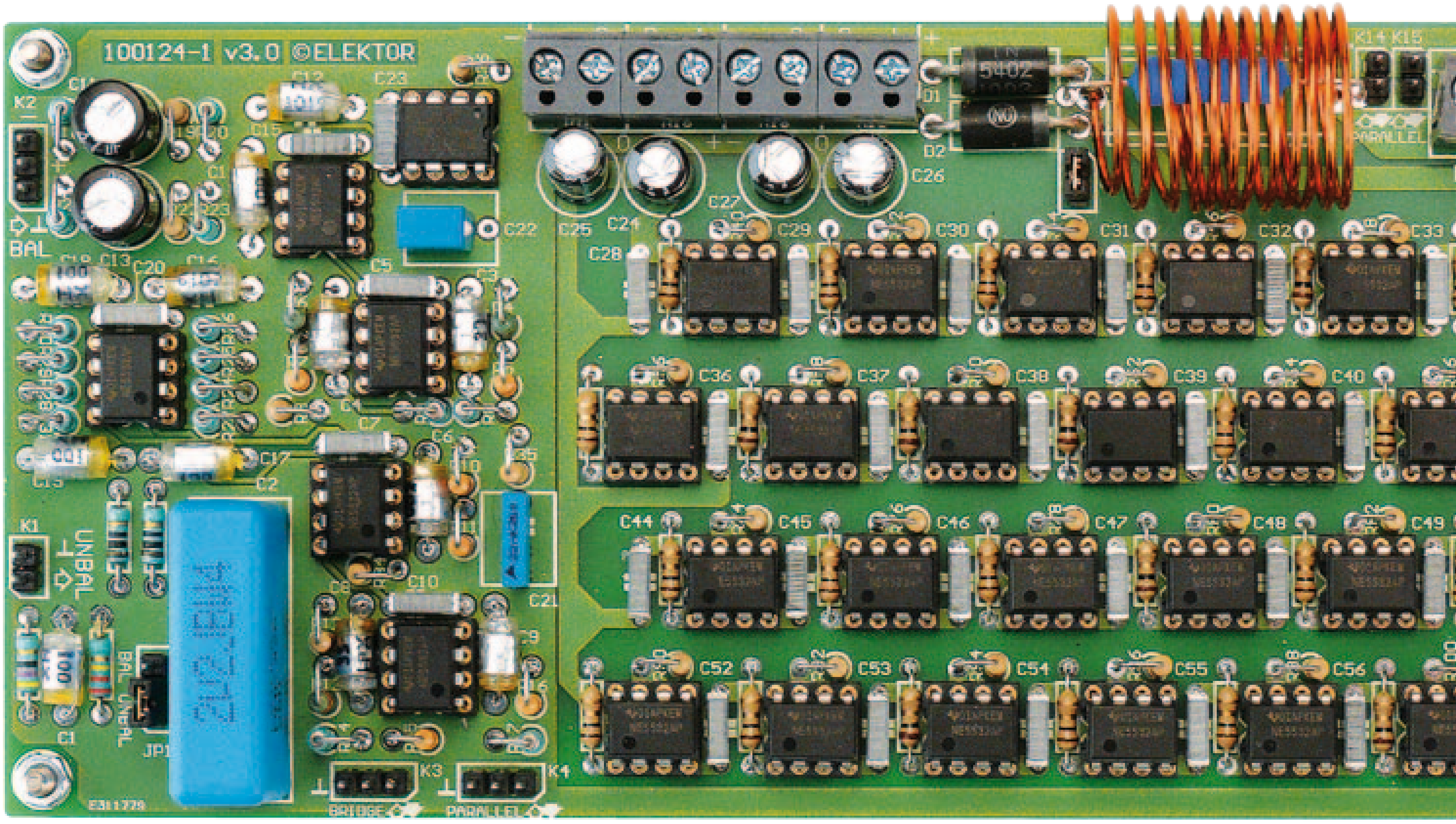
The 5532 OpAmplifier

Part 1: design philosophy and schematics



By Douglas Self (UK)

The most popular dual opamp in the world of audio is the (NE)5532. An interesting power amplifier can be made by connecting enough 5532s in parallel, how about 32 for a start? This may sound like a radical course of action, but it actually works very well, making it possible to build a very simple amplifier that retains not only the excellent linearity but also the power-supply rejection and the inbuilt overload protection of the 5532, which reduces the external circuitry required to a minimum.

While not exactly a brand-new design, the type (NE)5532 dual operational amplifier (opamp) is a very capable device giving low distortion with good load-driving capabilities, and a remarkably good noise performance. It is only quite recently that better opamps for audio work have become available. While these can give truly outstanding results, the cheapest of them costs ten times more than the 5532, which is available at a remarkably low price — in fact it is one of the cheapest opamps, because it is so widely used in audio applications.

It should be mentioned at once that the obvious limitation with using opamps to drive loudspeakers is that the output voltage swing is limited compared with a conventional power amplifier, and using a single-ended array of 5532s will give about 15 W_{rms} into 8 Ω. This output can be greatly extended by using two such amplifiers in bridge mode; one amplifier is driven with an inverted input signal so the voltage difference between the two amplifier outputs will be doubled, and the power output is quadrupled to about 60 W_{rms} into 8 Ω. This should be enough for most domestic hifi situations.

The other unalterable limit set by the opamps is the maximum output current, set by the internal overload protection. A single 5532 section (one half of the dual package)

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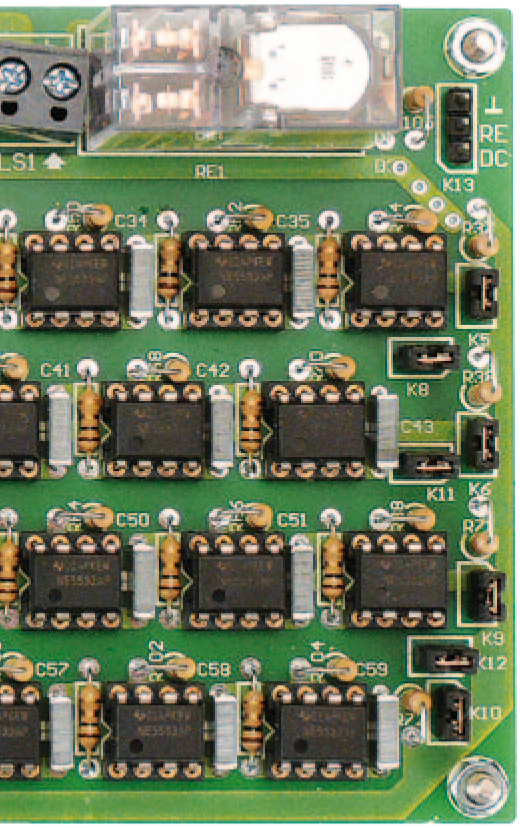

Specification — per channel, 8 ohm load

Supply voltage	±18.3 V	
Input sensitivity	- unbalanced	840 mV (16 W, 1 % THD)
	- balanced	833 mV (16 W, 1 % THD)
Input impedance	- unbalanced	38.8 kΩ
	- balanced	93.6 kΩ
Output power, sinewave	- 0.1 % THD	16 W
	- 1 % THD	16.8 W
Output power bandwidth		1.5 Hz – 275 kHz
Slew rate		5 V/µs
Rise time		4 µs
Signal/noise ratio	(1 W ref.)	110 dBA
	- 108 dB (B = 22 Hz – 22 kHz linear/unweighted)	
Harmonic distortion + noise	- 0.0005% (B = 22 kHz, 1 kHz, 1 W)	
	- 0.0009% (B = 80 kHz, 1 kHz, 1 W)	
	- 0.0004% (B = 22 kHz, 1 kHz, 8 W)	
	- 0.0005% (B = 80 kHz, 1 kHz, 8 W)	
	- 0.003 % (B = 80 kHz, 20 kHz, 8 W)	
Intermodulation distortion	- 0.0012% (1 W)	
	- (50 Hz : 7 kHz = 4 : 1) 0.0015% (8 W)	
Dynamic IM distortion	- 0.0011% (1 W)	
	- (3.15 kHz square wave + 15 kHz sine wave)	0.0035% (8 W)
Damping factor	- 194 (1 kHz)	
	- 111 (20 kHz)	
DC-protection	±1.5 V	
Quiescent current	300 mA	

will drive 500 Ω to the full voltage output, though it is advisable to keep the loading lighter than this to maintain low distortion at high levels. If 4 Ω operation is required, twice as many opamps must be used to supply the doubled current demand. This also applies to bridged operation into 8 Ω.
The system is designed so that either single-ended or bridged operation can be used; the basic design described here gives a working stereo amplifier with just three PCBs. The amplifier cards can be paralleled without problems, and facilities are provided to connect more PCBs in parallel for driving low-impedance speakers.
Overload protection is inherent in the opamps, but output relays are used for on/off muting and to protect loudspeakers against a DC fault.

A tour of the design

The schematic in **Figure 1** shows one channel of the complete amplifier, which consists of unbalanced and balanced line inputs, and the power amplifier itself, which is divided into a +22.7 dB gain stage and an array of paralleled output opamps configured as voltage-followers, giving the maximum amount of negative feedback around them to minimise distortion. Let's have a look at the various sections of the circuit.

The unbalanced input

This consists simply of RF filter R1, C1 and DC-drain R2, which are directly connected to the gain stage when JP1 is in the 'unbalanced' position.

The balanced input

This amplifier is an innovative design that gives very low noise. The conventional balanced input stage built with four 10 kΩ resistors and a 5532 opamp has a far worse noise performance than a simple unbalanced input, and is also much noisier than most power amplifiers; output noise is approximately –104 dBu. This balanced amplifier here solves this problem partly by the use of a dual balanced stage (IC5A, IC5B) amplifier that partially cancels the uncorrelated noise from each amplifier, giving a 3 dB noise reduction, and in a similar way improves the CMRR; it also uses much lower resistor values than usual (820 Ω instead of 10 kΩ) which produces less Johnson noise in the first place. This is only possible because it is driven by unity-gain buffers IC4A, IC4B, which also allow the input impedances to be much higher than usual, preventing loading of external equipment and further improving the CMRR. The noise output is less than –112 dBu, an 8 dB improvement over conventional technology.

The gain stage

The main input amplifier is another innovative design that achieves very low distortion by spreading the gain required over three stages. +22.7 dB could easily be obtained with one opamp but 5532s are not

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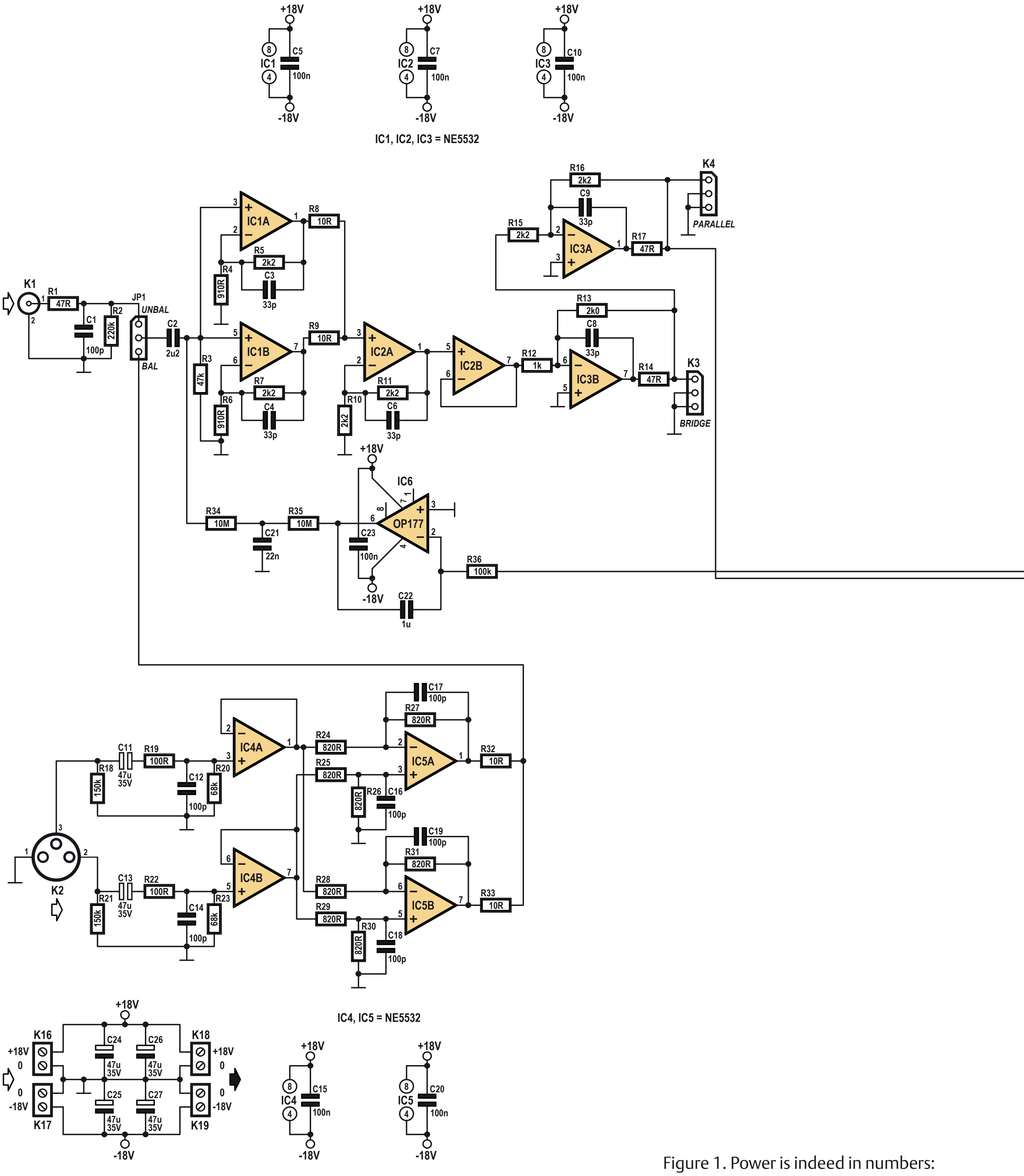

Figure 1. Power is indeed in numbers: circuit diagram of the basic NE5532 audio amplifier (one channel shown).

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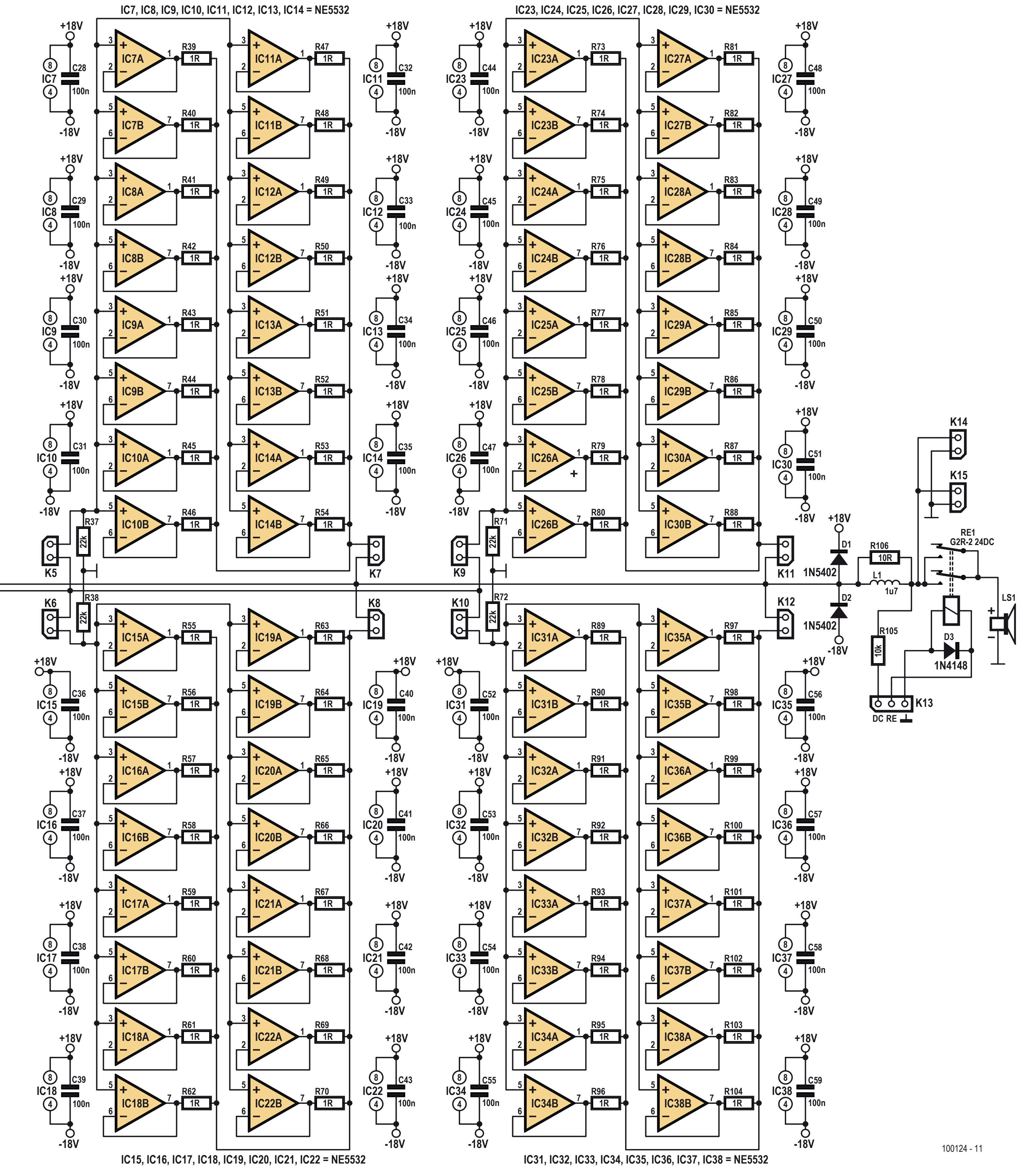

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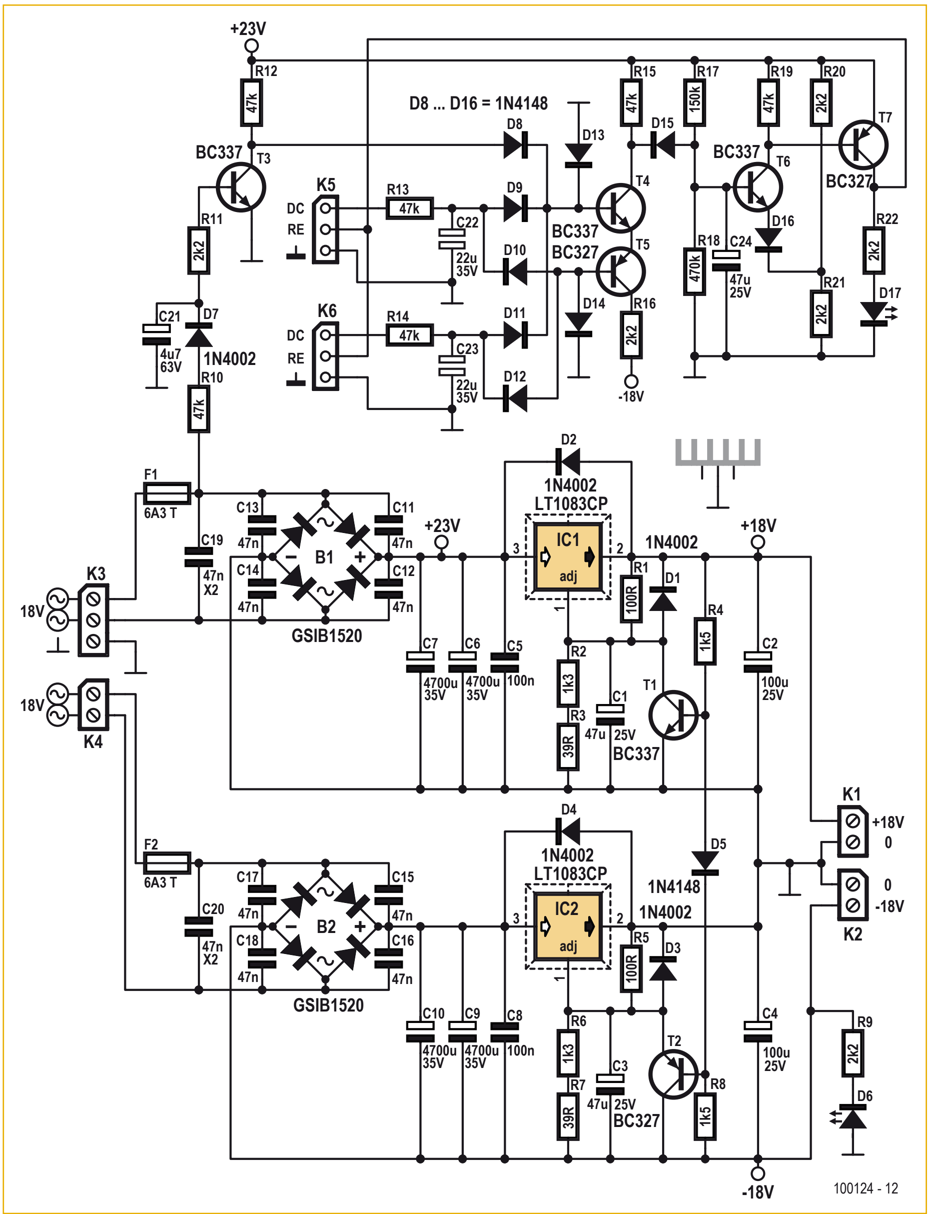

Figure 2. The symmetrical power supply is dimensioned for the 2x15-watt, 8 ohm basic version of the amplifier.

completely distortion-free, and the THD would be significant.

The first stage (IC1A, IC1B) gives +10.7 dB of gain; the two outputs are combined by R8, R9 to give a 3 dB noise advantage, as in the balanced amplifier. The second stage IC2A gives +6 dB of gain. The gain is less to maximise negative feedback because the signal level is now higher. IC2B is a unity-gain buffer which prevents the 1 kΩ input impedance of final gain stage IC3B from loading the output of IC2A and causing distortion. IC2B is less vulnerable to loading because it has maximal negative-feedback. IC3B gives the final +6 dB of gain; it is used in shunt-feedback mode to avoid the common-mode distortion which would otherwise result from the high signal levels here. It has a 'zero-impedance' output, with HF feedback via C8 but LF feedback via R13, so crosstalk is kept to a minimum while maintaining stability with load capacitance. The output at K3 is phase-inverted and can be used for bridging.

IC3A is a unity-gain inverting stage which corrects the signal phase. The output is also of the 'zero-impedance' type.

The power amplifier

The power amplifier consists of thirty-two 5532 dual opamps (i.e. 64 opamp sections) working as voltage-followers, with their outputs joined by 1 Ω current-sharing resistors. These combining resistors are outside the 5532 negative-feedback loops, and you might wonder what effect they will have on the output impedance of the amplifier. A low output impedance is always a good thing, but not because of the so-called 'damping factor' which is largely meaningless as the speaker coil resistance always dominates the circuit resistance. 'Damping factor' is defined as load impedance divided by output impedance; we have 64 times 1 Ω resistors in parallel, giving an overall output impedance of 0.0156 Ω. This gives a theoretical damping factor of 8 / 0.0156 = 512, very good by any standards. The wiring to the loudspeaker sockets will have more resistance than this!

The output opamps may be directly soldered into the board to save cost and give better conduction of heat from the opamp package to the copper tracks. However, on the prototype built in the Elektor labs, high quality sockets were used. Having a lot of opamps in parallel could make fault-finding difficult — if there is one bad opamp out of 32 then you are likely to have to do a lot of unsoldering (or IC unplugging) to find it. The opamp array is therefore split up into four sections of eight opamps, which are joined together by jumpers K5–K12, so on average you would only need to unsolder (or pull out) four opamps to find a defective one. In my many years of experience with it the 5532 has proven a very reliable opamp, and I think such failures will be very rare indeed. There is an output choke L1 for stability into capacitive loads, and catching diodes D1–D2 to prevent damage from voltage transients when current-limiting into reactive loads.

The output relay and its control

The output mute relay RE1 protects the loudspeakers against a DC offset fault and gives a slow-on, fast-off action so no transients are passed to the loudspeakers at power-up or power-down. The relay is controlled from the power supply board. With reference to **Figure 2**, at power-up R17 charges C24 slowly to give a turn-on delay. In operation C21 is charged and

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T3 is on; when the AC power is removed C21 discharges rapidly, T3 turns off, and D8 turns on T4–T5, which discharge C24 and cause the output relay contacts to be opened immediately. Even a brief AC power interruption gives the full turn-on delay. Normally T4 and T5 are off and D15 non-conducting, but if a DC offset fault applies either a positive or negative voltage via R13 or R14, T4–T5 turn on and the relays are opened at once to protect the loudspeakers.

Power supply

Again referring to the circuit diagram of the power supply unit in Figure 2, the ±18 V symmetrical supply is regulated by two type LT1083 TO3-P positive regulators. When a 5532 sees one supply rail disappear, this opamp can get into an abnormal state in which it draws excessive current. This could obviously be catastrophic with this design, so the PSU incorporates a mutual-shutdown facility which shuts off each supply rail if the other has collapsed due to short-circuiting or any other cause. If the positive rail collapses, T2 turns on and disables the negative supply. If the negative rail collapses, T1 turns on and disables the positive supply.

Cost

This project uses quite a lot of 5532s; 37 in each channel, but that does not mean the cost is excessive. In Great Britain, 5532s can be had from Rapid [1] for 24 p each at 100-off (Rapid are prepared to deal with anyone who has a credit card) This means that the cost of all the opamps would be about £18.00.

To be continued

Next month's closing instalment will cover approaches to constructing the amplifier on circuit boards, some performance figures obtained from our high-end test equipment, and an outline of challenges to those of you wishing to modify the amplifier for higher output powers and/or lower output impedance. Meanwhile this month's *E-Labs Inside* section has a page or so on issues with electrolytic capacitors encountered while the first prototype of the amplifier was tested.

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1. www.rapidonline.com

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