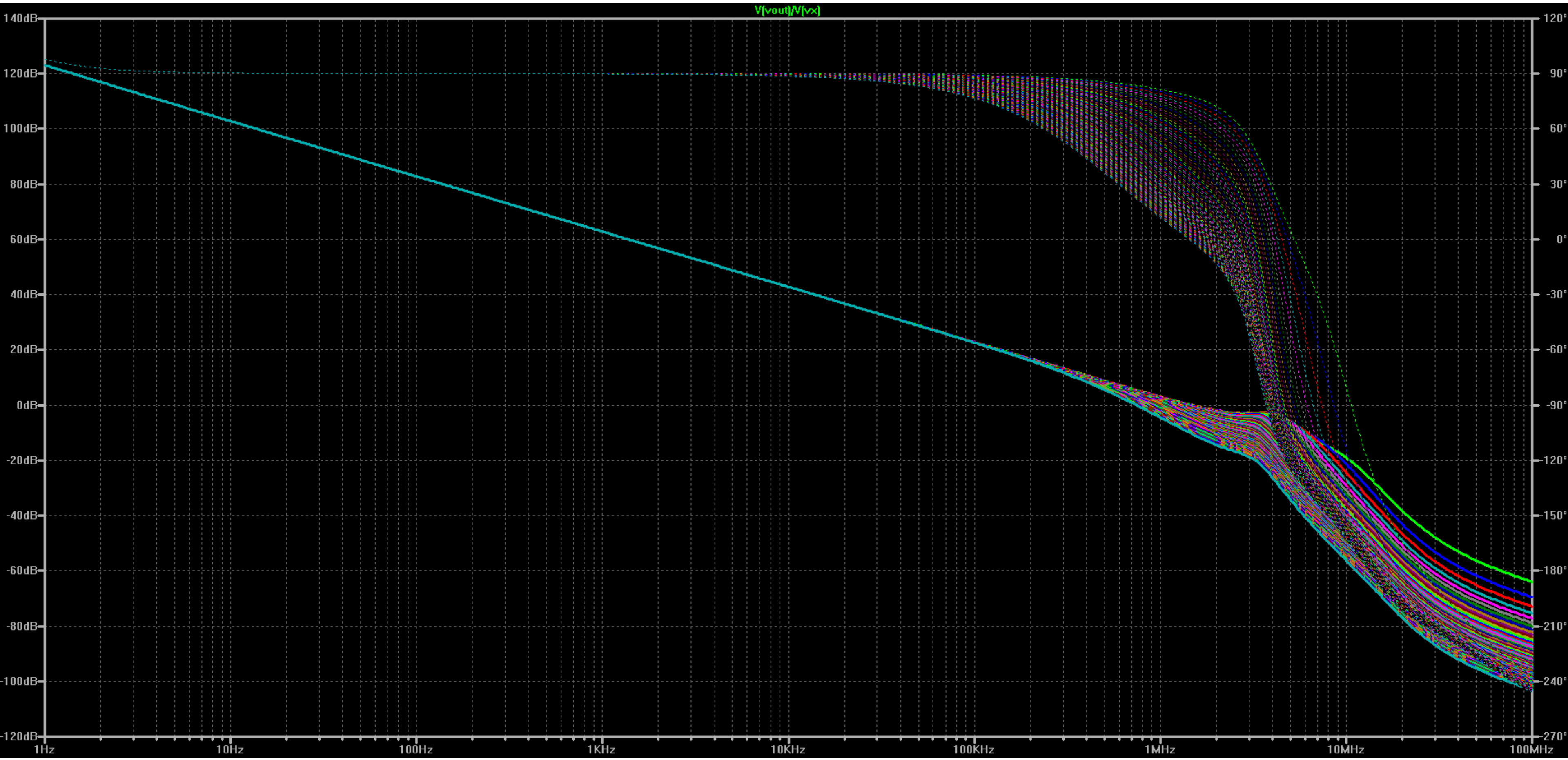
Because of the high supply rails, the HPA-1 has very high dynamic range. At 8V peak into 32 Ωs, the distortion is under 2 ppm, while at 12 V peak its is less than 5 ppm. It should be noted that operating at these levels into most headphone brands is highly unlikely and with typical 32 Ω 90 dBm sensitivity, 1V peaks correspond to about 105 dBm, while at 3 V peak, its around 115 dB, which is approaching rock concert levels. The recommended exposure to SPL at these levels is 7 minutes.



This plot shows the HPA-1 current details. The green trace is the output voltage at almost 12V peak, while the blue trace shows the output stage standing current. The red trace is the current delivered into the 32 Ohm load, and in this case corresponds to about 2 Watts.



Frequency response of the HPA-1 into 32 Ohms. The front end gain stage is AC coupled to the output stage via C7 – this ensures that any accumulated offsets do not appear at the headphone output socket – the LF -3 dB response is 1.6 Hz while at HF it extends to 340 kHz (-3 dB).



This plot shows the loop gain and phase as the load capacitance is stepped from 1 nF through to 100 nF in 1nF increments. 100nF is an extraordinarily high expected capacitance (100 pF to 500 pF is the norm) but nevertheless, demonstrates that the amplifier is unconditionally stable. A similar test, but running from 10 pF to 1 nF also confirmed the stability for more normal capacitive loads. The ULGF is conservatively set at 2.5 MHz – ample with the very fast output transistors being used (MJE15032/33 with 30 MHz Ft). The worst case gain margin is in the region of 10 dB. Without the R21. R20 and C5 network, the amplifier will peak at about 2.5 MHz, and run the risk of oscillation.

