Valve Final Amp

35 watts from a no-frills design

Design by Bob Stuurman

This valve power amplifier is a push-pull design using two EL34s (or their 6CA7 US equivalents). It has been kept fairly simple to avoid problems with DIY construction. The output power is well above 35 watts, with low distortion and a wide frequency range. This amplifier provides excellent sound reproduction when used with a pair of reasonably efficient, good-quality loudspeakers — and it shows that even a simple design with quite conventional specifications can sometimes make you tremble with excitement when listening to certain musical passages.

This final amplifier is based on a Philips design dating from the late 1950s, with a few modifications suggested by Claus Byrith. These modifications consist of a separate supply for the negative grid voltage for the EL34s, an AC balance adjustment for the output stage, an EF86 pentode wired as a triode in the preamplifier stage and a reduction in the amount of overall negative feedback (20 dB). Two documents on this subject have been published on the Internet. They describe the design in detail, and they are certainly worth reading if you are interested in this topic (see 'References').

Since the actual circuit is well documented, we limit ourselves to a brief description in this article. However, we do have a bit more to say about some of the less well-known aspects of the design, because they provide good insight into the problems associated with push-pull valve final amplifiers and the available solutions.

In the first part of the article, we address the theoretical aspects of the design, and in the second part we turn our attention to its construction. Since this is a DIY project, rather than a kit, certain parts of the construction are described in fairly extensive detail.

Schematic diagram

Figure 1 shows the complete schematic diagram of a single channel of the Valve Final Amplifier. There are three supply voltages: a positive high voltage of +440 V, a negative grid voltage of –55 V and a filament voltage of 6.3 V. Separate filament circuits are used for the preamplifier/phase splitter (Fil1 & Fil2) and the output valves (Fil3 & Fil4). The filaments are symmetrically connected to circuit ground via R28 and R29.

The output valves are operated in the 'ultralinear' mode by connecting their screen grids to taps on the anode windings of the output transformer via 1kΩ resistors. Due to the internal negative feedback via the screen grids, the pentodes exhibit characteristics lying between those of a triode and those of a normal pentode. Their internal impedance is reduced to practically the same level as that of a triode, and distortion is reduced to the triode level. However, the output power also drops to around 65 percent of that provided by a pure pentode output stage.

Instead of obtaining the negative grid voltage for the output valves from a voltage drop across the cathode resistors, we use a separate grid voltage supply. This prevents the operating point of the valves from shifting during operation. The magnitude of the negative grid voltage for the output valves can be adjusted using P2 ('DC current'), while the DC balance can be adjusted using P3.

The output stage operates in Class A for small signals, but it shifts increasingly towards Class B as the signal level increases. The current consumption also increases with larger signals. The operating point can be set within certain limits by adjusting the magnitude of the negative grid voltage. Since a separate supply is used for the negative grid voltage, the full anode supply voltage is present across the output valves.

The cathodes are connected to signal ground via 10 Ω resistors (R24 and R25). The voltages across these resistors are proportional to the currents through the valves (10 mV/mA).

Three test points are provided for aligning the circuit. TP0 is circuit ground, while TPV3 and TPV4 are the alignment test points for valves V3 and V4, respectively.

The EL34s provide maximum output power when the voltage on the control grid is

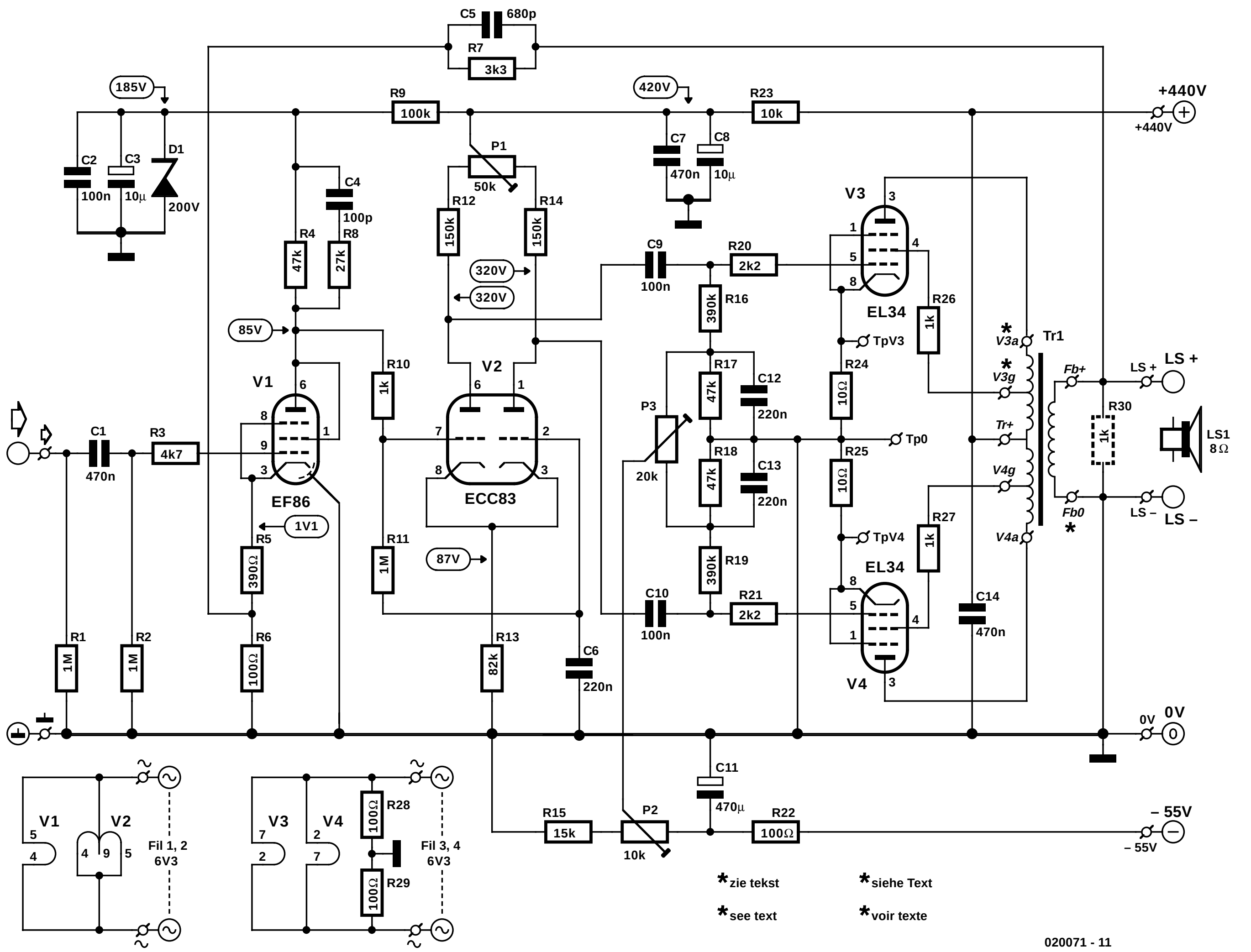
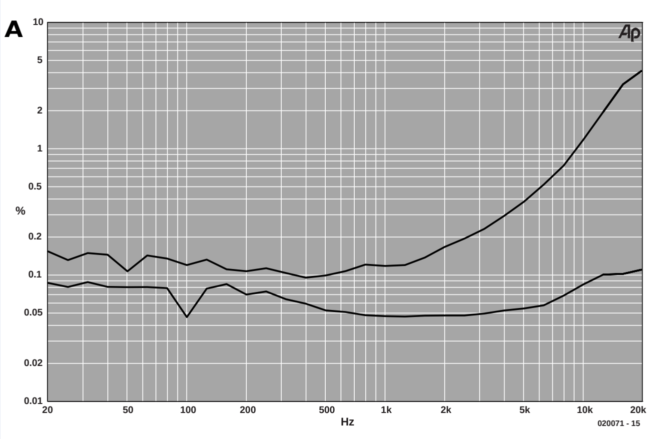
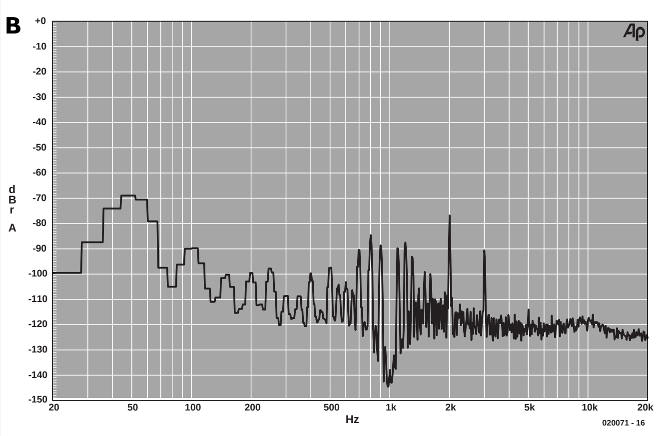


Figure 1. Schematic diagram of the Valve Final Amp.

Amplifier Specifications

Input impedance:	1 MΩ
Input sensitivity:	600 mV
Nominal loudspeaker impedance:	8 Ω (4 Ω optional)
Maximum output power:	39 W into 8 Ω
Bandwidth at 1 W:	5 Hz – >40 kHz
THD+ noise (1 W/8 Ω, 1 kHz):	0.06% (B = 80 kHz)
Signal to noise ratio:	62 dB (B = 22 kHz)
	88 dB (A-weighted)





Performance

A few measured results are shown here. **Plot A** shows harmonic distortion versus frequency. The lower curve was measured at an output power level of 1 W, and the upper curve at 27 W. The 1 W curve in particular is very nice, and this is a typical power level for listening to music. **Plot B**, which is rather more irregular, shows an FFT analysis of a 1 kHz signal at an output power of 1 W. The 1 kHz sine wave has been suppressed by the measuring equipment, and the remaining peaks represent the distortion residuals of the amplifier. You shouldn't be overly alarmed by this plot, since the very wide dynamic range of the analyser (150 dB) gives an exaggerated impression of the actual situation. The most important components are the distortion peaks at 2 kHz and 3 kHz, which lie at –77 dB and –90 dB, respectively. For a relatively simple design using valves and transformer output, this is a very good result. The bulge at 50 Hz results from residual hum in the supply voltage and has nothing to do with the distortion spectrum.

approximately 26 V. This drive level can be easily provided by the phase splitter. The phase splitter is a type having the cathodes connected together and the grid of the second triode (V2b) grounded for AC signals by C6. Since V3a is driven by the grid and V2b is driven by the cathode, there is a small imbalance in the magnitudes of the AC voltages on the anodes. The voltages can be adjusted to be exactly the same using P1 ('AC balance').

The phase splitter exhibits a gain of approximately 26 times, so a signal level of 1 V on the grid of V2a is needed to fully drive the output stage. The high resistance of the cathode resistor (R13) yields low distortion and a high cathode voltage (around 87 V), thus allowing the grid of V2a to be driven directly from the anode of the EF86 preamplifier valve without using a coupling capacitor.

The preamplifier is wired as a triode by connecting the screen grid to the anode, since the high gain that can be obtained with a pentode is not needed. This reduces the noise factor to that of a triode, while retaining the good internal screening and freedom from microphonics characteristic of this valve.

A signal level of 60 mV on the grid of the EF86 is needed to fully drive the output stage. Due to the 20 dB of negative feedback provided by R7 and R6, the input level needed to fully drive the output stage is 600 mV. At this level, the output power is 39 W. The amplifier starts to clip at an input level of 0.7 V, which corresponds to an output power of around 46 W.

The resonant frequency of the output transformer due to its leakage inductance is approximately 80 kHz. At this frequency, the open-loop gain must be small enough to ensure that the amplifier remains stable. The necessary gain roll-off is provided by C4 and R8, with a bit of help from C5. The values of these components were determined experimentally using square-wave signals.

When the amplifier is switched on, the high voltage and negative grid voltage are present almost immediately. However, the filaments must warm up before any current can flow through the valves. Diode D1 is thus included to prevent an excessively high voltage from appearing on the anode and screen grid of the EF86. The circuit reaches its normal operating state after a few tens of seconds, with a voltage of approximately 185 V across D1.

RF-suppression ('stopper') resistors are used for the control grids of all the valves. They were present in the original design, so we have kept them here as well.

In the original design, the screen coupling capacitors for the output valves (C9 & C10) had a value of 470 nF. The current through the output valves proved to have rather large fluctuations at a very low frequency (0.2–0.5 Hz), which were also present at the loudspeaker output. This was probably due to small variations in the negative grid voltage. Since these fluctuations have a small amplitude and the output transformer has a large self-inductance, they are not blocked by the output transformer, and they find their way to the amplifier input via the negative-feedback network. This phenomenon was reduced to an accept-

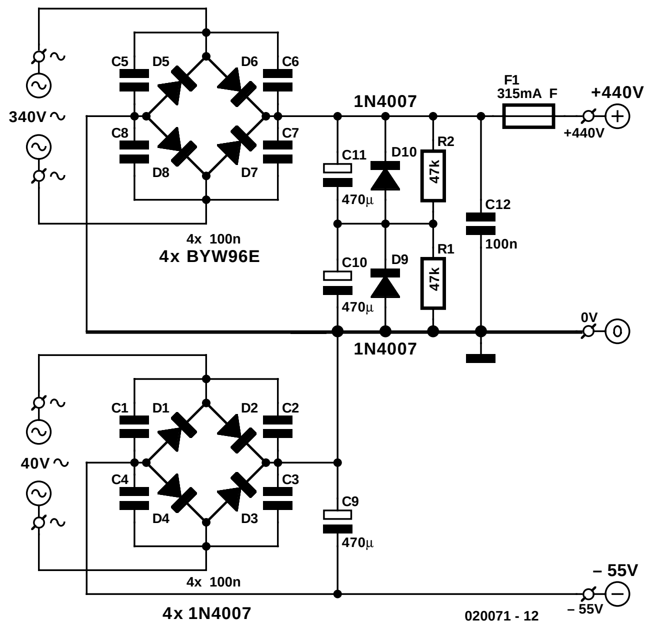
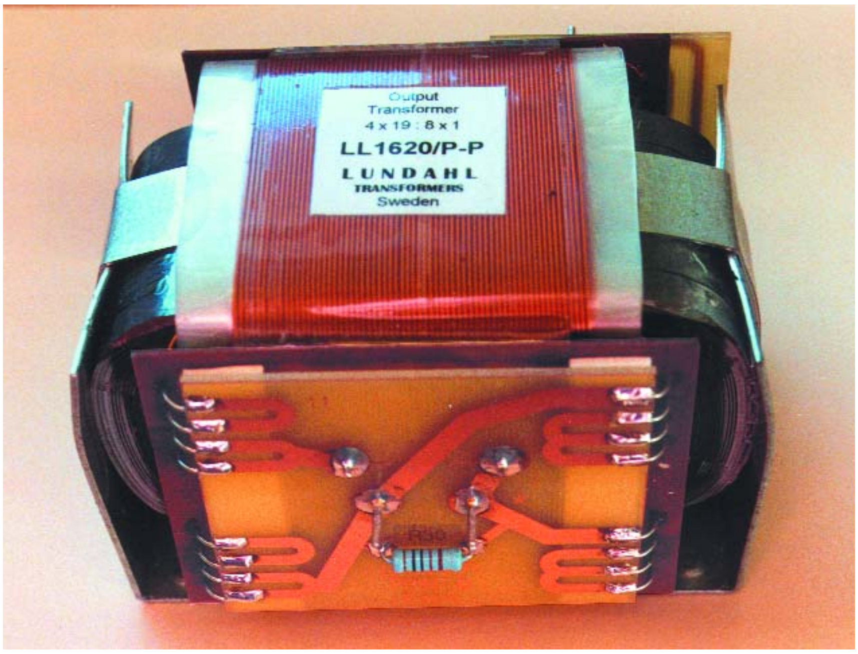


Figure 2. Schematic diagram of the power supply.



able level by decreasing the value of C9 and C10 to 100 nF. This does not have any audible effect on the reproduction of low frequencies.

Power supply

The good characteristics of the Valve Final Amp are in part due to its robust power supply. The Amplimo type 7N607 toroidal transformer, which weighs around 3.5 kg, can provide 340 V at a healthy 700 mA. After rectification and filtering, more than 400 mA at 440 V are available to the amplifier. The winding for the negative screen voltage provides 40 V at 100 mA, which yields an adequate voltage (55 V) after rectification and filtering. The total filament current of the valves is about 7 A. The 6.3-V winding is rated at 6.8 A, but since the load on the high voltage winding is fairly small and practically no power is drawn from the screen-voltage winding, this does not present a problem.

Figure 2 shows the schematic diagram of the power supply. The high voltage is rectified by four diodes wired in a bridge configuration. The diodes have a surge current rating of 60 A. Interference suppression ('anti-rattle') capacitors are connected across the diodes. Since it is practically impossible to buy high-voltage electrolytic filter capacitors with large capacitance, a pair of 470 µF/400 V electrolytic capacitors are connected in series to achieve an effective capacitance of 235 µF. Diodes D9 and D10 prevent the capacitors from being reverse-biased when the amplifier is switched off. Resistors R1 and R2 divide the voltage evenly across the capacitors and discharge them within several minutes after the amplifier is switched off. C12 provides RF decoupling. Protection is provided by a 315-mA, fast-acting (F) fuse, and it can be a lifesaver for the output valves if the negative grid voltage becomes too small (less negative).

Output transformer

The most important, most critical and invariably most difficult to obtain component of a push-pull valve amplifier is the output transformer. The original Philips design used an output transformer having ten primary windings connected in series, with eight secondary windings interleaved between the primary windings. The secondary windings could be connected in a series/parallel arrangement to obtain the desired input and output impedances. This must have been a real whopper of a transformer, and we estimate that it surely must have weighed more than 5 kgs.

You may be wondering why it was necessary to use a transformer wound in such a complicated manner. The reason is that the ability of a transformer to pass a sine-wave signal decreases as the frequency of the signal increases. Even with very good transformers, the drop-off at 25 kHz is already around 0.5 dB.

Figure 3 shows the equivalent circuit of a transformer driven by an electronic valve. Part (a) shows the situation at very low frequencies. Here the self-inductance of the primary must be high in order to limit the current and allow sufficient magnetic flux to be generated without going into saturation. Part (b) shows the situation at mid-range frequencies, where is a high impedance. Part (c) shows the situation at high frequencies, where the signal is attenuated by the leakage inductance (L_S) and the interwinding capacitance (C_W). The leakage inductance arises from the 'leakage' of magnetic flux as a result of incomplete coupling between the windings.

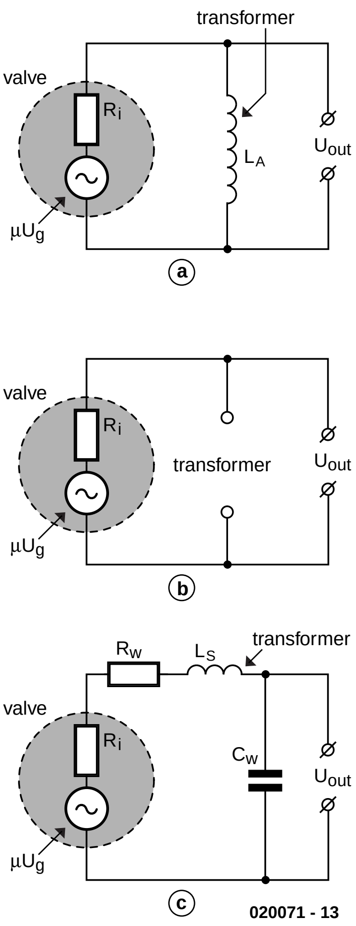


Figure 3. Output transformer equivalent circuit at various frequencies.

It takes time for a signal to pass through a transformer, since the low-pass filter formed by the leakage inductance and load impedance creates a time delay. The resulting phase difference between the input and output signals increases with increasing frequency. The output signal thus lags further and further behind the input signal as the frequency increases At 20 kHz, the phase difference can already be 14 degrees. Needless to say, this can have serious consequences for the reproduction of rectangular signals. Fortunately, there is a technique that can be used to deal with the problems of attenuation of high-frequency signals and increasing phase difference at higher frequencies. This technique is negative feedback.

Returning to the output transformer (see Figure 3), we see that L_S and the C_W also form a resonant circuit, so a rapid increase in the phase angle occurs when the signal frequency passes through the resonant frequency of this circuit. This can make the amplifier unstable. Consequently, the open-loop gain of an amplifier with negative feedback must be attenuated such that the gain–feedback product ($A \times \beta$) is less than 1 at this frequency. If the amplifier is to have a wide bandwidth, it is thus essential for the output transformer to have a sufficiently high resonant frequency. This requires the leakage inductance and winding capacitance to be small, which can only be achieved using complicated winding methods — such as the method used in the previously mentioned Philips output transformer. Naturally, such a transformer cannot be inexpensive.

After some searching, we found a valve output transformer that appears to be eminently suitable for the modified Philips amplifier design. This is the type LL1620PP transformer from the Swedish company Lundahl. This transformer has a ‘C’ core made from a special type of iron, with two primary windings and four secondary windings on each leg. The two halves of the core are held tightly together on the transformer frame by a welded ribbon. The push-pull version of this transformer (versions for use in single-ended amplifiers are also available) has a small (25 µm) air gap, so a slight imbalance in the DC currents through the primary windings can be tolerated without causing a large reduction in the primary self-inductance. The four primary windings are connected symmetrically in series, yielding taps at the 50-percent points the of windings that can be connected to the screen grids of the pentode output valves for operation in the ‘ultralinear’ mode. The eight secondary windings can be connected in series and/or parallel in various manners in order provide an output impedance of 4 Ω or 8 Ω. At 13 mH, the leakage inductance of the LL1620PP is somewhat on the high side, but this is inevitable with such a large primary self-inductance (no less than 300 H). Since the open-loop gain and negative feedback have both been reduced in the modified version of the amplifier, it remains stable despite the relatively leakage inductance.

The most important specifications of the transformer are listed in the ‘Basic LL1620PP Specifications’ box. The transformer dimensions are shown in **Figure 4a**. Paxolin boards with leads numbered as shown in the figure are fitted on both sides of the windings. The winding diagram of the transformer is shown in **Figure 4b**. Each primary winding is sandwiched between two secondary windings.

To make it easier to use the transformer and reduce the chance of wiring errors, the author has designed three small printed circuit boards for making connections to the transformer. They are not available from Readers Services, but if you want to make them yourself, you can download the layouts from the *Elektor Electronics* website (Free Downloads, reference number 020071-1, month of publication). However, it is certainly not difficult to wire the transformer into the circuit by hand. The necessary connections are shown next to each of the circuit board layouts.

For each of these circuit boards, the transformer is located on the ‘component side’ of the board. The numbers on the boards (1, 8 and 11) correspond to the lead numbers of the

Basic LL1620PP Specifications

Primary/secondary turns ratio:	4 x 19.2 / 8 x 1
Primary winding DC resistance: *	308 Ω (4 x 77 Ω)
Secondary winding DC resistance: (average per winding)	0.4 Ω
Primary winding self-inductance:	300 H
Primary winding leakage inductance: *	13 mH
Primary impedance in this design:	6 kΩ
Secondary impedance in this design:	4 Ω or 8 Ω
Air gap:	25 µm
Transformer loss at 62 W:	0.2 dB
Weight:	2.5 kgs

* all windings connected in series

transformer as shown in Figure 4a.

The connections and circuit board layout for the primary are shown in **Figure 4c**. Simply slip the circuit board over the leads and solder it in place. The connections are marked as follows: supply voltage = Tr+, anodes = A / A*, screen grids = G / G*. Here '*' indicates the start of the winding.

In the original Philips design, the taps for he screen grids were at the 40-percent points of the windings, as measured from the centre tap. Here the proportion is 50 percent, which shifts the output stage more toward triode operation and causes the output power to be somewhat lower. In order to keep the coupling between the anode winding and the screen grid part the winding as tight as possible, windings on the same leg of the transformer have been matched together.

The transformer has eight secondary windings, which can be connected together in series or parallel in various ways in order to obtain the desired secondary impedance for the loudspeaker (4 Ω or 8 Ω) and the required primary impedance (6.0 kΩ). In the 4 Ω configuration, two sets of secondary windings are connected in series, while three sets are connected in series in the 8 Ω version.

The circuit board layout and connections for a 4 Ω loudspeaker connection are shown in **Figure 4d** (note the two wire links on the bottom side of the board, marked with short lines). **Figure 4e** shows the circuit board layout and connections for an 8 Ω loudspeaker impedance. In this case, there is only one wire link. Both configurations include a 1 kΩ shunt resistor at the output (R30). This resistor provides a certain amount of protection for the output transformer if no loudspeaker is connected. It also improves the stability of the amplifier with a capacitive load, such as may be present with a long speaker cable.

The leads for the secondary of the transformer are formed by bringing the tinned ends of the windings out to the terminal board. If you use one of the illustrated printed circuit boards for the 4 Ω or 8 Ω connections, bend the secondary leads flat against the wide tracks on the board and solder them in place.

The construction of the amplifier will be described in the next instalment. Since this involves a fair number of illustrations, a few plots of the measured performance of the amplifier are included in this instalment (see 'Performance').

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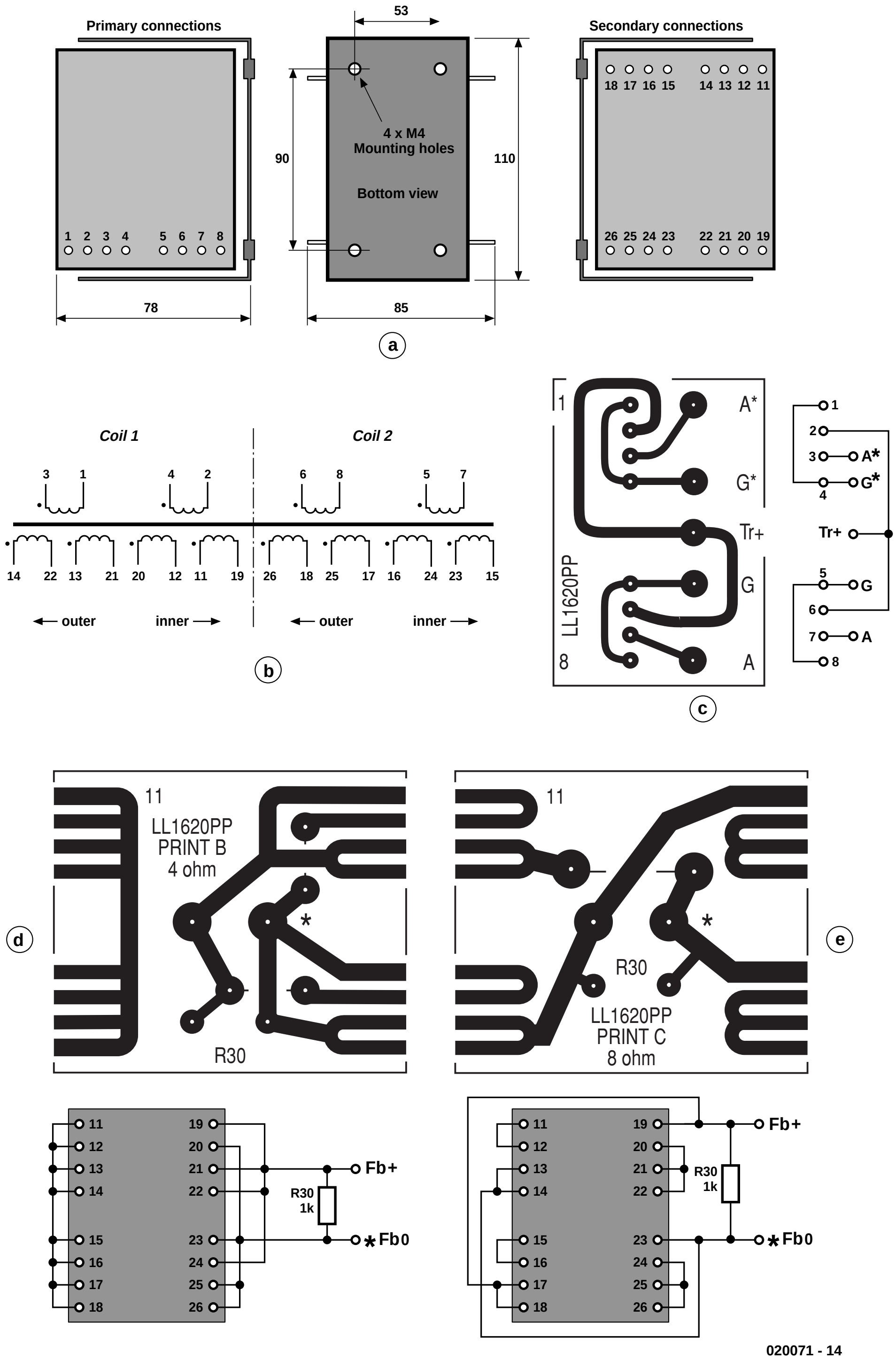

Figure 4. LL1620PP transformer: (a) dimensions and leads, (b) winding diagram, (c) primary winding connections and layout of the optional printed circuit, (d &, e) secondary winding connections and layouts of the optional printed circuit boards for 4-Ω (d) and 8-Ω (e) loudspeakers