# 18

The VDV100 Power Amplifier

This amplifier, originally designed in 1987, utilizes a quartet of EL34s. A wide frequency response and a high damping factor are achieved by means of unusual coupling with the output transformer, combined with local feedback. Both the phase splitter and the driver stage are more complex than in previous circuits. I present the original version of the amplifier first, followed by some modifications made in later years.

18.1 | The basic circuit

Figures 18.1 and 18.2 (overleaf) shows the circuit diagram of this design. The actual amplifier is on the left, with the power supply to the right. The four EL34 power valves are arranged as two pairs – B_3 with B_4 and B_5 with B_6 – while a single ECC81 is used at the input in a fairly standard preamplifier and phase-splitter configuration. As the latter circuit is used frequently in this book, I will not discuss it in any more detail.

The interesting part comes right after the ECC81: the two halves of valve B_2, an ECC82. At first glance these look like ordinary triode amplification stages – one for each phase – but the circuits around the cathodes are unusually complicated. The two networks $R_{25}-R_{27} \parallel C_7-C_9$ and $R_{28}-R_{30} \parallel C_{10}-C_{12}$ couple the signals at the primary of the output transformer to the cathodes of the driver stage, providing local feedback. This is the central point around which the entire design gravitates, as I show below.

The power supply is fairly standard and does not contain any exotic parts. Each power valve is biased individually. The negative grid voltages are adjusted by trimpots P_1, P_2, P_3 and P_4. Originally, I did not fit the amplifier with a standby switch, but just switched the mains voltage to the primary. In retrospect, this is not such a good idea. I therefore advise you to fit a sturdy switch to open the upper lead of the high-voltage secondary winding; this will substantially lengthen the life of both the valves and the electrolytic capacitors.
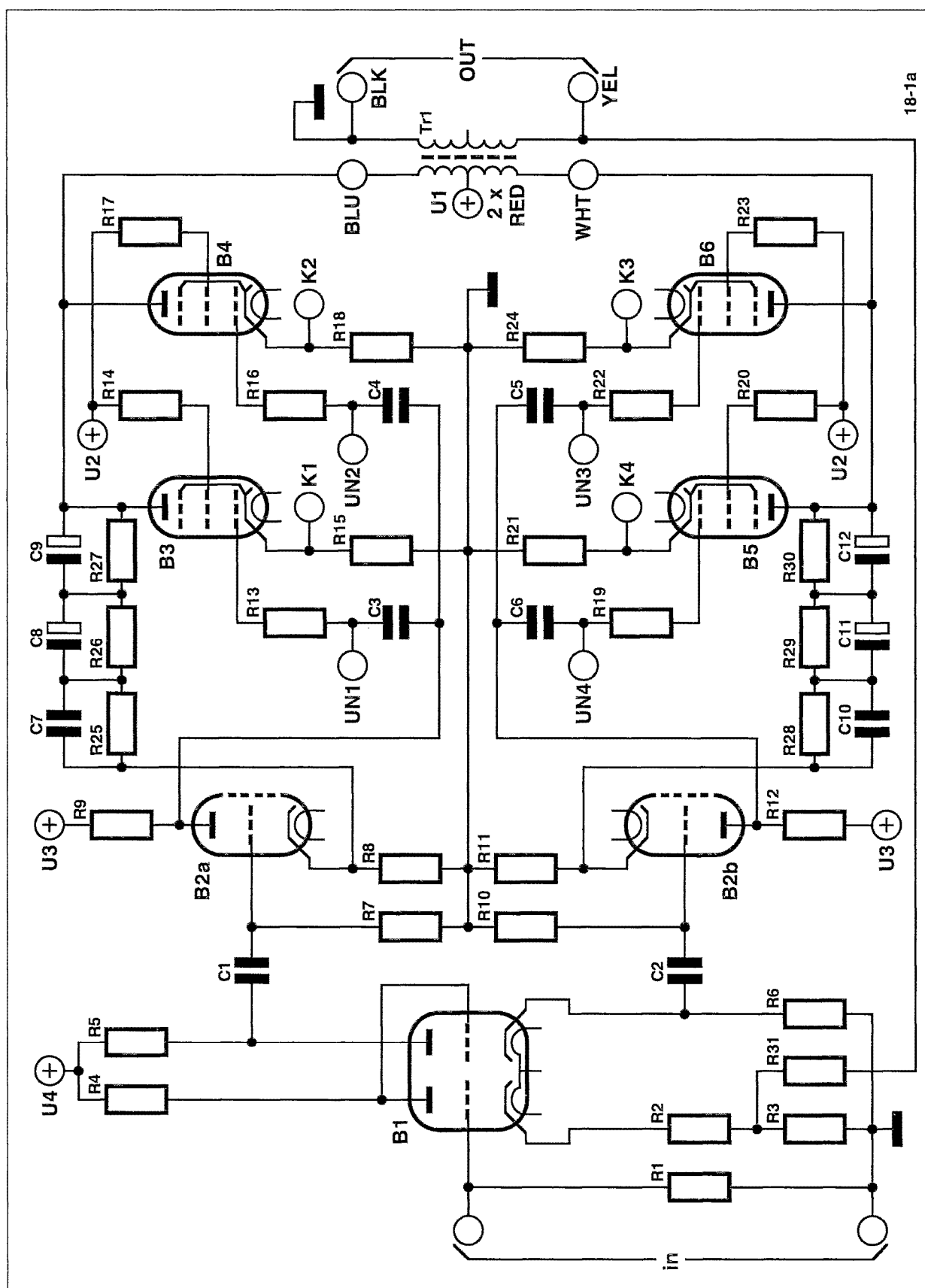
Figure 18.1 Circuit diagram of the VDV100 power amplifier. Component values are listed in Table 18.1.
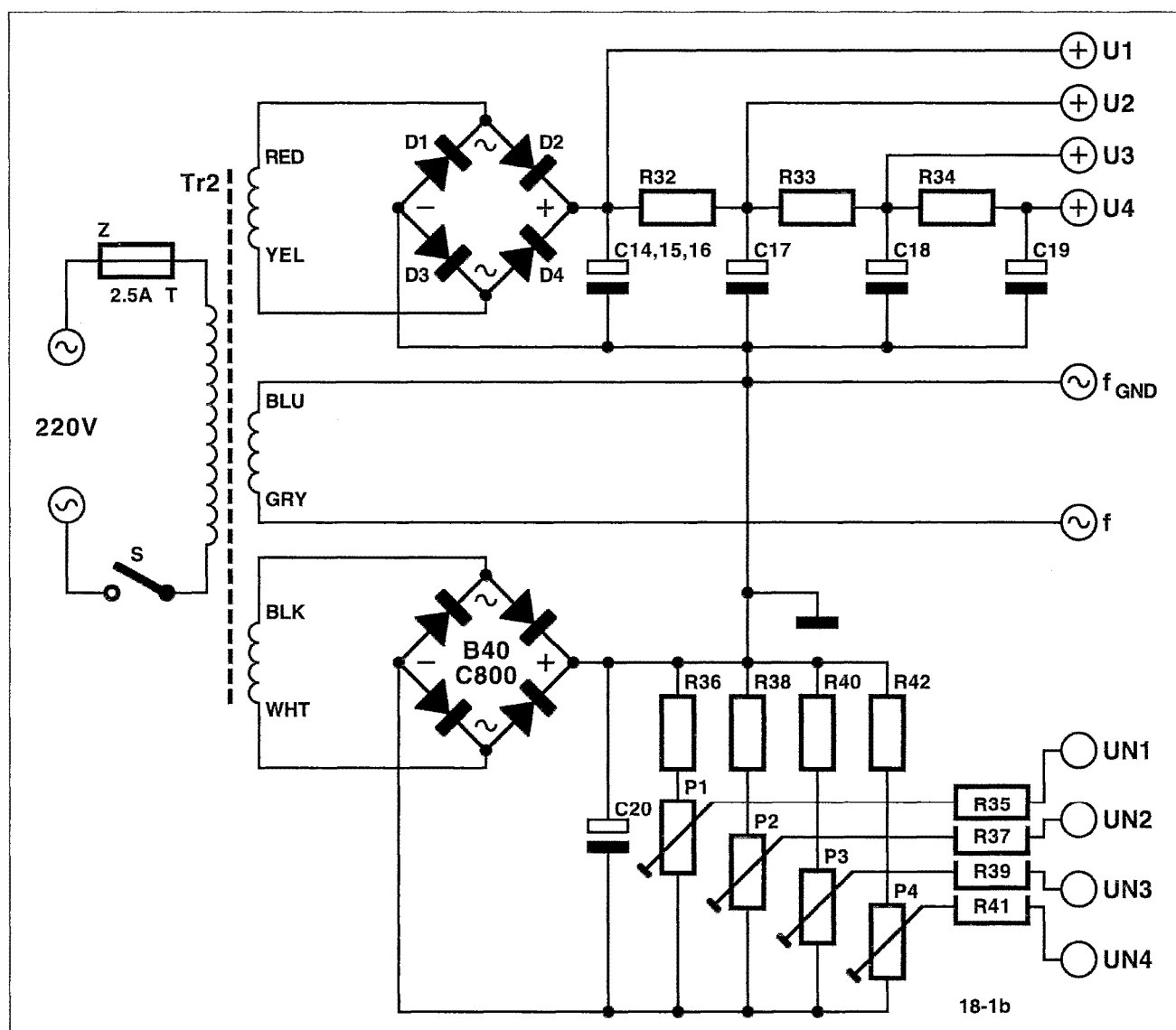
▲ *Figure 18.2* *The power supply circuit for the VDV100 amplifier.*

18.2 | Why use local feedback?

I encountered a peculiar phenomenon while developing this amplifier. Originally, I did not utilize local feedback, and the amplifier sounded fine when driving dynamic loudspeakers. However, pronounced colouration occurred when Quad ESL63 speakers were connected, and measurements soon revealed why. These loudspeakers require high damping, but the amplifier's damping factor turned out to be around 2. This explained everything.

To increase the damping, the effective internal resistance of the valves must be lowered. This has the additional benefit of broadening the frequency response. There are several ways to reduce the effective internal resistance, including changing the

configuration of the power valves to triode or ultra-linear and increasing the amount of overall negative feedback. In this case I chose a third possibility, which is changing the coupling between the output transformer and the valves. In order to understand how this works, you should have another look at the circuit diagram.

The power valves do not function independently, since each one is strongly coupled to its driver stage via feedback. The signal on the plate of each EL34 flows back to the cathode of the preceding ECC82 triode via a decoupling network. Any deviation in this signal causes an instantaneous correction by B_{2a} or B_{2b}.

A little thought experiment will clarify how this arrangement produces higher damping. Imagine that we have a signal source connected to the amplifier with no loudspeaker connected, so there that there is a certain output voltage at the loudspeaker terminals. As soon as a loudspeaker is actually connected, this voltage will decrease due to Z_{out}, the internal resistance of the amplifier (see Chapters 3 through 5 for an explanation). The voltage at the primary will decrease as well — remember that a transformer does what its name suggests! Now the extra network kicks into action; the reduced anode voltage will reach the cathodes of B_2, which immediately churns out more amplification to compensate for the decrease. As a result, the output voltage will be reduced less than it would be if this network was not present. This more resilient behaviour is equivalent to a lower value of Z_{out}, and therefore results in higher damping. Local feedback thus lowers the effective output resistance by means of tight coupling between B_2 and the power valves.

Now for a more detailed look at the local feedback networks. We only have to look at the upper network, since the lower network works in the same way. Resistors R_{26} and R_{27} have high values; they are 'bleeder' resistors whose sole function is to divide the AC voltage evenly between capacitors C_8 and C_9. These large-value capacitors effectively conduct AC signals to the important resistor R_{25}.

Resistors R_{25} and R_8 (and similarly R_{28} and R_{11}) determine the amount of local feedback. The lower the value of $R_{25}:R_8$, the stronger the local feedback and the lower the effective output resistance of the power valve. The damping factor can thus be varied widely – within reasonable limits – by adjusting the value of R_{25} and R_{28}. This means that the output valves, output transformer, frequency range and damping factor can all be tuned to each other by choosing a suitable value for R_{25} and R_{28}.

In this design, both local and overall (external) feedback are utilized. The former is much stronger than the latter, so the total amplification is largely defined by the local feedback. The role of R_{31} – which determines the amount of overall negative feedback – is minimal. This is a good thing, given the bad effects on auditory image and timbre that usually result from strong overall negative feedback. The value of R_{25} and R_{28} is based on both subjective criteria (how the amplifier sounds) and objective requirements (electrostatic speakers, such as the ESL63, require a large damping factor). Additional considerations are discussed below, where modifications to this circuit are described. In any case, this design provides a simple and elegant way to combine local and overall feedback.

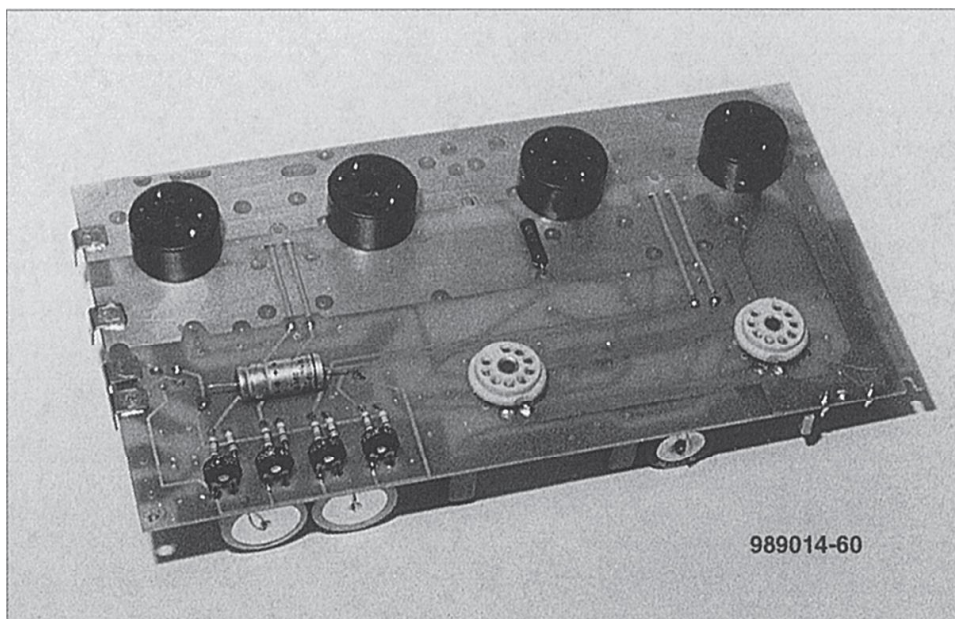| Resistors[1]		Capacitors		
R_1, R_7, R_{10}, R_{36}, R_{38}, R_{40}, R_{42}	100 kΩ	C_1, C_2	150 nF	400 V
R_2	820 Ω	C_3, C_4, C_5, C_6	330 nF	400 V
R_3	180 Ω	C_7, C_{10}	82 pF	1000 V !
R_4	220 kΩ	C_8, C_9, C_{11}, C_{12}	10 µF	450 V
R_5, R_6	15 kΩ, 1 W	C_{14}, C_{15}, C_{16}, C_{17}	50 µF	500 V
R_8, R_{11}	1 kΩ	C_{18}, C_{19}	47 µF	400 V
R_9, R_{12}	47 kΩ, 2 W	C_{20}	100 µF	63 V
R_{13}, R_{16}, R_{19}, R_{22}	10 kΩ			
R_{14}, R_{17}, R_{20}, R_{23}	150 Ω, 1 W	**Diodes**		
R_{15}, R_{18}, R_{21}, R_{24}	10 Ω, 1 W	D_1–D_4	1N4007	
R_{25}, R_{28}	27 kΩ, 2 W	D_5	B80C100 bridge	
R_{26}, R_{27}, R_{29}, R_{30}	2.2 MΩ	**Valves**		
R_{31}, R_{34}	10 kΩ, 1 W	B_1	ECC81	
R_{32}	100 Ω, 5 W	B_2	ECC82	
R_{33}	4.7 kΩ, 2 W	B_3–B_6	EL34	
R_{35}, R_{37}, R_{39}, R_{41}	220 kΩ	**Transformers**		
P_1–P_4	100 kΩ trimpot 10 mm horizontal Piher	Tr_1	XC462 output transformer (original)	
		Tr_2	7B649 mains transformer	

1) All resistors are 0.25 W, except as otherwise noted.

▲ *Table 18.1 Component values for the VDV100 amplifier.*

18.3 | Construction and specifications

A printed circuit board, available from the sources listed in the Appendix, has been developed for the amplifier. This double-sided board has plated-through holes and measures 22.9 by 12.7 cm. Most components are fitted on the lower side of the PCB to keep them cool, while the valves are fitted on the upper side. The entire circuit – amplifier and power supply – fits on the board, except for the two transformers. These are connected along the narrow sides of the board, thus minimizing external wiring. The component layout is shown in Figures 18.3 and 18.4, while Figures 18.5 and 18.6 show how the amplifier can be housed.

You should give some thought to safety before you switch on this power amplifier for the first time, since the valve supply voltages are quite high. By all means review the various parts of this book that deal with safety, in particular Section 12.1. One point that can easily be overlooked is that you should take care to mount the printed

◀ **Figure 18.3**
The 'valve side'
of the circuit
*board. Note*
that the bias
adjust trimpots
are readily
accessible.

989014-60
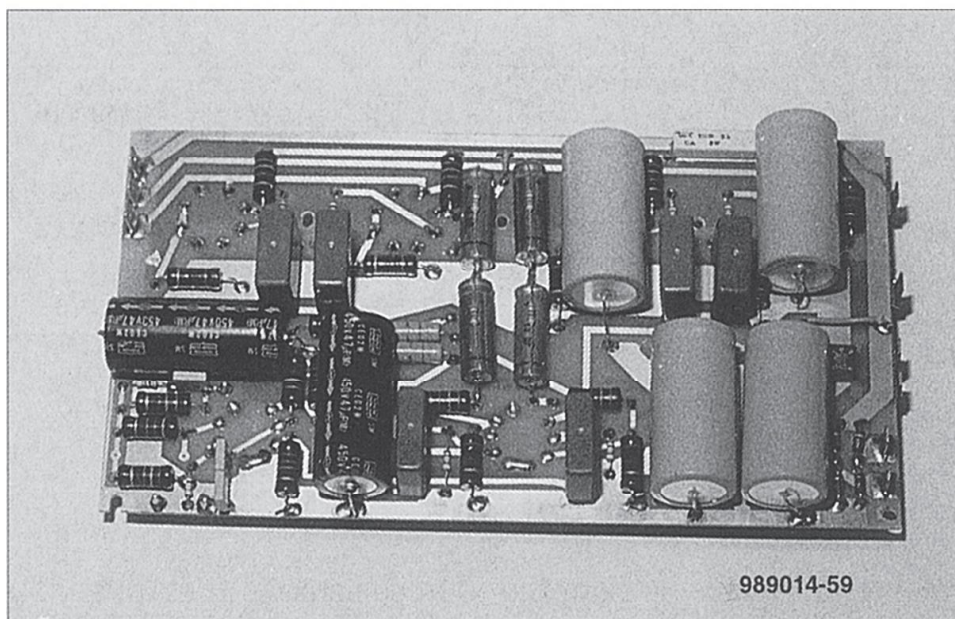
◀ **Figure 18.4**
The component
side of the circuit
board. Capacitors
C_8, C_9, C_{11} & C_{12}
are in the centre,
with the parallel
*resistors soldered*
directly on top.

989014-59

circuit board some distance away from the metal of the case, to prevent discharges. The minimum allowable separation is 1 cm.

The quiescent currents of the four power valves must be set to 45 mA each, using trimpots P_1, P_2, P_3 and P_4. This corresponds to a voltage drop of 450 mV across R_{15}, R_{18}, R_{21} and R_{24}, respectively. The adjustment procedure is described in Chapters 11 and 13. Be sure to verify that the negative grid voltage is present at each output valve before you flip on the standby switch!

Now on to the specifications, which are listed in Table 17.2. This amplifier is rated at 100 watts, but test versions delivered quite a bit more: 121 watts of continuous RMS power, and an impressive 156 watts of short-term transient output power, show
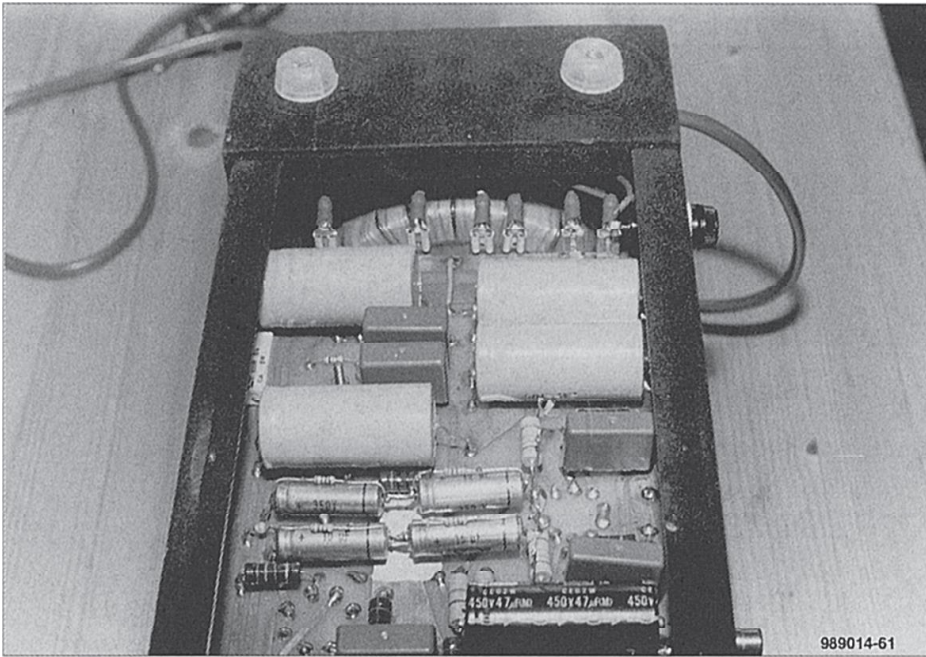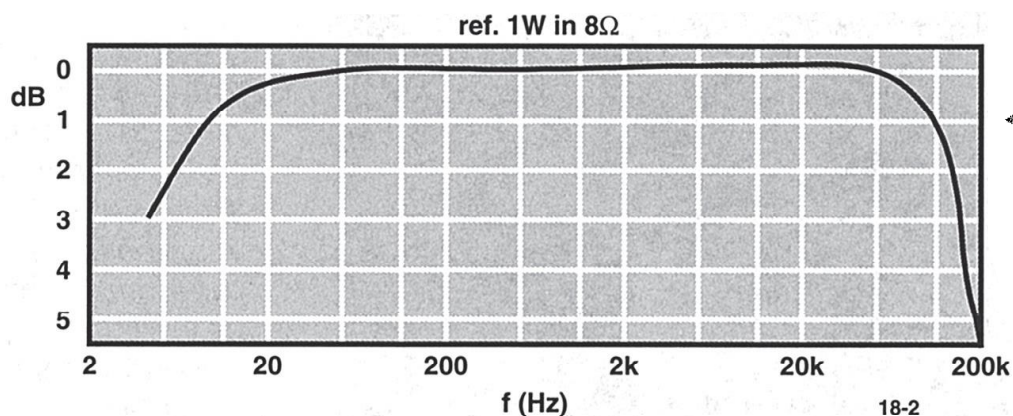
Figure 18.5
The transformers can be located at either end of the circuit board. The power supply end is shown here. This arrangement makes for an oblong chassis; each transformer has its own compartment.
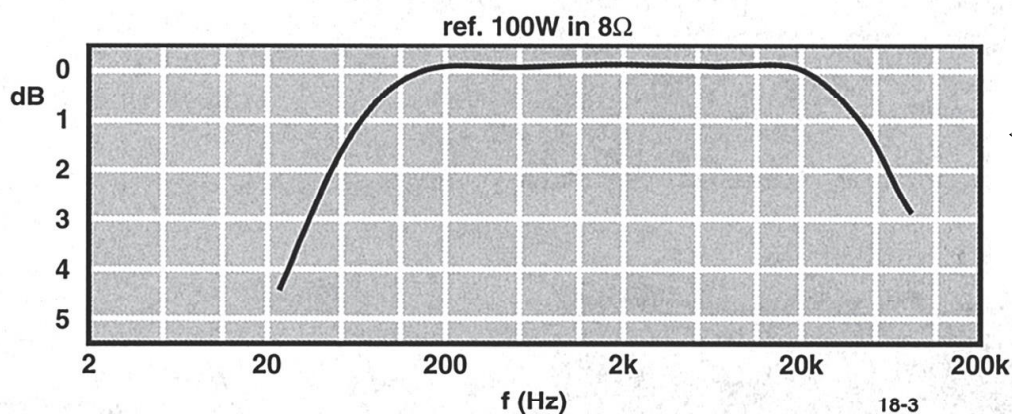
989014-61
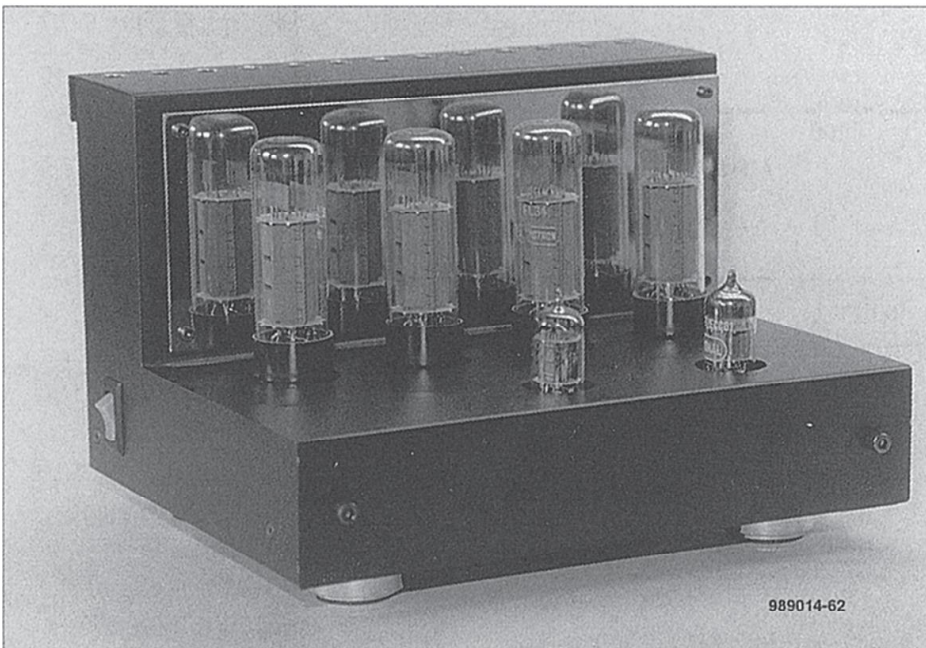
Figure 18.6
The transformers can be located in a separate compartment behind the circuit board. This makes a distinguished-looking amplifier. (Design by J. de Zwart.)
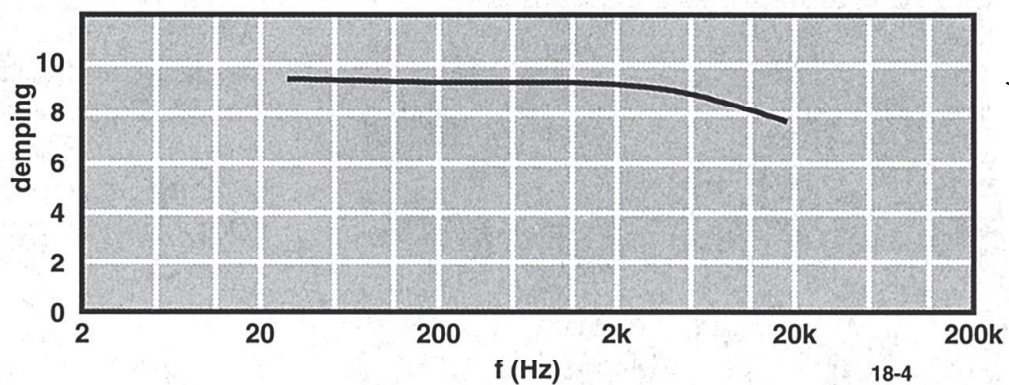
989014-62

that this amplifier is a true powerhouse! The combination of the toroidal output transformer and local feedback yields a frequency response range of 5 Hz to 125 kHz (and that is only the beginning — read on to see what happens when a modern output transformer is used). The power bandwidth is 30 Hz to 80 kHz. At the low end the core saturates, while the high end is limited by the valves themselves. Churning out 50 watts at 80 kHz makes them literally turn red in the face: the plates and screen grids will show a dull red glow when driven to this level. The specifications thus state '5 s maximum at 80 kHz'– you have been warned! The remaining specifications and characteristic curves are self-explanatory (see Figures 18.7 through 18.10).
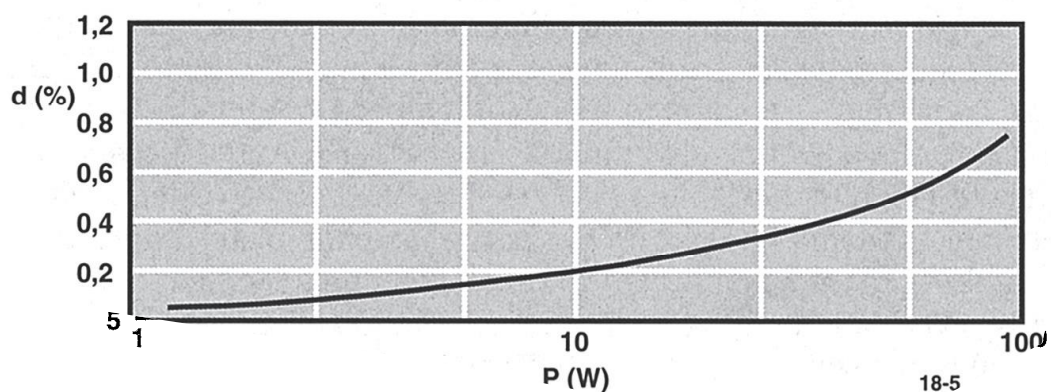
ref. 1W in 8Ω

dB

2   20   200   2k   20k   200k

f (Hz)

18-2

◀ *Figure 18.7*
Frequency
response of
the VDV100.

ref. 100W in 8Ω

dB

2   20   200   2k   20k   200k

f (Hz)

18-3

◀ *Figure 18.8*
The power
bandwidth of
the VDV100.

demping

2   20   200   2k   20k   200k

f (Hz)

18-4

◀ *Figure 18.9*
The VDV100
damping
factor versus
frequency.

d (%)

1   10   100

P (W)

18-5

◀ *Figure 18.10*
Total
harmonic
distortion
versus
output power.

VDV100 Specifications (standard configuration)	
Description:	100 W Monobloc valve amplifier
Valves:	1 x ECC81
	1 x ECC82
	4 x EL34
Frequency range:	5 Hz to 125 kHz (−3 dB, ref. 1W, 8 Ω load)
Continuous output power:	121 W (1 kHz, 8 Ω load)
Burst power:	156 W (1 ms on, 64 ms off, 8 Ω load)
Power bandwidth:	30 Hz to 80 kHz (−3 dB, ref. 100 W)
	5 s maximum at 80 kHz!
Total harmonic distortion:	0.78% (1kHz, 100 W, 8 Ω load)
Slew rate:	14.2 V/μs (50 W, 80 kHz sine wave)
Operating mode:	Class A up to 16 W, 8 Ω load
	Class AB, 16 W to 100 W, 8 Ω load
Damping factor:	8.7 (see Figure 18.10)
Input sensitivity:	0 dBm (0.775 Vrms) (ref. 100 W, 8 Ω load)
Input impedance:	100 kΩ, DC coupled
Loudspeaker impedance:	8 Ω
Hum and noise:	−87 dBa(rms) (ref. 100 W, 8 Ω load)
Stability:	will tolerate 80 V_{pp} at 1 kHz with no load

⚠ **Table 18.2** *Measured specifications of the VDV100 amplifier.*

18.4 | Modifications

■ | Modification 1: UL configuration with older-model transformers

The VDV100 can be built with the XC462 balanced output transformer, as shown in the schematic diagram, but the 5B535 (another first-generation toroidal Vanderveen design) can also be used. The primary of the 5B535 has ultralinear taps that can be connected to the screen grids. Various circuits in previous chapters use this configuration, so you can refer to them for information on wiring and so on. In this case the screen grids are not connected to U_2, but to the UL taps of the transformer, which results in twofold local feedback: first via B_2, and second inside the power valves themselves via the ultralinear coupling. Opinions are divided about the audible effects of this configuration, with comments ranging from 'less warmth in the

bass' to 'tighter; better definition'. This is understandable, if you consider the effect of this modification. The twofold feedback increases the damping, so the woofer excursions are better controlled. The 5B535 and the XC462 have the same high-frequency behaviour, so we must look for other means to improve the latter aspect.

■ Modification 2: Pentode configuration with a VDV2100PP

The older generation of transformers (i.e. XC462 and 5B535) can be replaced by their successor, the VDV2100PP. This is a compatible transformer with a better core and a significantly improved winding structure. As a result, the frequency response is much wider, compared to the XC462 and 5B535. The replacement is easy, since the colour codes of the transformers are identical except for the primary, where the blue and white wires of the XC462/5B535 correspond to the green and yellow wires of the VDV2100PP.

The new configuration is a pure pentode; all feedback networks must therefore be eliminated. This means removing R_{31} (the external feedback resistor) and the two local feedback networks $R_{25}-R_{27} \parallel C_7-C_9$ and $R_{28}-R_{30} \parallel C_{10}-C_{12}$.

The bandwidth of this amplifier extends to 65 kHz, which is not all that spectacular. This is due to the combination of the of limitations of the preamplifier and drivers and the abominably high internal resistance of the power stage, and is not the fault of new transformer. The effective impedance at the secondary measures 109 ohms! This corresponds to an impedance of 44 kΩ for the power valves. As there are four valves, arranged as two parallel pairs connected in series through the primary, the total resistance of the chain equals the resistance of a single valve. A value of 44 kΩ may appear abnormally high to those familiar with what is specified in the valve data books (17 kΩ). However, the specified value applies for V_{ak} = 250 V and I_a = 100 mA, while the EL34s are operated in this circuit at a higher voltage and lower current, with V_{ak} = 450 V and I_a = 45 mA. The characteristics of the EL34 are much more horizontal under these conditions, which is reflected in a higher internal resistance. Although the leakage inductance and internal capacitance of the output transformer are both small, they combine with the limitations of B_1 and B_2 to produce a network whose −3 dB bandwidth is around 70 kHz.

Given all of the above, it is easy to predict that this amplifier will sound both dark and intensely coloured. The loudspeakers are not damped at all, resulting in a strong dropoff at high frequencies. This is no good for hi-fi applications, and there is not much that can be done about it. However, the dark tone colour may be useful for guitar amplifiers.

■ | Modification 3: Ultralinear configuration with a VDV2100PP

Let us move on to the ultralinear configuration. Here the screen grid resistors R_{14} and R_{17} are connected to the brown leads of the VDV2100PP, while R_{20} and R_{23} are connected to the violet leads. The feedback networks are still out! The output impedance drops to 10.4 Ω, ten times lower than with the pentode configuration — a clear consequence of using internal feedback. The damping factor is still low, at $(8 \div 10.4) = 0.8$ for an 8 Ω loudspeaker, but this may be sufficient for some applications. The square-wave response looks perfect, with good flanks and clean transitions to flat plateaus. Nevertheless, the bass response will be too 'round' in most cases, so let's move on to the next modification.

■ | Modification 4: Pentode configuration with local feedback and a VDV2100PP

In this configuration the screen resistors $(R_{14}, R_{17}, R_{20}$ and $R_{23})$ are disconnected from the UL taps and reconnected to U_2, so that the pentode reigns again. Next, the two local feedback networks $R_{25}-R_{27} \parallel C_8-C_9$ and $R_{28}-R_{30} \parallel C_{11}-C_{12}$ are reconnected (excluding C_7 and C_{10}). The latter two capacitors would restrict the bandwidth; they can be left out as long as we do not apply overall external feedback with R_{31}. Due to the hefty amount of feedback in this circuit, the output impedance plummets to a measured value of 3.43 Ω, corresponding to a primary r_i of 1371 Ω — triode impedance combined with pentode output power, not bad! The damping factor is increased to $(8 \div 3.43) = 2.3$.

This is however not all. As the source impedance of the stage driving the output transformer decreases, the cutoff frequency of the second-order network formed by the transformer's leakage inductance and internal capacitance shifts to a higher value. Valve B_2 has a low-pass characteristics well, and its cutoff frequency is also raised by local feedback. The combined result is a −3 dB bandwidth of more than 100 kHz.

The limits of the VDV2100PP have not yet been reached; the bandwidth of this transformer extends to 250 kHz. The limitations of both B_1 and B_2 restrict the overall response. The bandwidths of these valves were sufficient for the original design of 1987.

The increased damping factor and wide bandwidth of this modification allow brilliant reproduction over the full frequency range, from *de profundis* bass to bat-frequency trebles. The power bandwidth has also increased. The original design allowed short power bursts at 80 kHz, but this configuration allows 109 watts of *continuous* power at this frequency, a clear sign of its superior speed and stability at high frequencies. The low end has improved as well; the original 50 watts at 30 Hz has risen to 90 watts. The 'old' amplifier with the 'new' transformer thus performs

significantly better than the original configuration. The input sensitivity has also increased somewhat, to around 390 mV$_{\text{eff}}$ for 100 watts into 5 ohms, about twice the sensitivity of the original design. The square-wave response is clean as a whistle, no overshoots or anything – the amplifier is unconditionally stable with capacitive loads.

■ Modification 5: Complete negative feedback

As a final experiment, the external feedback resistor R_{31} is reconnected. Capacitors C_7 and C_{10} must also be included, to keep the constellation stable. The good news is that the frequency response extends to 125 KHz, and the damping factor rises to 11.2. The square-wave response shows a slight overshoot; the amplifier has become more sensitive to capacitive loads. The input sensitivity, at 775 mV$_{\text{eff}}$, is close to its original value. This all looks good on paper, but ... the amplifier sounds bland, and much less lively and open than before.

18.5 | Conclusion

Using the VDV2100PP transformer has substantially enriched what was essentially an old design. The amplifier has become both faster and more stable, especially when operated close to its power limits. Modification 4 has proved to be the best, both on the measuring bench and in listening tests. It provides increased depth of image and freshness of timbre, both substantial gains.

Were the original transformers no good then? Yes, they were good, but they had to be more heavily corrected than the VDV2100PP by means of additional components — C_7, C_{10} and R_{31}. Overall negative feedback can be eliminated with the new transformer, while retaining a sizeable damping factor and a broad frequency response, resulting in a much more detailed and wider auditory image.

The VDV100 still has room to grow, making it an ideal target for further modifications. It is robust enough to be used for evaluating new types of components. In this respect, it is a pretty universal design that encourages new improvements.