555 Class-D Audio Amplifier

A novel use for an old-timer

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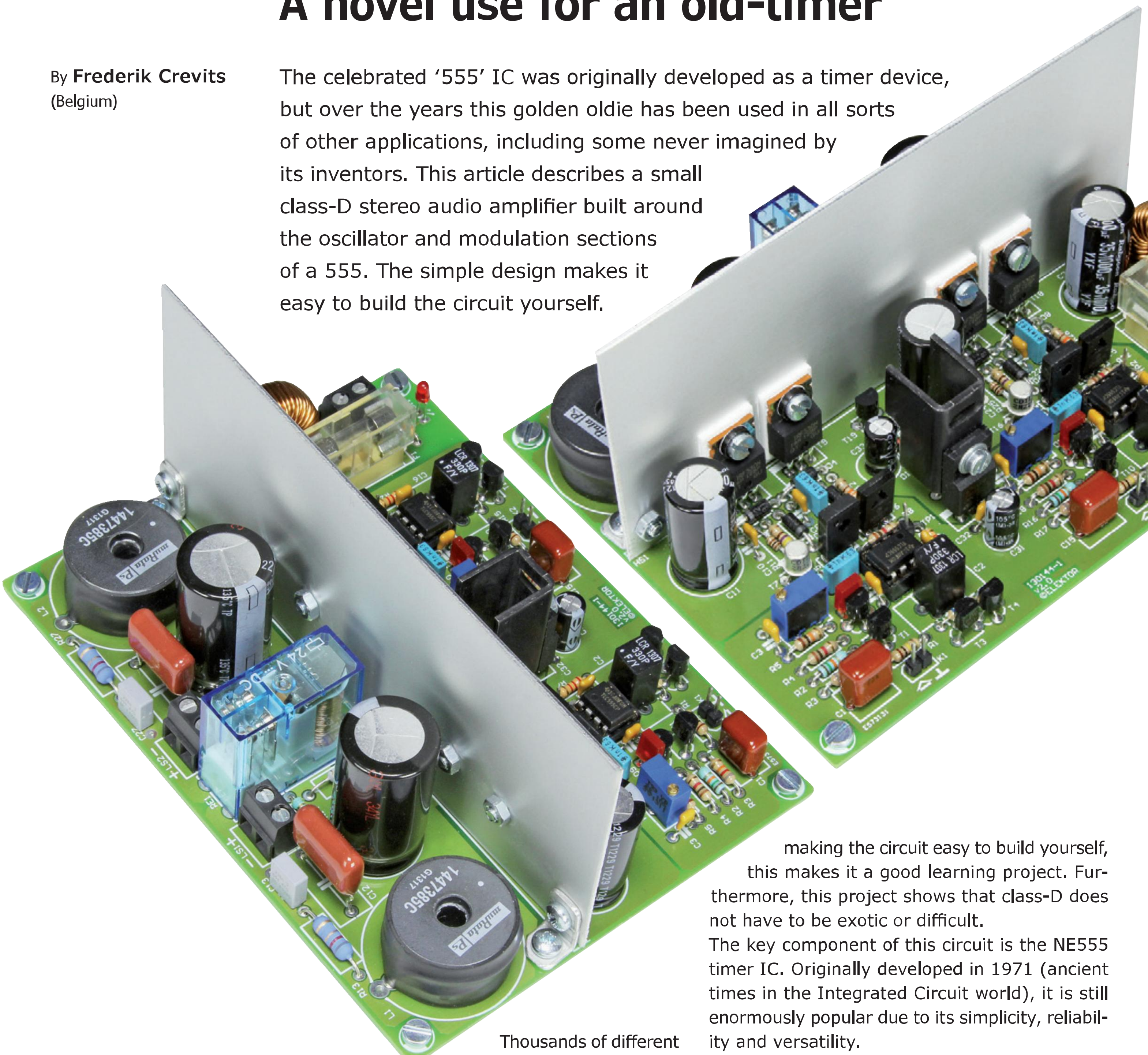
The celebrated '555' IC was originally developed as a timer device, but over the years this golden oldie has been used in all sorts of other applications, including some never imagined by its inventors. This article describes a small class-D stereo audio amplifier built around the oscillator and modulation sections of a 555. The simple design makes it easy to build the circuit yourself.



Thousands of different applications can be implemented using the popular 555 timer IC. Here this IC is used as the basis for a simple class-D audio amplifier that operates without overall negative feedback. Only standard components are used in the circuit. In addition to making the circuit easy to build yourself, this makes it a good learning project. Furthermore, this project shows that class-D does not have to be exotic or difficult.

The key component of this circuit is the NE555 timer IC. Originally developed in 1971 (ancient times in the Integrated Circuit world), it is still enormously popular due to its simplicity, reliability and versatility.

A pair of MOSFETs (type IRF530) driven by a voltage level shifter enable the circuit to deliver sufficient output power. To avoid making the circuit unnecessarily complicated, we opted for a single supply voltage, which means that an output capacitor is required.

Schematic

First a comment about the schematic diagram in **Figure 1**, which shows a complete stereo amplifier. To avoid having to mention a whole raft of component numbers in the following circuit description, we limit ourselves to the components in the upper channel.

In a class-D audio amplifier, the analog audio signal is converted into a pulsewidth modulated signal that drives the output transistors. Here this is implemented by employing the 555 as an astable multivibrator and using the analog audio signal to modulate the voltage for the charge/discharge capacitor (C2). In standard 555 circuits this capacitor is usually charged by

Measured Performance @ Elektor Audio labs

• Input sensitivity:	580 mV (*THD+N* = 1%)
	830 mV (*THD+N* = 10%)
• Input impedance:	11 kΩ
• Continuous output power:	6.3 W (*THD+N* = 1%)
	10.8 W (*THD+N* = 10%)
• Power bandwidth:	11 Hz – 37.5 kHz (–3 dB)
	21.5 Hz – 31 kHz (–1 dB)
• Signal to noise ratio:	69 dB (1 W / 8 Ω; *B* = 22 Hz – 22 kHz)
• Total harmonic distortion + noise:	0.23% (1 kHz; 1 W / 8 Ω)
• Channel separation:	42 dB (100 Hz, P_{max})
	54 dB (1 kHz, P_{max})
	60 dB (20 kHz, P_{max})
• Current consumption:	0.8 A at 2 x 6.3 W / 8 Ω

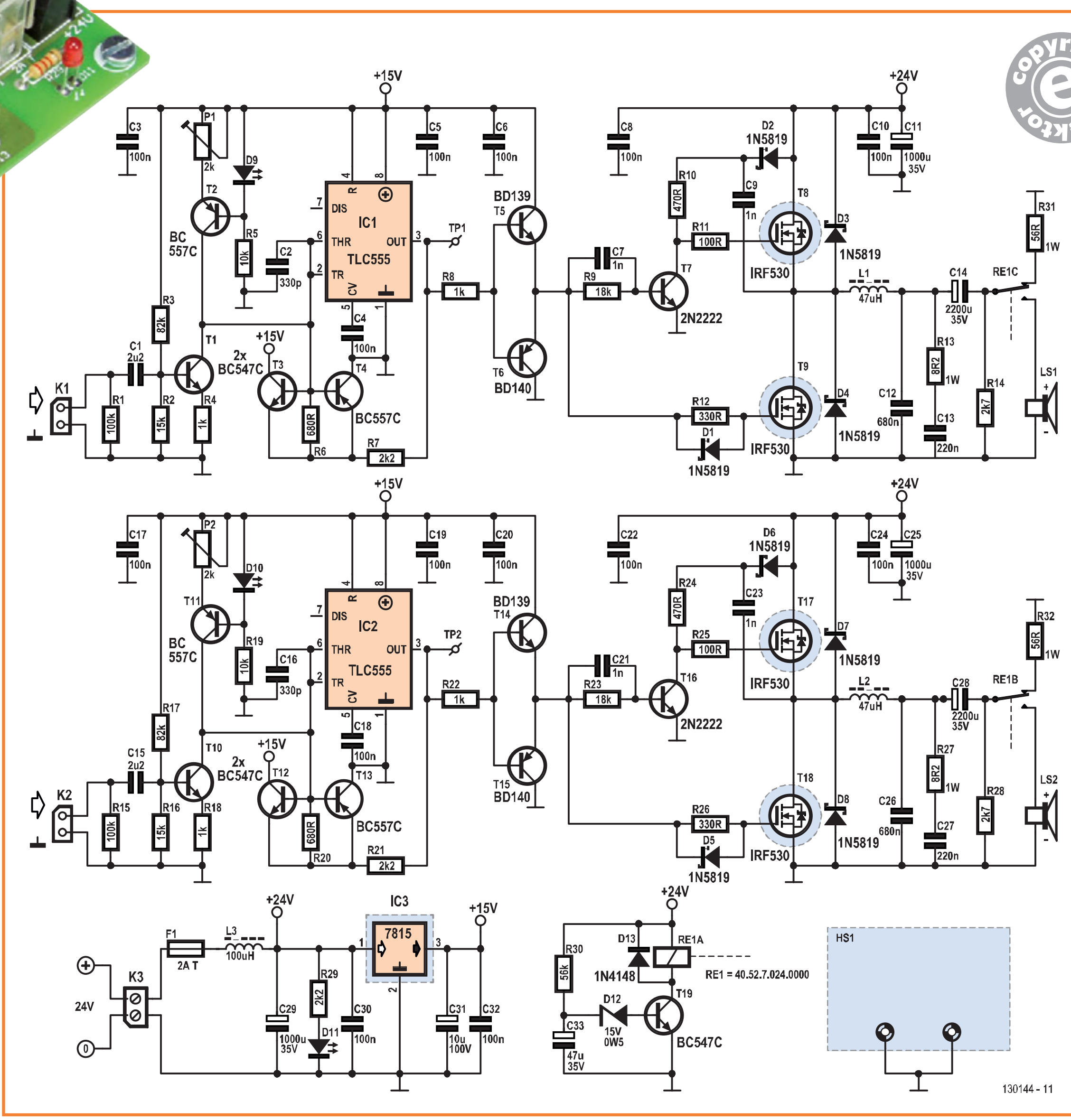


Figure 1.
Full stereo version of the class-D amplifier based on the 555 IC. A simple switch-on delay circuit is included.

A Nearly Perfect V-to-I Converter

Although the arrangement with T3 and T4 dramatically improves the linearity, it is somewhat less than perfect. The current through the capacitor is the sum of the current determined by the base–emitter voltage over R6 and the base current of T3 or T4. Since the collector current of T3 or T4 depends on the current through R7, the base–emitter voltage (and therefore the base current) also depends on this current. This relationship is not linear, and another factor is that the two transistors are not perfectly complementary, so they have slightly different gain curves.

Component List

Resistors

R1,R15 = 100kΩ
R2,R16 = 15kΩ
R3,R17 = 82kΩ
R4,R8,R18,R22 = 1kΩ
R5,R19 = 10kΩ
R6,R20 = 680Ω
R7,R21,R29 = 2.2kΩ
R9,R23 = 18kΩ
R10,R24 = 470Ω
R11,R25 = 100Ω
R12,R26 = 330Ω
R13,R27 = 8.2Ω, 1W
R14,R28 = 2.7kΩ
R30 = 56kΩ
R31,R32 = 56Ω, 1 W
P1,P2 = 2kΩ multiturn preset (Vishay Sfernice T93YB202KT20)

Capacitors

C1,C15 = 2.2µF 50V, 5mm or7.5.mm pitch (e.g. Panasonic ECQV1H225JL)
C2,C16 = 330pF 1%, polystyrene, 7,18mm pitch (e.g. LCR Components EXFS/HR 330PF ±1%)
C3–C6,C8,C10,C17–C20,C22,C24,C30,C32 = 100nF, X7R, 0.2'' pitch
C7,C9,C21,C23 = 1nF MKT, 5mm pitch
C11,C25,C29 = 1000µF 35 V, radial, 12.5mm dia. 5mm pitch (e.g. Rubycon 35YXF1000MEFC12.5X25)
C12,C26 = 680nF polypropylene, 15mm pitch (e.g. Panasonic ECWF2684JAQ)
C13,C27 = 220nF metallized film (MKT), 5mm pitch
C14,C28, = 2200µF 35V, radial, 18mm diam. 5mm or 7.5mm pitch (e.g. Panasonic EEUTP1V222)
C31 = 10µF 100V, radial, 6.3mm diam., 2.5mm pitch
C33 = 47µF 35V, radial, 8.5mm max. diam., 2.5mm pitch

Inductors

L1,L2 = 47µH, 21mΩ/8.5A, pot core type (Murata Power Solutions 1447385C)
L3 = 100µH, 35mΩ/5A ring core type (Würth Elektronik 7447070)

Semiconductors

D1–D8 = 1N5819
D9,D10 = LED, red, 2x5mm rectangular
D11 = LED, red, 3mm
D12 = 15V/0.5W zener diode
D13 = 1N4148
T1,T3,T10,T12,T19 = BC547C
T2,T4,T11,T13 = BC557C
T5,T14 = BD139
T6,T15 = BD140
T7,T16 = 2N2222
T8,T9,T17,T18 = IRF530
IC1,IC2 = TLC555CP
IC3 = 7815

Miscellaneous

K1,K2 = 2-pin pinheader, 0.1'' pitch
K3,LS1,LS2 = 2-way PCB screw terminal block, 0.2'' pitch
RE1 = Relay, 24V, 1200Ω, 8A, DPDT-CO (e.g. Finder 40.52.7.024.0000)
F1 = glass fuse, 2A(T), slow-blow, with PCB mount holder and cover
TP1,TP2 = 1 pin of pinheader
HS1 = heat sink for MOSFETs, aluminum plate 130 x 50 mm (5.1 x 2 inch), 1-2mm thick
4 x isolating washers for TO-220 case (e.g. Bergquist SIL-PAD K-10, .006'', TO-220)
4 x isolating bush, 3mm
Heat sink for IC3, 30K/W (e.g. Fischer Elektronik SK 12 SA 32)
Switch-mode power supply, sec. 24V, 2.5A min.
PCB # 130144-1 [1]

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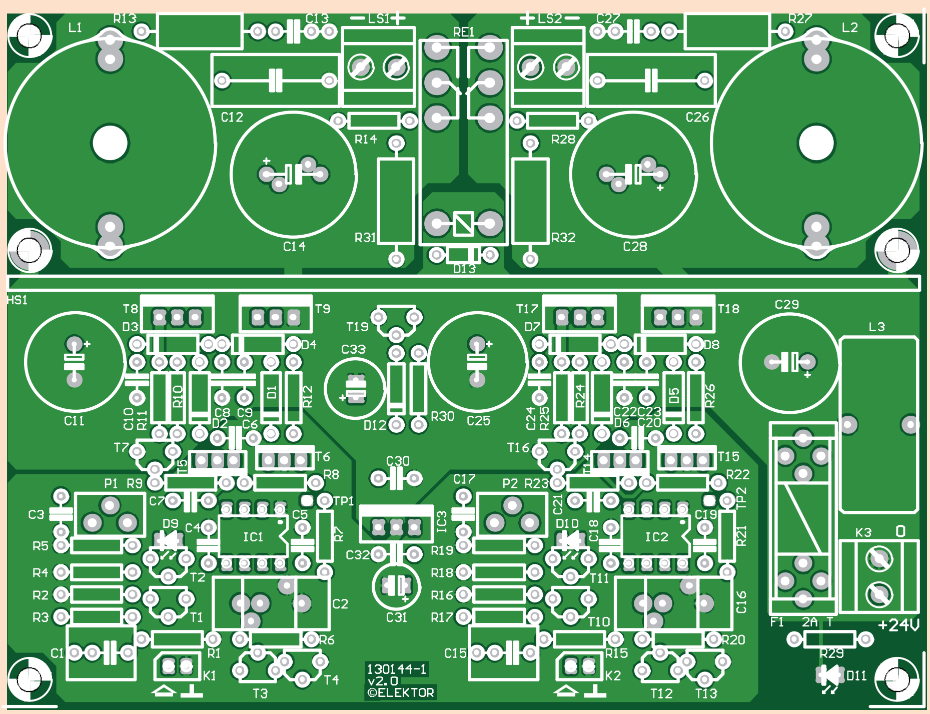


Figure 2. The PCB layout is uncrowded, with room for an aluminum plate heat sink for the MOSFETs—although the dissipation is low with the class-D architecture.

a constant voltage. This leads to nonlinearity because the charge and discharge curves are always exponential. That's not an especially good basis for building an amplifier.

To eliminate this problem, here we charge the capacitor with a constant current instead of a constant voltage. This is handled by a current source built around T2 and a voltage to current converter built around T3 and T4. This results in a fairly linear triangular voltage waveform on C3, and the ratio between the PWM output signal of the 555 and the input signal is close to linear. The input signal on connector K1 affects the charge/discharge time of the capacitor via T1, and in this way modulates the output signal. The switching frequency is approximately 250 kHz.

A buffer stage consisting of a BD139 and a BD140 complementary pair (T5 and T6) at the output of IC1 prevents excessive loading by the downstream circuitry.

The resulting PWM signal drives a push-pull output stage with two MOSFETs (T8 and T9), which are able to deliver enough current to drive a 4-Ω or 8-Ω loudspeaker. It is essential to ensure that T8 and T9 never conduct at the same time, since that would short out the supply voltage. However, the dead time (the time when neither of the MOSFETs is conducting) must be kept as short as possible in order to minimize harmonic distortion.

This creates a dilemma. With the 15 V supply voltage for the 555, it is not possible to deliver very much power to a 4-Ω loudspeaker. We solve this problem by connecting the MOSFETs to a higher supply voltage—in this case 24 V.

Since the high-side MOSFET (T8) always sees the low-side MOSFET (T9) as a load, the voltage U_{GS} from the driver stage will never be high enough to drive T8 fully on. As a result, the output voltage will never rise above 15 V and the rest of the power will be dissipated by the MOSFETs as heat. This is not how class-D is supposed to work. The circuitry around T7, which bootstraps the gate of T8, remedies this situation. When the output of the T5/T6 buffer stage is high (15 V), T7 is driven into conduction and cuts off T8. Capacitor C9 is then charged through D2 and T9 (which is conducting because its gate is connected directly to the buffer stage) to a level close to 24 V. When the output of the T5/T6 buffer stage goes low (0 V), T7 and T9 are cut off. This puts the 24 V supply voltage in series with the voltage on C9, resulting in a level of approximately 45 V relative to ground. This voltage is sufficient to drive T8 fully on, so the circuit works the way it should. At the output there is a PWM signal with an amplitude of 24 V, while T8 and T9 remain nice and cool.

The network D1/R12 is included to control the dead time. It causes the turn-on and turn-off times of T9 to be different because the gate capacitance is charged through R11 but discharged through D1, which is much faster.

An LC filter is placed at the output to suppress the 250 kHz square-wave signal. The output from the filter is a clean audio signal that can be feed to the loudspeaker through a cable. The filter is dimensioned to have its 3-dB corner frequency at approximately 37 kHz. The network R13/C13 prevents undesirable oscillation when no loudspeaker is connected.

The power supply section is very simple. A 7815 provides a regulated 15 V supply voltage for the 555 stage. Due to the simple design, the amplifier does not have any real protection circuit, but the circuitry around T19 provides a switch-on delay to prevent audible switch-on pops.

A good choice for powering the amplifier is a low-cost switch-mode power supply with a regulated 24 V output voltage. Such power supplies are available from electronics distributors at reasonable prices. RFI choke L3 is included in the power supply section to block any noise from the switch-mode power supply, so that it does not reach the amplifier stages.

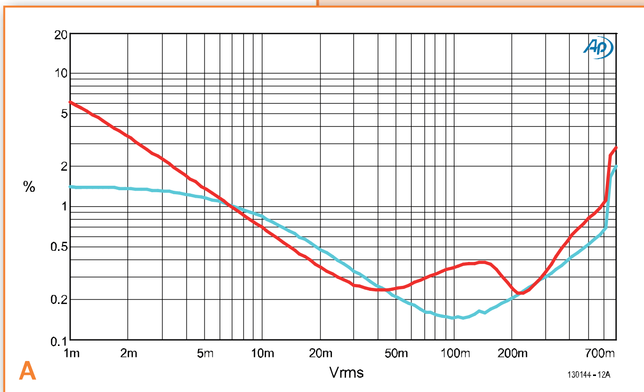
Construction

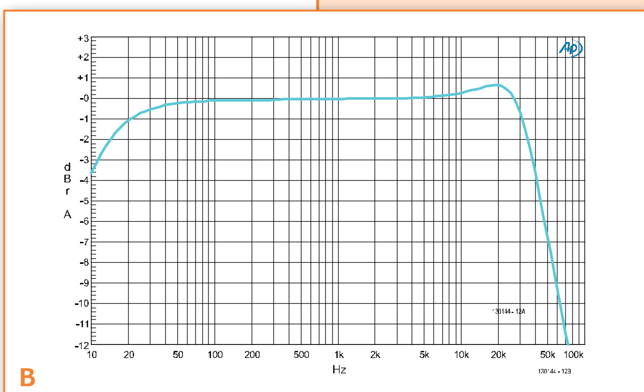
Figure 2 shows the circuit board layout designed for this amplifier. As already mentioned, this is a stereo version that only requires the connection of an external power source.

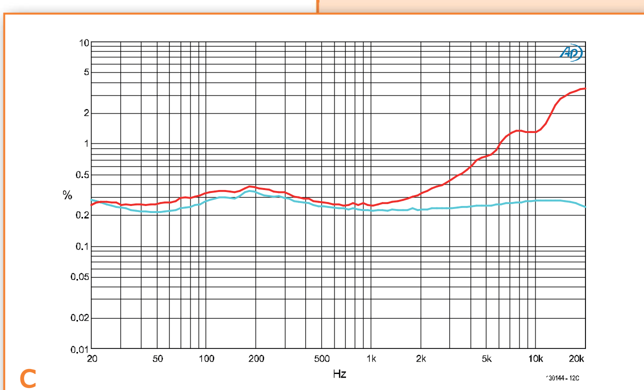
All components are leaded (through-hole) types to make assembly easy. There is room in the middle to fit a small aluminum plate that provides extra cooling for the output transistors. This is not absolutely necessary, since the transistors remain fairly cool.

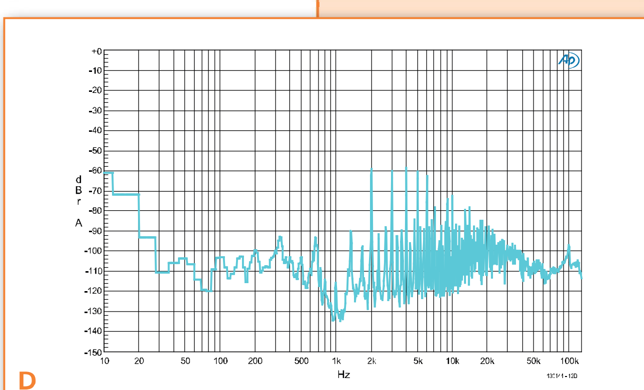
A few details deserve mention. You should use the best possible components for the frequen-

A Few Measurements









Due to the simple design and the absence of overall negative feedback, you shouldn't count on especially low distortion figures—but all things considered, the results are much better than expected. During the measurement session, it was interesting to see that the distortion components from the different stages of the amplifier partially cancel each other at some output amplitude levels.

Plot A shows this effect (THD versus input level, 1 kHz, *THD+N* with *B* = 22 kHz). The *blue* curve shows the distortion at the output of the 555 (pin 3) after filtering out the oscillator frequency. The *red* curve shows the distortion at the output of the amplifier. At input levels between 7 mV and 40 mV, the distortion at the amplifier output is lower than the distortion at the 555 output. This may be due to the dead time in the output stage (similar to the distortion of a standard class-B output stage), or it may be due to the output filter.

Plot B shows the frequency characteristic of the amplifier at 1 W into 8 Ω. The lower corner frequency is 11 Hz, and at the other end the –3 dB point is at 38 kHz. There is a small bump (0.66 dB) in the vicinity of 19 kHz. The slight overshoot can be reduced by decreasing the value of filter capacitors C12 and C26 to 390 nF, but this also reduces the attenuation of the modulation frequency by some 4 dB.

Plot C shows the total harmonic distortion plus noise versus frequency with an 8-Ω load. The red curve shows the distortion ahead of the output filter of the amplifier, while the blue curve shows the distortion at the output (after the filter). It is evident that the filter does its job properly and effectively suppresses the intermodulation products in the higher frequency region. Both measurements were made using the class-D measurement filter described in Elektor in 2011 [3], with the bandwidth of the analyzer limited to 80 kHz.

Plot D shows the Fourier spectrum of a 1 kHz signal (1 W / 8 Ω). The five harmonics responsible for the majority of the distortion (*THD+N* = 0.23%) are at a level of –60 dB. Intermodulation products are also visible with a spacing of 326 Hz. They result from the difference between the clock frequencies of the two modulators. However, these products are under –85 dB. They disappear if one of the channels is switched off. To avoid these intermodulation products, the clock frequencies would have to be at least 40 kHz apart.

cy-determining capacitors C2 and C16. Polypropylene and silver-mica are both good choices. To keep the temperature coefficients of the current sources T2 and T11 as low as possible, the (rectangular) LEDs D9 and D10 should be fitted in close contact with the corresponding transistors (T2 and T11). They are therefore located close together on the PCB. Murata pot cores and polypropylene capacitors are recommended for the output filters (L1/C12 and L2/C26).

In the prototype we used ceramic insulators for the MOSFETs, but you can also use insulators made from other materials (mica, Kapton, etc.) because the power dissipation is low. First mount the MOSFETs firmly in the right positions on the aluminum plate, and then bend the leads so they fit precisely in the corresponding holes in the PCB without exerting any lateral force on the MOSFETs. The aluminum plate can be mounted on the PCB using two small brackets. This also ensures that the plate is connected to circuit ground. Mount the heat sink on the board before soldering the leads of the MOSFETs to the board. Fit a small heat sink on the 15 V voltage regulator (IC3). A Fischer type SK 12 SA 32 (30 K/W) is suitable, but you can also use a small piece of aluminum. Make sure that the heat sink is not jammed against C33.

Adjustment

Short the input to ground and then adjust multiturn potentiometer P1 to obtain the best possible symmetry of the output signal. The voltage measured at the output (behind L1) should then be exactly half the supply voltage, i.e. 12 V.

That's it—now the amplifier is ready to use. Connect it to a pair of loudspeakers and an audio signal source, sit back and enjoy the pleasant sound of this amplifier, which in many ways resembles the sound of a tube amplifier.

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Internet Links

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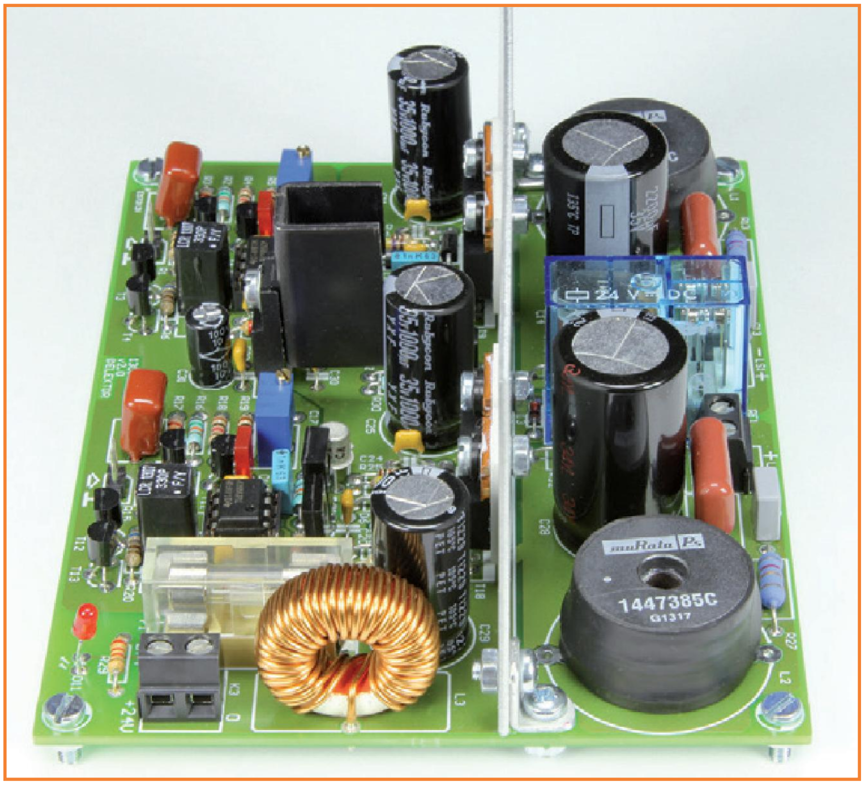

Figure 3. This side view clearly shows the position of the aluminum plate.

Figure 4. In the prototype the MOSFETs were mounted on the aluminum plate heat sink using screws with 3-mm insulating washers and ceramic insulators.