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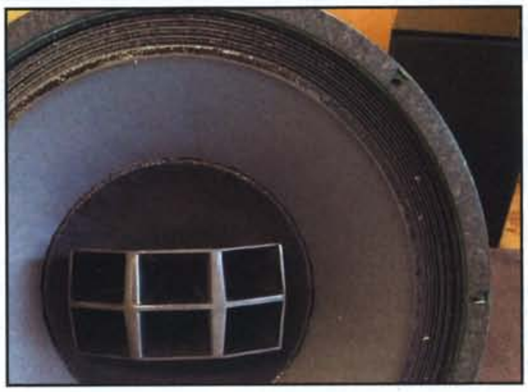

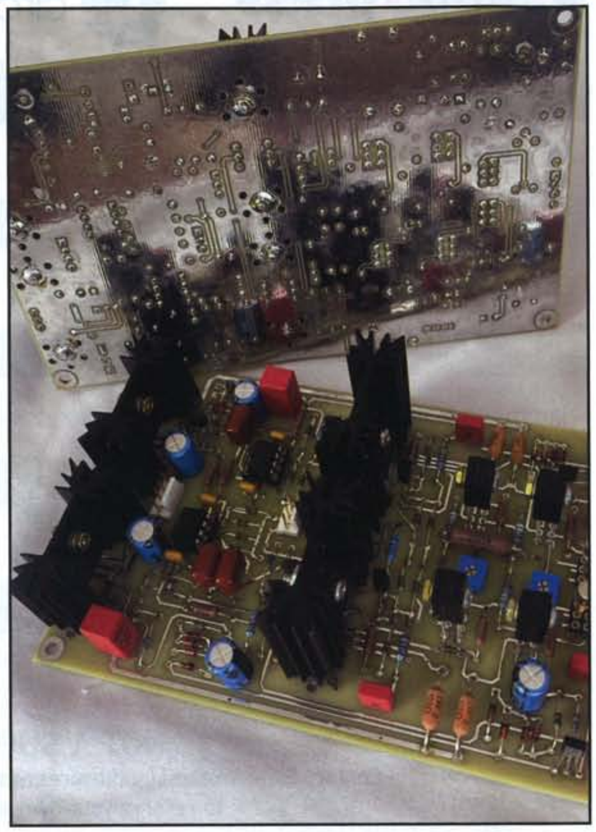

Features

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Build a Fully Balanced Transconductance Preamplifier

A few years ago, Dimitri Danyuk shared his complex design for a transconductance preamplifier with a balanced JFET input and single-ended output. Now, he has designed an open-loop transconductance amplifier with less parts and easily found through-hole parts.

By
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(United States)

A few years ago I designed a transconductance preamplifier with a balanced junction field-effect transistor (JFET) input and single-ended output. The preamplifier has an high output impedance and is loaded by a volume control potentiometer with very low resistance. The preamplifier sound is transparent with a good width and depth without the smallest hint of listener persuasion. The preamp itself is rather complex and was built with surface-mount parts and is not easy to construct by untrained enthusiasts.

So I asked myself, if it would be possible to make an open-loop transconductance amplifier with less parts and from readily available through-hole parts. I chose a fully symmetrical topology, which can be found in the equally famous and rare Blowtorch preamplifier by Curl-Thompson-Crump (CTC) Builders. This preamplifier is expensive and well-regarded among a minuscule group of owners. The topology of the preamplifier gain block is shown in **Figure 1**.

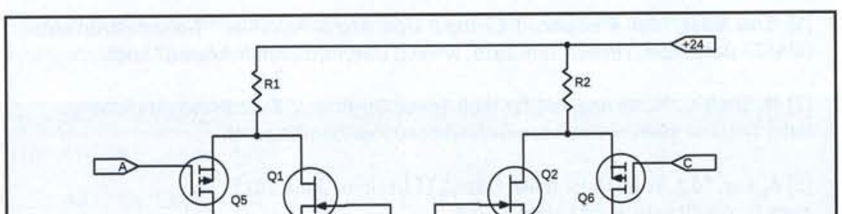


Figure 1: This is the Blowtorch preamplifier gain stage topology.

The Topology

The circuit follows Vendetta Research's SCP1 MC phono stage complementary folded cascode topology. The Vendetta Research's SCP1 MC phono stage is single ended. With the addition of an identical mirrored input stage (Q2, Q4) to the original one (Q1, Q3), we get a fully symmetrical balanced input/balanced output topology.

The second step is to disconnect source networks from the ground and tie them together with resistor Rs. JFETs with the highest possible Idss (2SJ73V/K146V) were used in the Blowtorch. This allows linear operation of the stage. MOSFETs (2SJ76/K213) and JFETs were connected as folded cascode stages, in the same manner as in the Ayre V3 amplifier. (For more information about this topic, see Resources.)

The voltage between inputs is almost equal to the voltage drop on source resistor Rs. The value of Rs

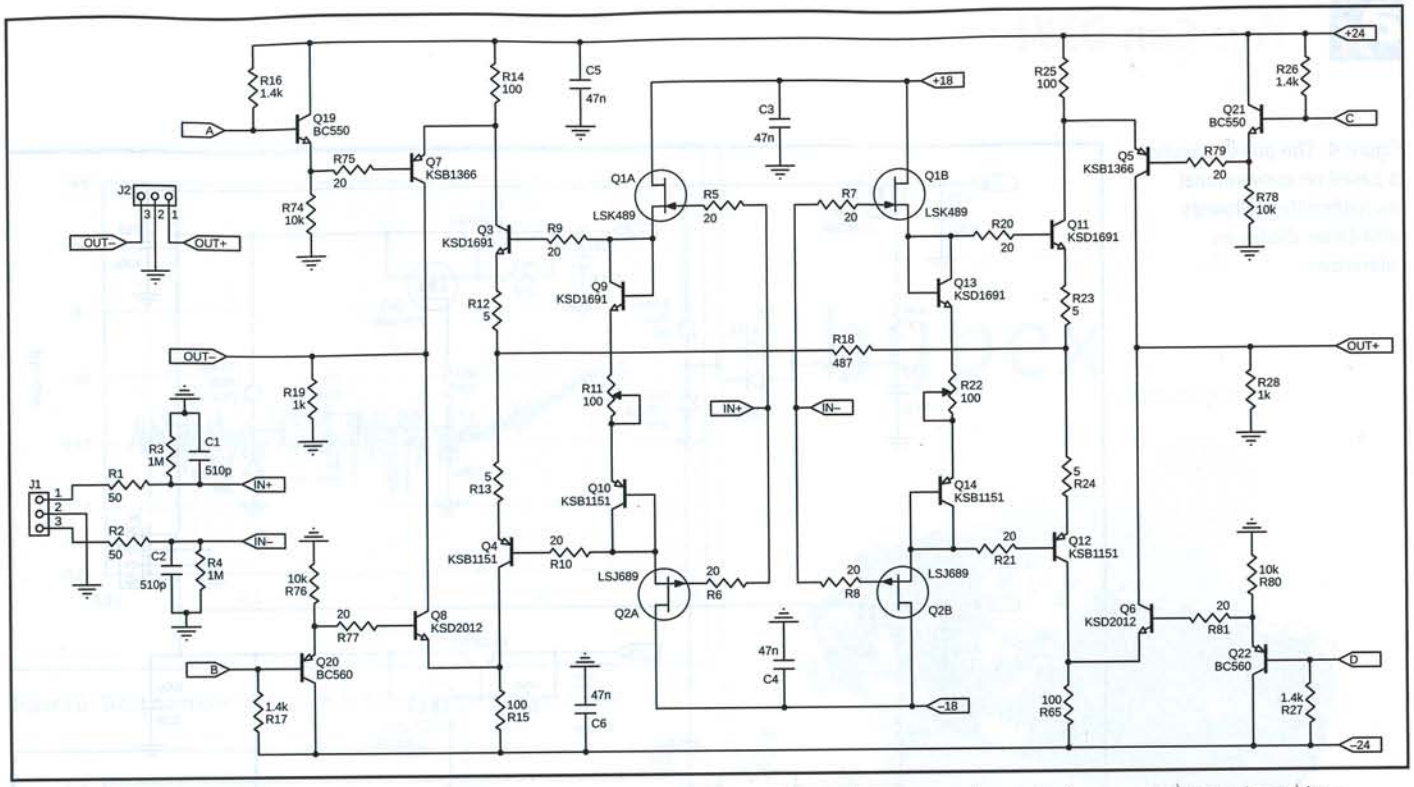


Figure 2: This is the symmetrically balanced transconductance gain stage.

is chosen considerably higher than transconductance of Q1, Q3 and Q2, Q4. Source resistor Rs decreases JFET stage transconductance with a correspondent increase in linearity of transfer characteristics. Devices Q5-Q8 act as common gate stages with unity current gain. Common gate stages maintain stable voltage on the drains of the input stage, thus reducing distortion associated with nonlinearity of JFETs output characteristics.

My realization of the symmetrical balanced transconductance gain stage is shown in **Figure 2**. I chose the amplifier's input stage to be comprised of readily available n- and p-channel JFET matched pairs (LSK489/LSJ689). LSK489/LSJ689 devices have desirable qualities of low voltage noise, low current noise, low input capacitance and high input impedance.

JFET pairs work as a self-biasing source followers, being loaded with bipolar transistor common emitter stage (Q3, Q4, Q11, and Q12). Four bipolar transistors (Q9, Q10, Q13, and Q14) are connected as diodes and supply bias to the bipolar junction transistor (BJT) stage (Q3, Q4, Q11, and Q12). Each transistor, connected as a diode, has a thermal contact with the correspondent amplifying device. The voltage drop across diodes (Q9, Q10 and Q13, Q14) also sets quiescent current through JFETs. The overall transconductance of the stage is set by R18.

The value of R18 establishes collector currents in Q3, Q4, Q11, and Q12 being proportional to the input signal. The collector currents are equal without the input signal. Currents through R14, R15, R25, and R65 split between Q3, Q4, Q11, Q12 and Q5-Q8. Resistors R14, R15, R25, and R65 set quiescent current through common base devices (Q5-Q8). Having essentially unity current gain and low distortion, the common base devices Q5-Q8 shield the gain transistors Q3, Q4, Q11, and Q12 from voltage changes on the output terminals. Resistors R19 and R28 function as load resistors. I decide to use the same value for load resistors (2 × 1 kΩ) as in the Blowtorch. The gain of the symmetrical balanced transconductance gain stage is equal to 4 (12 dB).

The servo circuit is shown in **Figure 3**. The servo circuit has two channels, similar to the Blowtorch

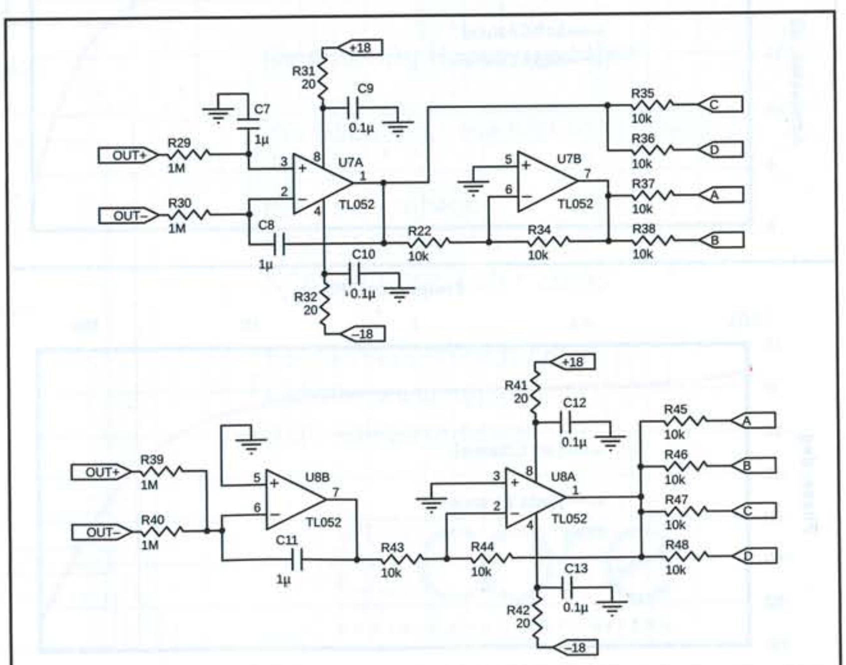
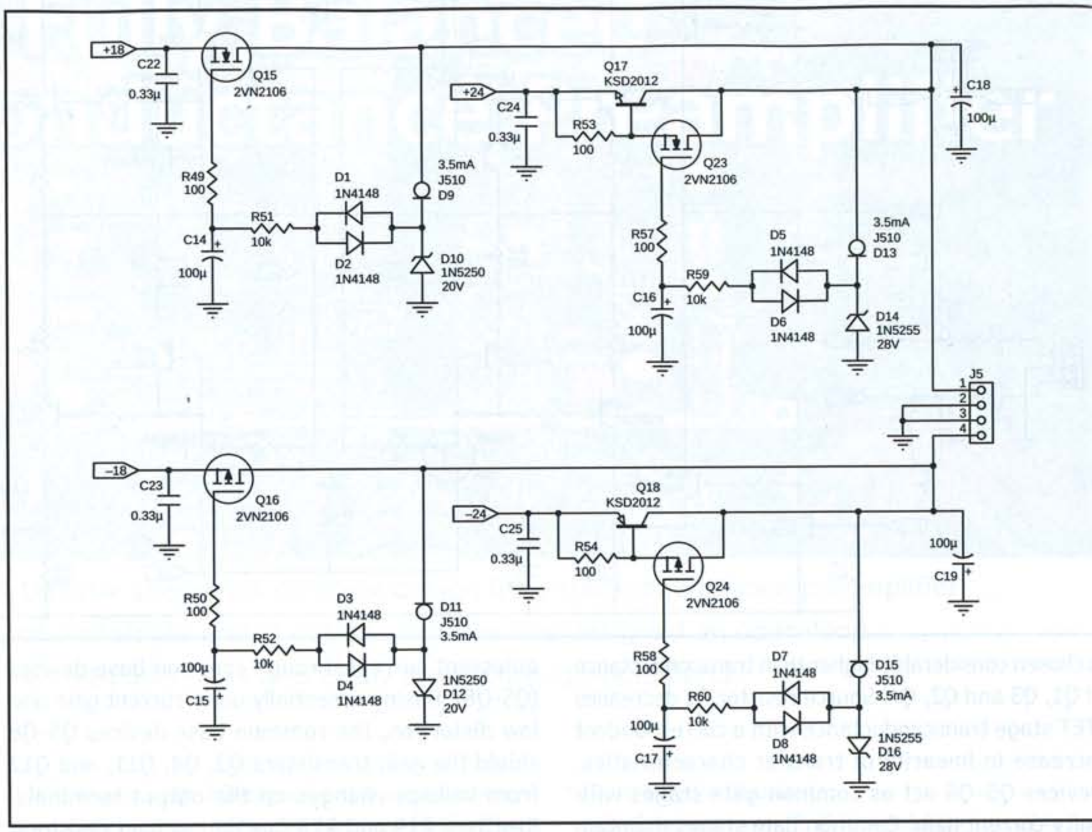


Figure 3: The DC servo circuit has two channels.

Figure 4: The power supply is based on conventional source/emitter followers with Zener diodes as references.



servo. Common mode servo channel (U8) senses the DC output voltage with respect to ground and makes it equal to zero, while differential servo channel (U7) maintains zero DC voltage between outputs. The power supply circuit is shown in **Figure 4**. It is based on conventional source/emitter followers with Zener diodes as references.

The schematic and PCB design made in ExpressPCB format is available on the *audioXpress* web server. A dozen of boards were manufactured according to these design files, stuffed, and tested.

The Amplifier's Performance

The amplifier's objective performance is very good. The bandwidth extends above 150 kHz with the phase shift less than 10° at 20 kHz. The most important measurement results are shown in **Figures 5-9**.

The distortion figure remains constant with the signal frequency up to 5 kHz. There is a 10 dB increase in distortion when the signal frequency rises up from 5 kHz to 20 kHz. The typical distortion spectrum is shown in Figure 8 and Figure 9; the even harmonics are largely suppressed. I can say that the distortion figures are excellent for the circuit without overall feedback.

I measured the noise density at 1 kHz around 38nV/√Hz, which corresponds to the noise of 90 kΩ resistor. This is considerably higher than

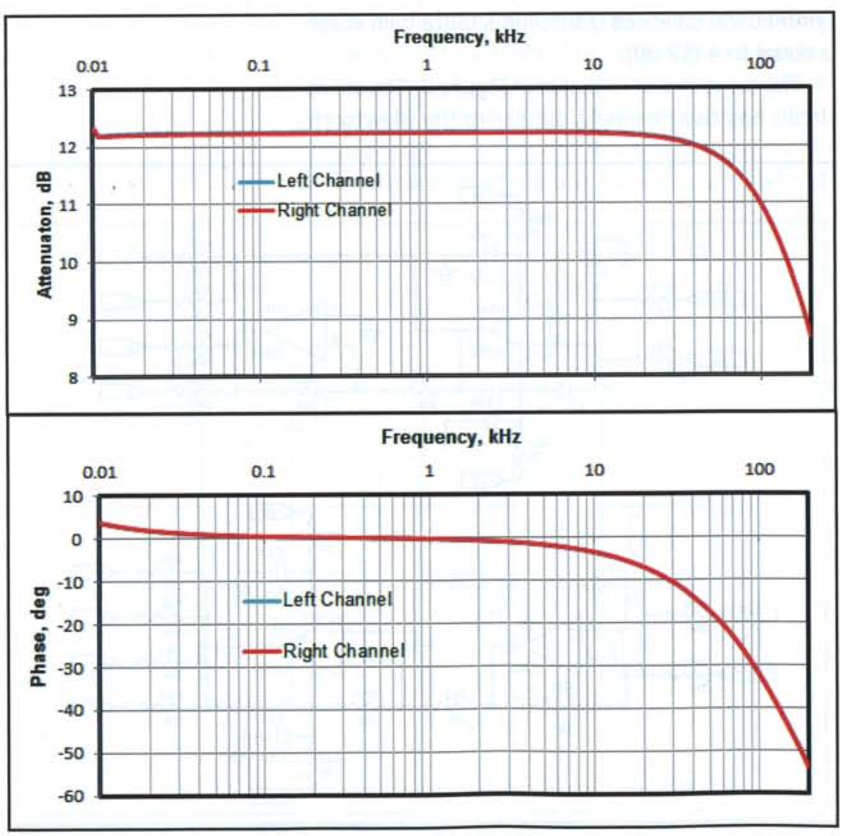


Figure 5: The amplifier's frequency and phase response

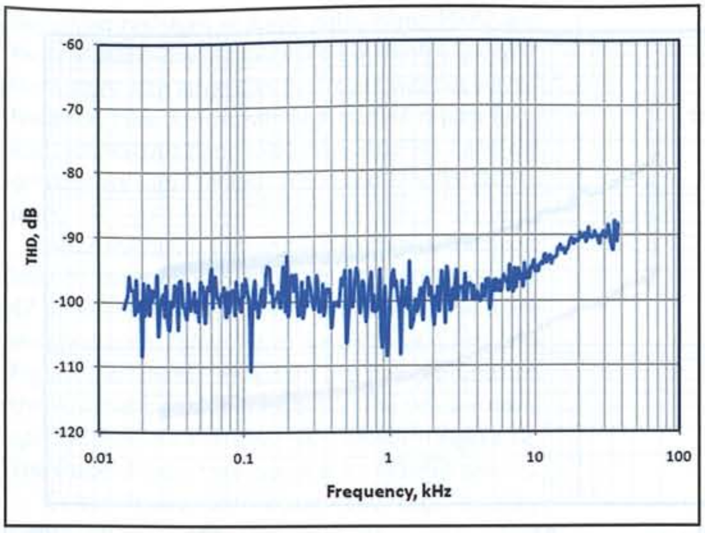


Figure 6: Total harmonic distortion at 4 V_{RMS} output (1 V_{RMS} input)

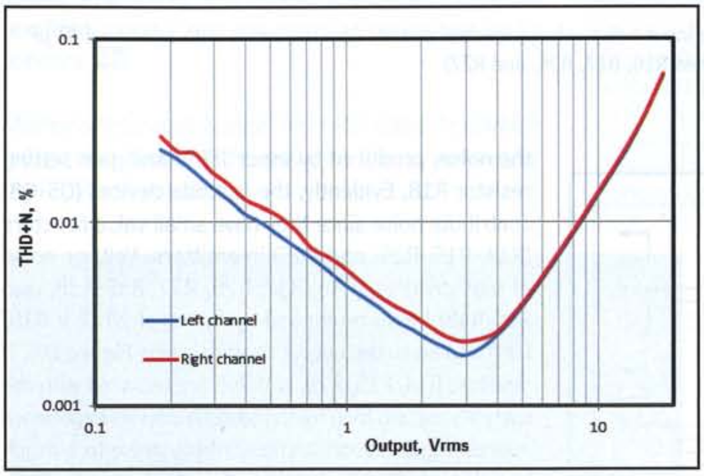


Figure 7: Total harmonic distortion plus noise (THD+N) at 1 kHz.

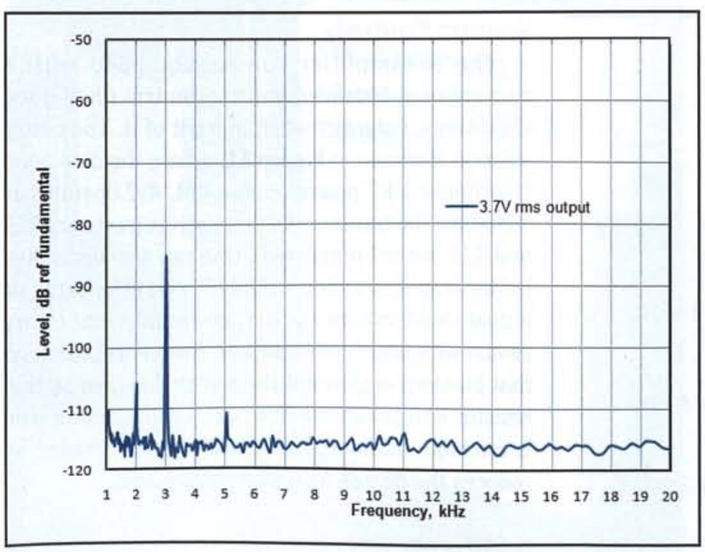
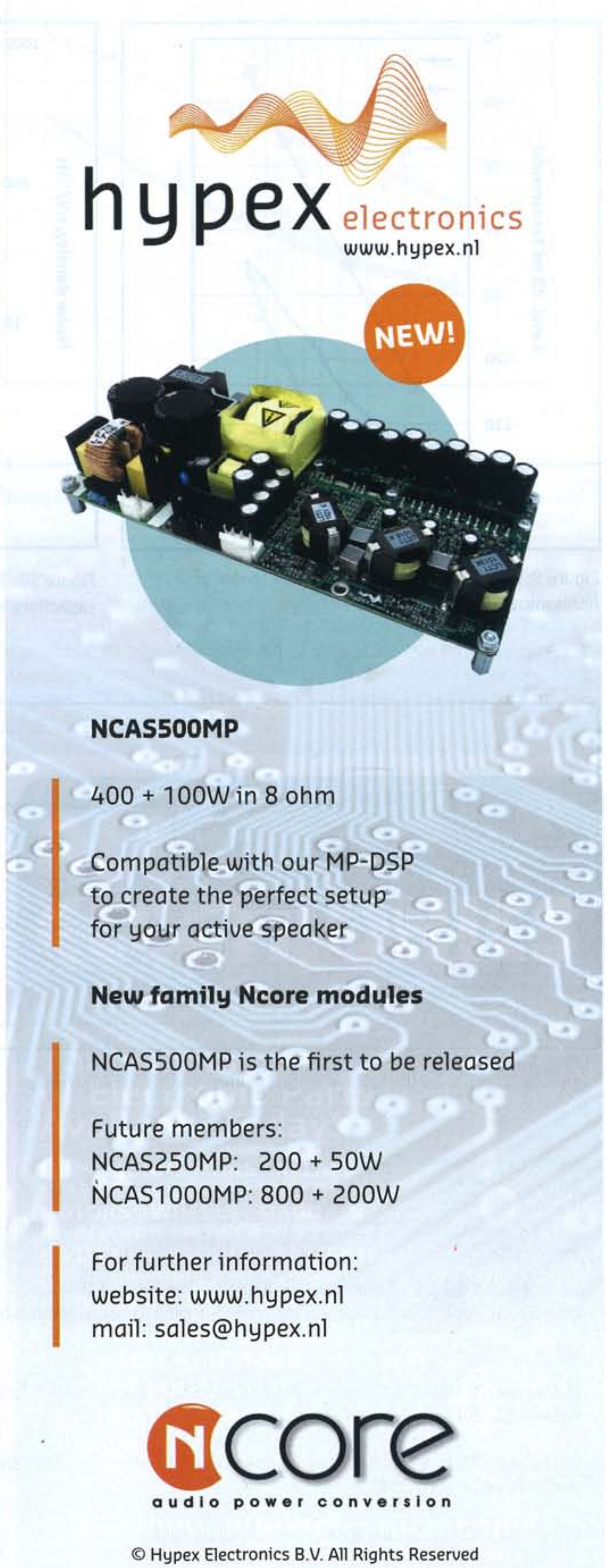


Figure 8: Distortion spectrum for 1 kHz sine wave, 4 V_{RMS} output, 1 V_{RMS} input



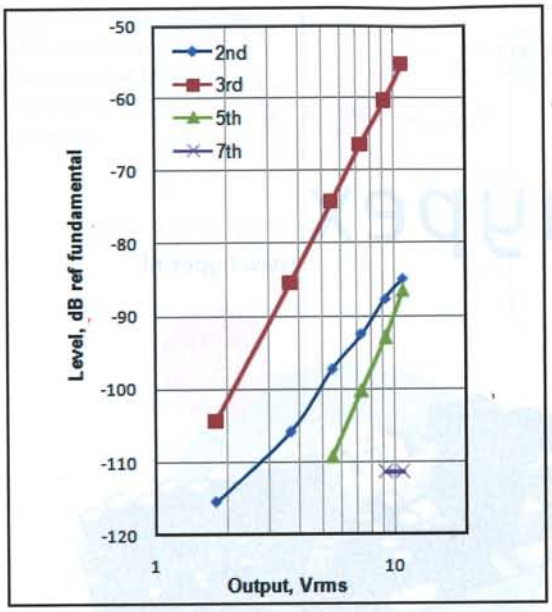


Figure 9: Individual harmonic distortion (order of harmonic as parameter)

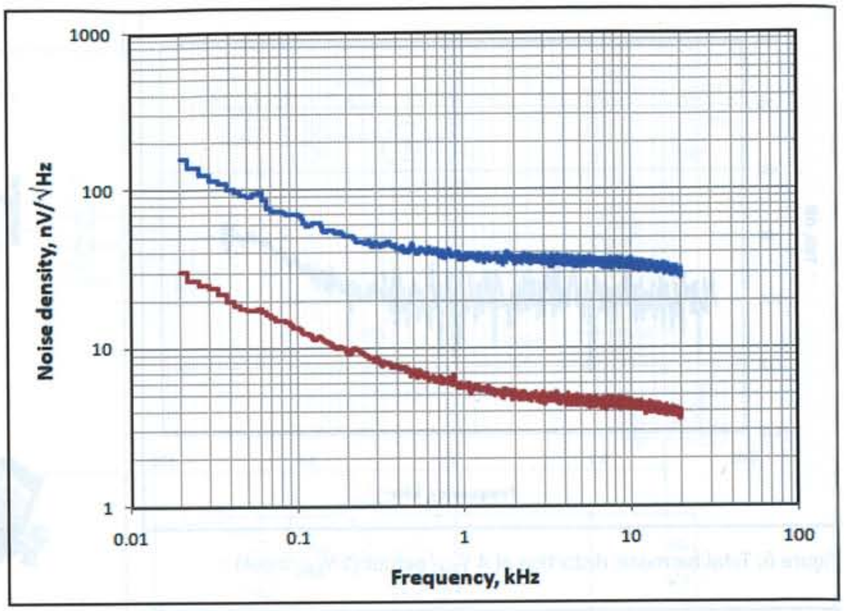


Figure 10: The input noise voltage spectral density (the red line is with additional 47 µF capacitors across R16, R17, R26, and R27)

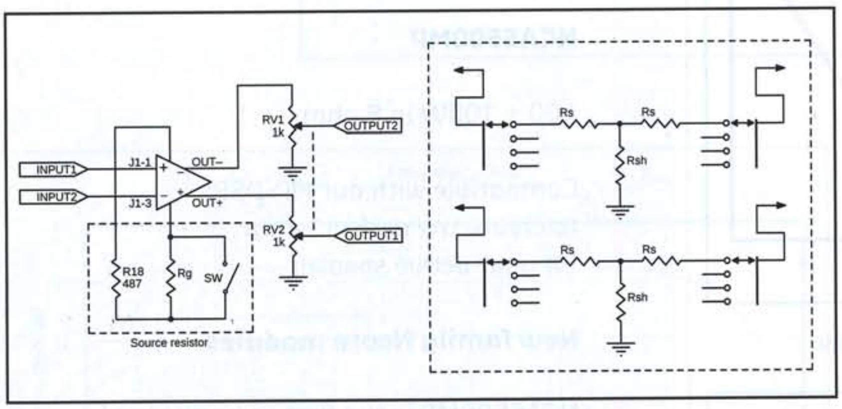


Figure 11: This shows the recommended volume control arrangement.

the noise, produced by input JFETs and gain setting resistor R18. Evidently, the cascode devices (Q5-Q8) contribute noise since they have small value resistors (R14, R15, R25, and R65) in emitters. Voltage noise of bias dividers (R16, R17, R26, R27, R35-R38, and R45-R48) being multiplied by factor of 20 (2 × R19/R14) applies to the output terminals (see **Figure 10**). If resistors R14, R15, R25, and R65 are replaced with the current sources, then folded cascode devices experience source degeneration and contribute noise to a much less degree. Simplicity is an important consideration in a design, but over-simplicity is harmful.

Volume Controls

The preamplifier can be equipped with a conventional balanced volume control (dual gang logarithmic potentiometer) in front of it. The better solution is shown in **Figure 11**, where the dual gang logarithmic 1 kΩ potentiometer Rv1, Rv2 operates as a load for the transconductance stage (resistors R19 and R28 are not populated). One can also use a dual ladder step attenuator, a dual "T" pad attenuator, or a dual shunt volume control, preferably with rotary switch with silver coin contacts. I would recommend that builders implement the switchable gain setting resistor R18 (as shown in Figure 11) if 12 dB of gain is too high. Additional switchable series resistor Rg reduces the overall gain to desirable level.

Additional Notes

I populated the boards with conventional high-grade parts: CMF/CCF Vishay/Dale and MB* Vishay/

Project Files

To download the bill of materials (BOM and other files, visit http://audioxpress.com/page/audioXpress-Supplementary-Material.html

Resources

D. Danyuk, "A High-Performance Single Gain-Stage Preamplifier," *Linear Audio*, Volume 11, 2016.

D. Danyuk, "Built a Discrete High-Output Current Buffer with JFET Input," *audioXpress*, March 2019.

DIY Audio website, J. Curl posts, www.diyaudio.com

Beyschlag resistors in audio path, Wima MKP2 and Nichicon audio-grade capacitors. I prefer the sound of transistors with large dies in circuits without overall feedback. I use devices with high current ratings (e.g., KSB1366/KSD2012 and KSB1151/KSD1691). I also get good results with TTA004/TTC004 and TTA008/TTC015 pairs.

After the build, I attempted to reduce the noise level by shunting R16, R17, R26, R27 resistors with 47 µF aluminum electrolytic capacitors. The noise dropped from 38nV/√Hz to 6 nV/√Hz at 1 kHz (see Figure 10). These capacitors are not captured on the schematic shown in Figure 2. The voltage noise spectral density for supply rails is shown in **Figure 12.** The shape of the curves is typical for MOSFET devices.

Subjectively, this open-loop high-quality transconductance amplifier has very good transparency and stage. I sincerely hope that building, modifying, and upgrading this design will lead to an exciting journey into the world of open-loop audio circuits.

Author's Note: audioXpress' *Technical Editor Jan Didden suggested checking the noise on the power supply rails. Thank you Jan.*

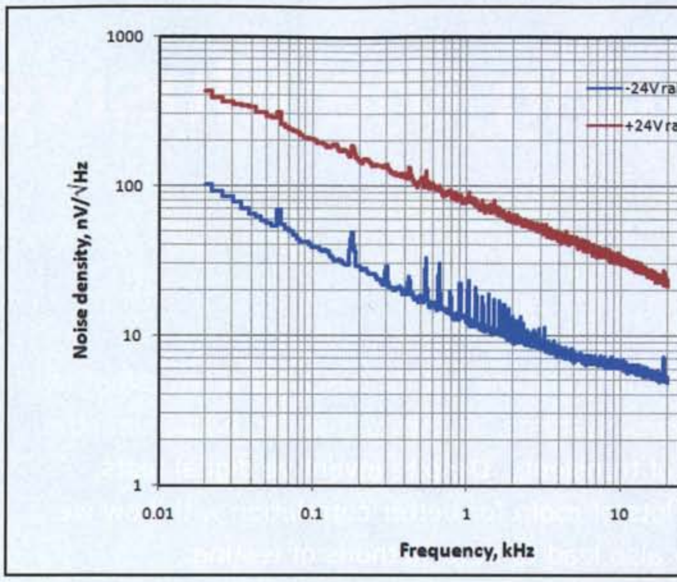


Figure 12: This shows voltage noise spectral density for the supply rails.

About the Author

Dimitri Danyuk has been the principal hardware engineer at Harman luxury audio since 2013. He graduated with honors from Kyiv Polytehnic in 1985. His passion is to help audiophiles in all aspects of audio design. His articles have appeared in a number of magazines including the *Journal of the Audio Engineering Society*, *IEEE Transactions*, *EDN*, *Electronic Design*, etc. Danyuk also provides consulting services for various businesses.