High-End Amplifier for Active Speakers

Max-out your loudspeakers with this compact amplifier module

By
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Although active loudspeakers are more complex and more costly than passive loudspeakers, they have clear advantages in terms of audio technology and the resulting sound. To keep the complexity and cost within limits, we have developed a simple power amplifier module. Along with a suitable active crossover, you can install two, three or four of them in a speaker cabinet (depending on whether it is a two-way, three-way or four-way loudspeaker) and power them from a single supply.

Loudspeakers equipped with more than one speaker unit usually contain passive crossovers, which (in good-quality units) are made with hefty air-core coils and fairly expensive film capacitors. Their job is to divide the audio power between the woofer, midrange and tweeter units (assuming a conventional three-way loudspeaker) according to their respective frequency ranges. For stereo sound, you therefore need two power amplifiers (or output stages) in a passive system. By contrast, in an active loudspeaker each speaker unit is connected to its own amplifier and the crossover is active, which means that it is built with transistors or opamps and is located ahead of the power amplifiers.

Pros and cons

The main drawback of active loudspeakers is the complexity: with three-way loudspeakers, you need six power amplifiers for the active version instead of the usual two. This additional circuitry makes active loudspeakers more expensive, so they are significantly less common. Even in the high-end sector, active loudspeakers are relatively rare.
The complexity is more than offset by the technical and audible advantages of active loudspeakers.

To start with, the fact that each speaker unit is connected to the output of its power amplifier by a short cable is an enormous advantage. Among other things, this eliminates the need for hefty and correspondingly expensive cables, which can also be difficult to install. Eliminating the crossover network between the output stage and the speaker unit results in optimal damping of the speaker and avoids the distortion that can be caused by high currents flowing through passive components. This is particularly the case with low-cost crossovers, which are made with inexpensive ferrite-core coils and bipolar electrolytic capacitors instead of high-quality and correspondingly expensive air-core coils and film capacitors.

Another advantage of active loudspeakers is that frequency curves with steeper skirts (which means better separation of the frequency bands) can be achieved with active crossovers, and they also enable special features such as phase correction. In 2.1 speaker systems the subwoofer does not require a special speaker with two voice coils, since an active crossover can easily add the low-frequency signals from the two stereo channels to generate a signal for a channel with one power amplifier. If you search the web or the Elektor website for crossovers, you can find a lot of different crossover designs for every imaginable application. To avoid any misunderstanding, it must be said that there are passive loudspeakers available with excellent sound and active loudspeakers are not necessarily better than passive ones just because they are active. However, it's always possible to tune a passive loudspeaker by replacing the passive crossover with an active crossover and adding suitable power amplifiers to convert it into an active loudspeaker. The difference is more than just measurable.

Power stage designs

Compared with passive loudspeakers, active loudspeakers contain a lot of electronics. Placing the active elements outside the loudspeaker cabinet would increase the cable length between the power amplifier and the speaker unit and thereby reduce the high damping factor, which is one of the advantages of an active speaker. With a three-way loudspeaker, the three thick cables required for connection to the speaker units would also create an unsightly cable jungle. There's thus no alternative: the electronics must be housed in the loudspeaker cabinet along with the speaker units, and the space available for this is usually limited.

Space is also limited in another regard: power amplifiers in the "killerwatt" range and the associated power supplies are bulky. This means that for home listening you should go for class instead of mass and avoid getting caught up in the power mania. For living-room loudspeaker applications you therefore need fairly simple, compact power amplifiers with excellent specs and relatively low to moderate power.

It is also important to be able to operate several power amplifiers from a single power supply without mutual interference. In this regard you should bear in mind that strong bass signals draw corresponding currents from the power sup-

Tech Data and Performance

Compact high-end power amplifier for active loudspeakers

Maximum input voltage:	0.62 V for 23 W / 8 Ω
Output power (at ±25 V):	34 W / 4 Ω; 23 W / 8 Ω
Supply voltage:	±25 V for 4 Ω; ±42 V for 8 Ω
Bandwidth (1 W / 8 Ω):	16.4 Hz to 230 kHz (-3 dB)
SNR (signal to noise ratio):	>100 dB (22 Hz to 22 kHz)
SNR (1 W / 8 Ω):	>103 dB(A)
THD (distortion):	<0.1% (34 W / 4 Ω; 23 W / 8 Ω)
THD+N (with noise):	0.0023% (1 kHz; 1 W / 8 Ω)
THD+N (B = 22 kHz):	0.006% (11 W / 8 Ω)
	0.006% (1 W / 4 Ω)
	0.015% (17 W / 4 Ω)
Damping factor:	>600 (1 kHz)
Damping factor (1 W / 8 Ω):	>400 (20 kHz)
Output offset voltage:	54 mV

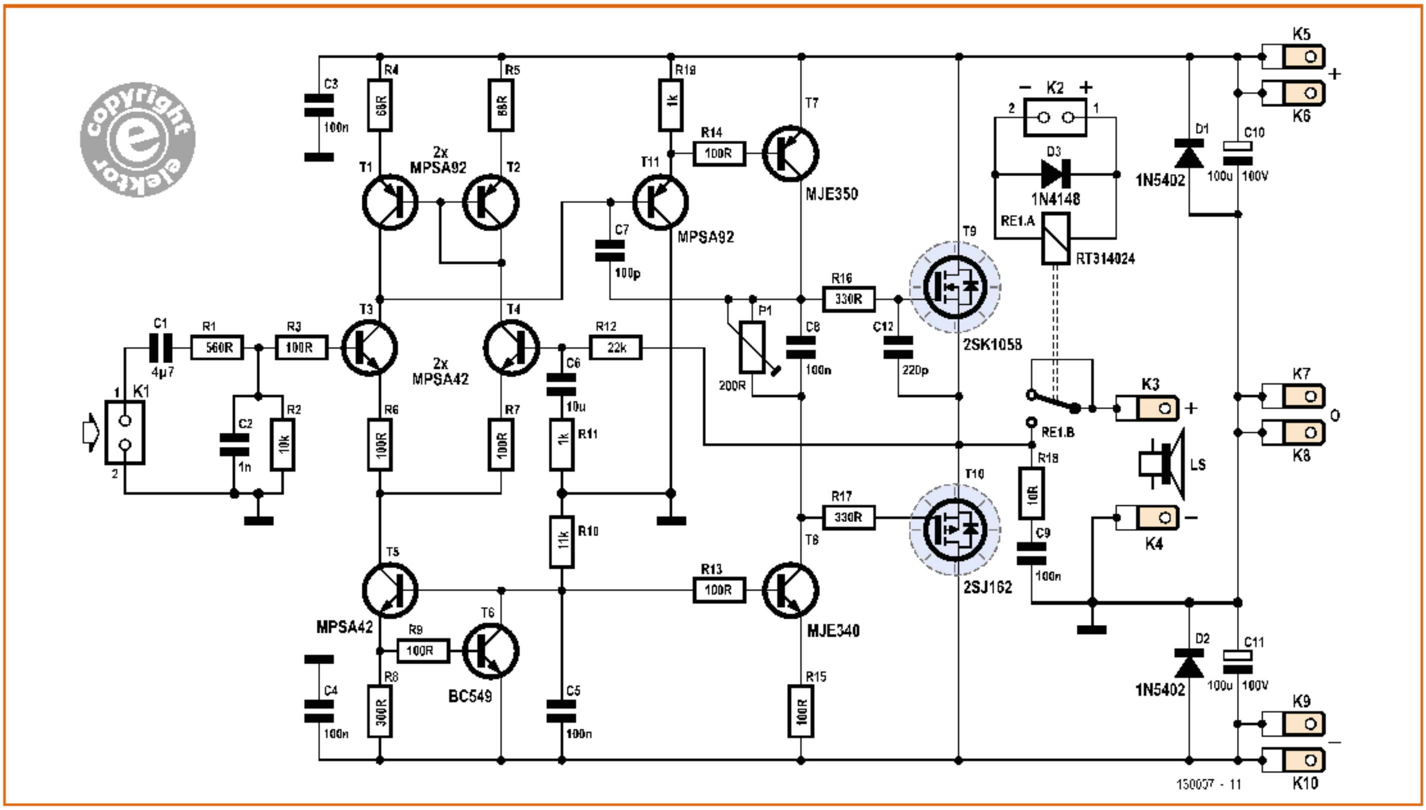

Figure 1.
Schematic diagram of the complete high-end amplifier.

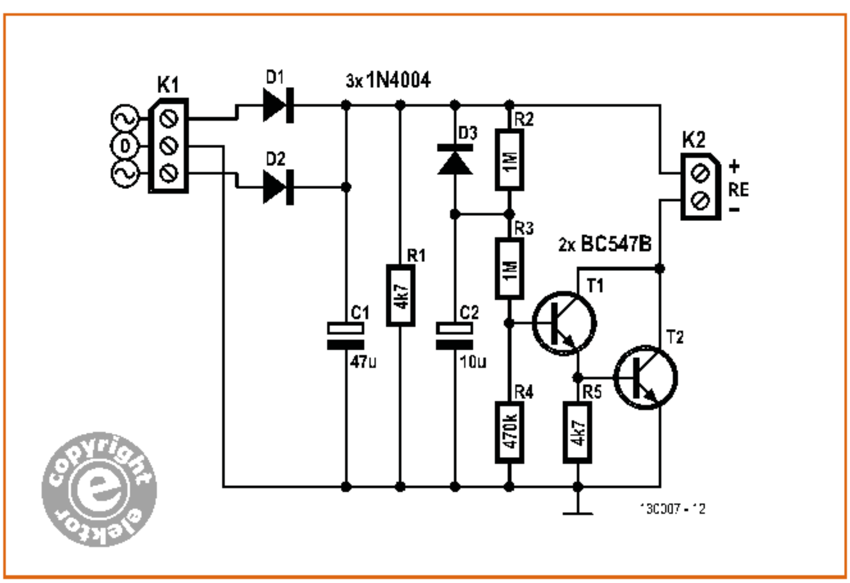

Figure 2.
The relay control circuit is very simple.

ply, and this can easily cause voltage variations. These should not impair the midrange or tweeter channels. Otherwise you would need a separate power supply for each power amplifier, which is too much of a good thing.

In line with these requirements, the author designed a modular power amplifier that is very suitable for use in active loudspeakers. In the circuit design the author was guided by the ideas of Douglas Self [1]. Along with other audio circuit designs, Self previously published an especially good preamplifier design in Elektor [2] that is ideal for driving active loudspeakers.

Amplifier circuit

As usual with modern power amplifiers, this amplifier is powered by a balanced supply. This eliminates the need for an output capacitor, which is particularly undesirable in active loudspeakers. The first thing you notice in the schematic diagram shown in **Figure 1** is that complementary power MOSFETs are used as output transistors. These are not the same types as those used in switch-mode power supplies or similar applications, but instead Hitachi MOSFETs with fairly low transconductance and relatively high on resistance. They have often been used in power amplifier circuits published in Elektor. There is a good reason for this: although the relatively high drain-source resistance causes higher power dissipation and therefore lower output power at a given supply voltage, you get better sound because their limiting behavior at drive levels approaching maximum output power are softer (very similar to tubes, by the way).

The Hitachi devices also have very low gate-source capacitance compared with MOSFETs with lower on resistance. The input capacitance of the N-type device (T9) is just 600 pF, while that of the P-type device (T10) is 900 pF. C12 largely neutralizes this difference. These low capacitance values allow relatively simple, high-impedance drive at audio frequencies with correspondingly low driver current. They also reduce the high-frequency attenuation due to resistors R16 and R17 (330 Ω). Another benefit is that driver transistors T7 and T8 do not have to supply high drive power and therefore stay reasonably cool even without heat sinks. A simple trimpot (P1) is all that is necessary for adjusting the quiescent current; there is no need for stabilization circuitry. This is because the temperature characteristics of T9 and T10 are the opposite of the temperature characteristics of bipolar transistors, so the quiescent current is self-limiting and does not rise with increasing temperature.

The driver stage works as follows. The quasi-Darlington common-emitter stage formed by T11 and T7 has a constant-current source (built around T8) in the collector lead instead of a resistor. The current through T7 and T8 is determined by the voltage across R15. This voltage is in turn determined by voltage on the collector of T6, which consists of the base-emitter voltage of T6 plus the collector-emitter voltage of T5 minus the base-emitter voltage of T8. The resulting voltage across R15 is approximately 0.67 V, which yields a current slightly less than 7 mA. The power dissipation of T7 or T8 is therefore only 170 mW with supply voltages of ±25 V, so heat sinks are not necessary. Even at supply voltages of ±42 V, the driver transistors do not become alarmingly hot.

Now let's look at the input stage. Transistors T3 and T4 form a nearly classic differential amplifier. The collectors are connected to a current mirror consisting of T1 and T2, which is an elegant way to boost the relatively low open-loop gain of the transistors in the input stage. The emitter currents are fed through R6 and R7 from a current source built around T5 and T6, whose current is determined by the value of R8 and the base-emitter voltage of T6. The resulting current through each of T3 and T4 is about 1.1 mA. A lowpass network formed by R1 and C2 is located ahead of the base of T3, which is the non-inverting input. It blocks RFI on the input and restricts the slope of the input signal, which effectively limits the bandwidth of the amplifier. Capacitor C1 blocks DC voltages on the input. The corner frequency of the high-pass network formed by R2 (plus R1) is about 3.5 Hz, which is low enough to allow the lower corner frequency of the amplifier (16 Hz) to be largely determined by the lowpass network formed by R11 and C6. The overall gain is determined by the ratio of R12 to R11, which is approximately 22 (corresponding to 27 dB).

The current mirror and constant current source decouple the input stage from the supply voltage and thereby make the entire amplifier largely insensitive to supply voltage variations. This is what makes it possible to operate several of these power amplifiers from the same power supply, which may even be unregulated, despite their apparently simple circuitry.

Relay connection

When you switch on an amplifier, it takes a little while (like any circuit with negative feedback) to settle down to a steady operating state. An offset at the input or some other phenomenon can generate a transient at the output, which results in a clearly audible popping noise. In the case of a woofer with a large voice coil, this may only result in unpleasant noise, but for a directly connected tweeter it can be the kiss of death. This is because active loudspeakers do not have a protective capacitor in series with the tweeter to limit the transferred energy. Tweeters are sensitive because they are not designed for high continuous power, but instead for the average high-frequency audio power of typical music signals, which is rather low.

It is therefore advisable to use a time-delay relay with heavy-duty contacts to connect the speaker, instead of connecting it directly to the amplifier. Delayed relay actuation prevents any sort of switch-on pop. Ideally the speaker is also disconnected more quickly when the supply voltage drops out. This also prevents untoward events when the power is switched off. That is why relay RE1 is included in the circuit. Each power amplifier has its own relay.

It is driven by the circuit shown in **Figure 2**. Connector K1 is simply wired in parallel to the secondary of the power transformer. When the power is switched on, C1 is charged quickly and C2 is charged slowly through R2. This delays the pull-in of the relay connected to K2 by several seconds. When the power is switched off, the energy stored in the relatively small capacitor C1 is quickly used up by the relay, causing the volt-

About the Author

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age on the base of T1 to drop quickly because D3 provides a direct discharge path for C2. Although T2 (a BC547B) may appear to be a bit light for the job, the relay shown in Figure 1 needs only 18 mA at 25 V. The control circuit can therefore easily handle three relays of this type. The entire circuit is so simple that it can easily be built on a small piece of prototyping board and fitted in a suitable location.

Construction

A PCB layout has been designed for this nice amplifier module, with the component layout shown in **Figure 3**. If you use the PCB Prototyper [3] or your own choice of tools to make this double-sided board [4] yourself, the through-hole plating will be missing. This means that you have to solder component leads on both sides of the board where necessary and possible. For example, there are extra holes provided for ceramic capacitors with different lead spacings. You can solder short lengths of wire on both sides in the unused holes to connect the upper and lower surfaces. You can also mount the electrolytic capacitors spaced above the board so you can solder their leads on both sides. With a ready-made board you do not have this problem, and board assembly is fairly relaxed thanks to the use of leaded components (see **Figure 4**).

Fitting T9 and T10 is a bit more complicated. They come last in the process and are mounted directly on the heat sink (see **Figure 5**). The PCB

Component List

Resistors

Default: 0.25W 1%
R1 = 560Ω
R2 = 10kΩ
R3,R6,R7,R9,R13,R14,R15 = 100Ω, .4W
R4,R5 = 68Ω
R8 = 300Ω
R10 = 11kΩ
R11,R19 = 1kΩ
R12 = 22kΩ*
R16,R17 = 330Ω
R18 = 10Ω 1W 5%
P1 = 200Ω multiturn, vertical mounting

Capacitors

C1 = 4.7µF 63V, 5/7.5mm pitch
C2 = 1nF 63V 2.5/5mm pitch
C3,C4 = 100nF 100V, X7R, 2.5/5mm pitch
C5 = 100nF 63V, MKT, 2.5/5mm pitch
C6 = 10µF 63V, MKT, 5/7.5/10/15mm pitch
C7 = 100pF 1000V, MKP, 5mm pitch
C8 = 100nF 63V MKT, 2.5/5mm pitch
C9 = 100nF 63VAC, MKT, 2.5/5mm pitch
C10,C11 = 100µF 100V, electrolytic, max. diam. 13.5mm, 5mm pitch
C12 = 220pF 1000V, 5%, MKP, 5mm pitch

Semiconductors

D1,D2 = 1N5402
D3 = 1N4148
T1,T2,T11 = MPSA92
T3,T4,T5 = MPSA42
T6 = BC549C
T7 = MJE350
T8 = MJE340
T9 = 2SK1058
T10 = 2SJ162

Miscellaneous

K1,K2 = 2-way PCB mount screw terminal block, 5mm pitch
RE1 = Relay, RT314024, PCB mount, 24V 1440 Ω, 1x c/o, 250VAC 16A
K3-K10 = Faston terminal, vertical, 0.2" pitch
T9,T10 = TO-3P style isolating washer, e.g. Kapton MT Film .15mm
Heatsink, 1.2K/W, e.g. SK 85/75 SA (Fischer Elektronik)
PCB # 130007-1 v1.1*

* see text

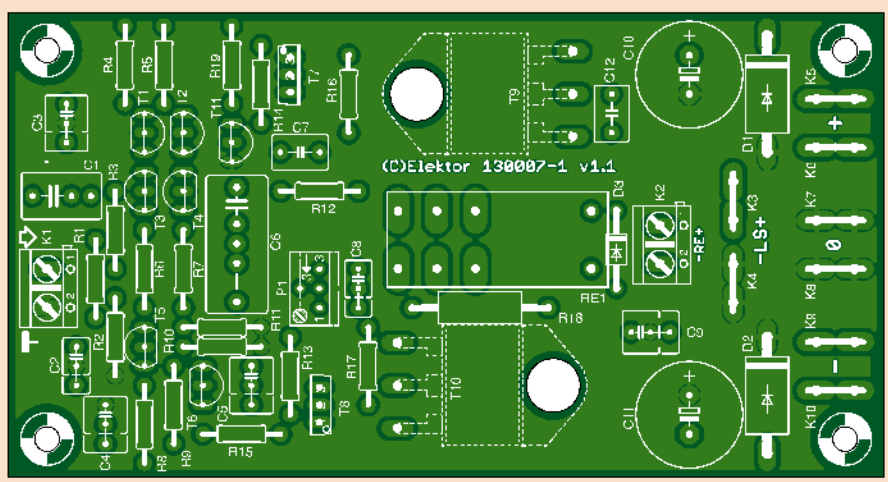

Figure 3. The PCB component layout of the high-end amplifier.

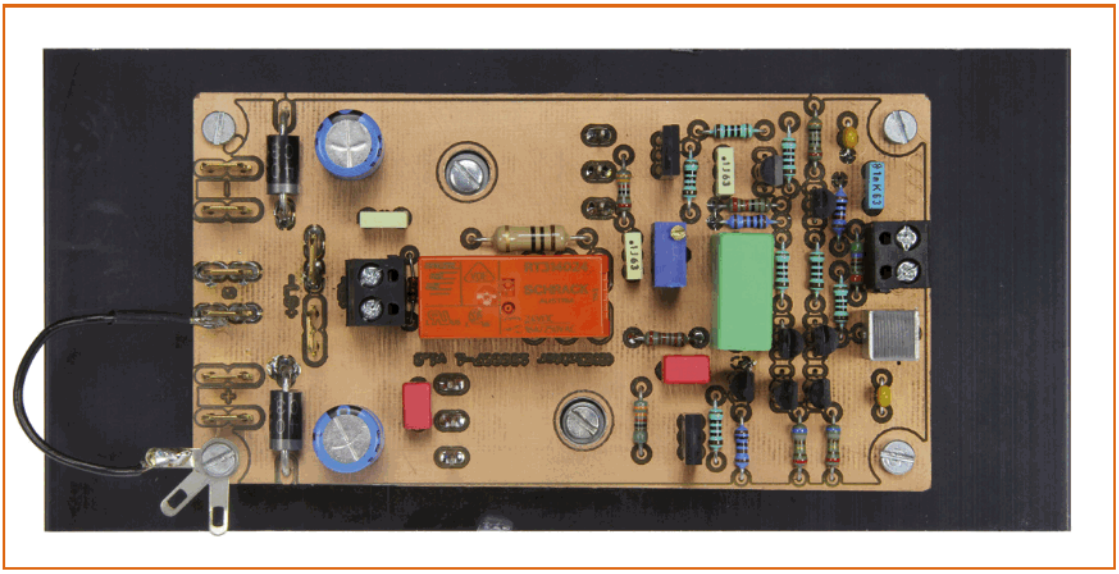

Figure 4.
Top view of the fully assembled prototype circuit board.

has matching holes for the screws that secure the transistors. It can be used as template for marking the positions of the holes to be drilled in the heat sink. The board should be mounted at least 6 mm above the heat sink. This can be achieved by using 5-mm metal standoffs and split washers or suitable studs. T9 and T10 together with their insulation pads stand a bit less than 5 mm above the heat sink, so there is no direct thermal contact between them and the PCB.
After drilling the holes in the heat sink, screw T9 and T10 together with their insulation pads to the heat sink with light pressure. After bending up the leads appropriately, you can slide the board over them and solder the leads on the top. After removing the fastening screws for T9 and T10 (which is easy because the holes in the board have a diameter of 7 mm), you can then lift up board together with the transistors and solder the leads on the bottom. After this, screw the board back onto the heat sink, and don't forget the screws for T9 and T10. M3 washers also fit through the 7-mm holes.

Initial operation

The amplifier modules are designed to operate from ±25 V supply voltages. The easiest way to provide these is to use a power transformer with two 18-V secondaries rated at 1.2 A (for 8-ohm loudspeakers). You also need a B40C2200 bridge

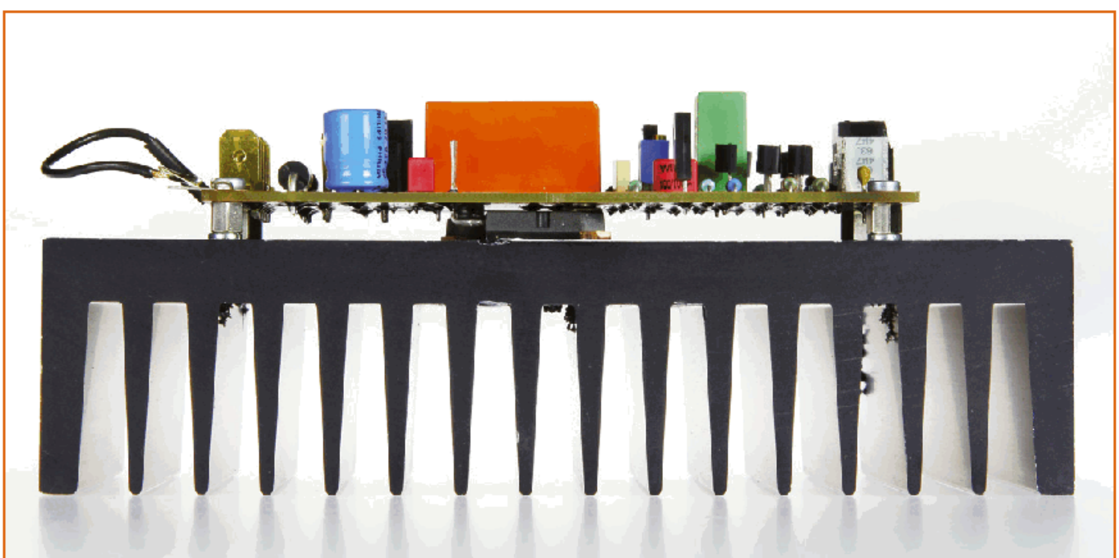

Figure 5.
Here you can clearly see how the output transistors are mounted.

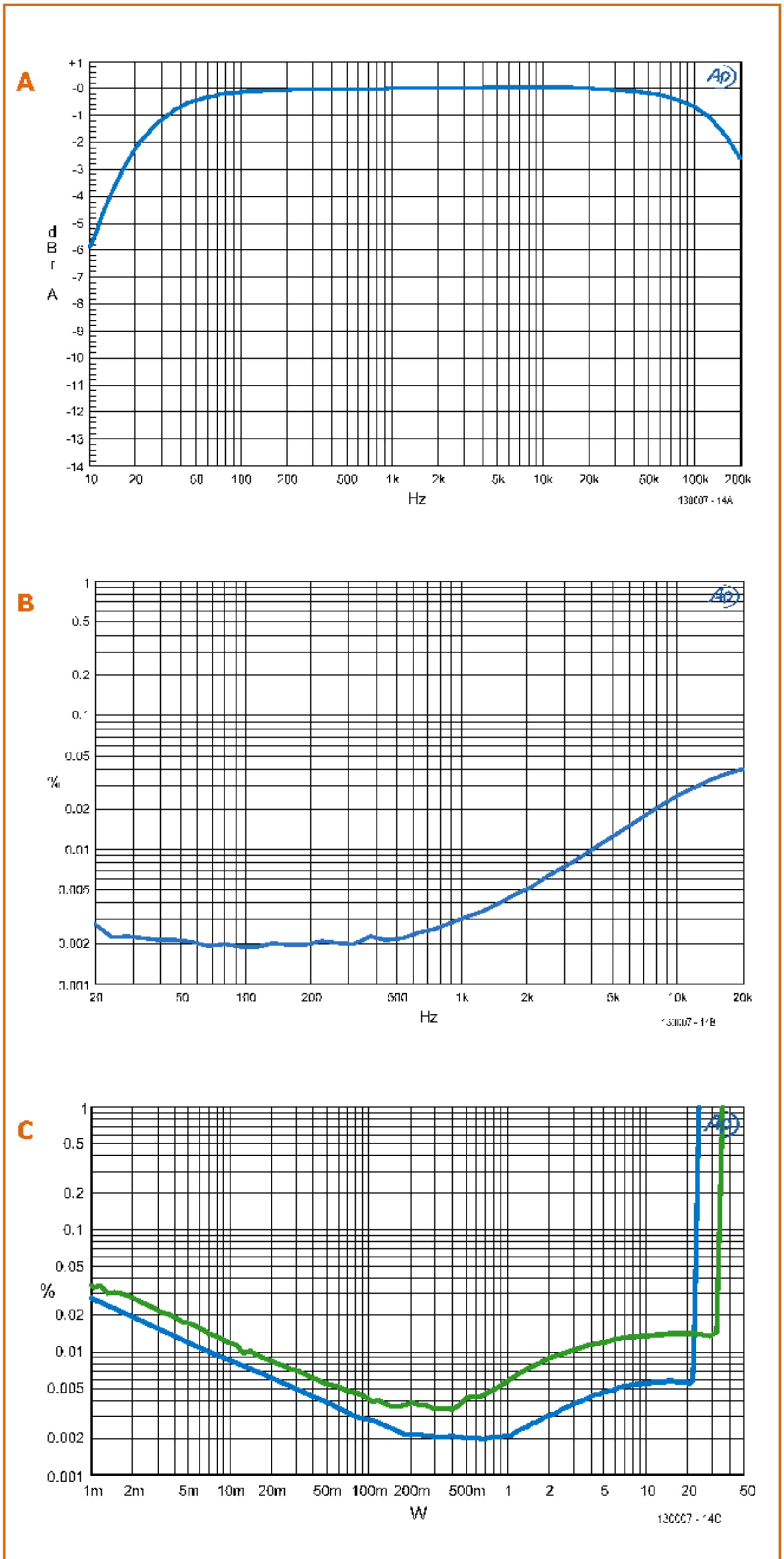

Figure 6.
The three measurement plots show the bandwidth (A), distortion plus noise versus frequency (B), and distortion versus power (C) with 4-ohm (green) and 8-ohm (blue) loads.

rectifier and two filter capacitors each rated at 4,700 µF / 35 V. That's more than enough for three high-end amplifier modules. With 4-ohm loudspeakers and correspondingly higher power, the transformer should be rated at 2 A.

Before connecting an amplifier module, you should set P1 to minimum resistance. As a precaution, it is advisable to initially connect the module to a suitable laboratory power supply or to connect a pair of high-wattage 12-V car light bulbs in series with the supply leads. That way if something goes wrong, your bench will only get bright instead of smoky. With the input shorted, set the quiescent current to 90 mA. To do this, adjust the circuit without any loudspeaker connected for a current of 99 mA in the positive supply lead (which corresponds to a current of 101 mA in the negative lead). If that works and the DC voltage on the output with the relay engaged is within the range of ±50 mV, everything is okay and you can connect a loudspeaker and an input signal source for testing.

If instead you see a higher DC voltage on the output, you can try fitting another transistor of the same type for T3 or T4, since the DC output voltage depends on the difference between their current gains, or try adjusting the value of R2. Increasing the value reduces the voltage, and vice versa. Values in the range of 4.7 kΩ to 33 kΩ are acceptable for R2.

Curves

The high-end amplifier was extensively tested and measured by Elektor Labs. The measurements yielded the nice curves shown in **Figure 6**, which testify to the high quality of this amplifier.

The top curve (A) shows the power bandwidth at 1 W into 8 Ω. It extends from 16 Hz to more than 200 kHz (−3 dB). The transfer function is considerably flatter than what you get with any loudspeaker or listening room.

The middle curve (B) shows the percentage THD+N versus frequency at 1 W into 8 Ω. The distortion and noise components are minimal at low frequencies. The distortion rises slowly above

Web Links

[1] Audio Power Amplifier Design by Douglas Self: www.douglas-self.com/ampins/books/apad.htm

[2] Preamp 2012: A DIY high-end preamplifier – www.elektor-magazine.com/110650

[3] PCB Prototyper: www.elektor.com/PCBprototyper

[4] Elektor website with downloads for this project: www.elektor-magazine.com/130007

1 kHz. However, 0.04% at 20 kHz is unquestionably excellent.

The two curves on the bottom chart (C) show the distortion versus power with a 4-ohm or 8-ohm load, respectively. With 8 ohms the distortion rises above 1 watt. With 4 ohms the rise starts at the same current level, and therefore at half the power level. The distortion quickly rises to more than 1% when signal limiting occurs.

Miscellaneous

If you want to get more power from the amplifier modules, you can raise the operating voltage to a maximum of 42 V. This gives you a good 60 W at 8 Ω with slightly higher distortion. With this voltage a 1 kΩ / 1 W resistor must be connected in series with each relay. A transformer with two 30 V / 2 A secondaries is a suitable choice in this case. The filter capacitors need to have a rated voltage of 63 V.

The author even drove 4-ohm speakers with ±42 V supply voltages, yielding a good 100 W of output power. The transformer must be able to supply 3 A in this case. Even with the specified heat sink this does not cause any problems for listening to music in a home setting, since the average output power is much less than the peak power. However, this is not true in some other applications, such as a guitar amplifier. The higher peak power mainly increases the dynamic range and raises the level at which signal limiting occurs.

The circuit board has two blade connectors for each supply voltage. This simplifies daisy-chaining the supply leads. Obviously the woofer module should be the first in the chain, since it draws the most current.

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