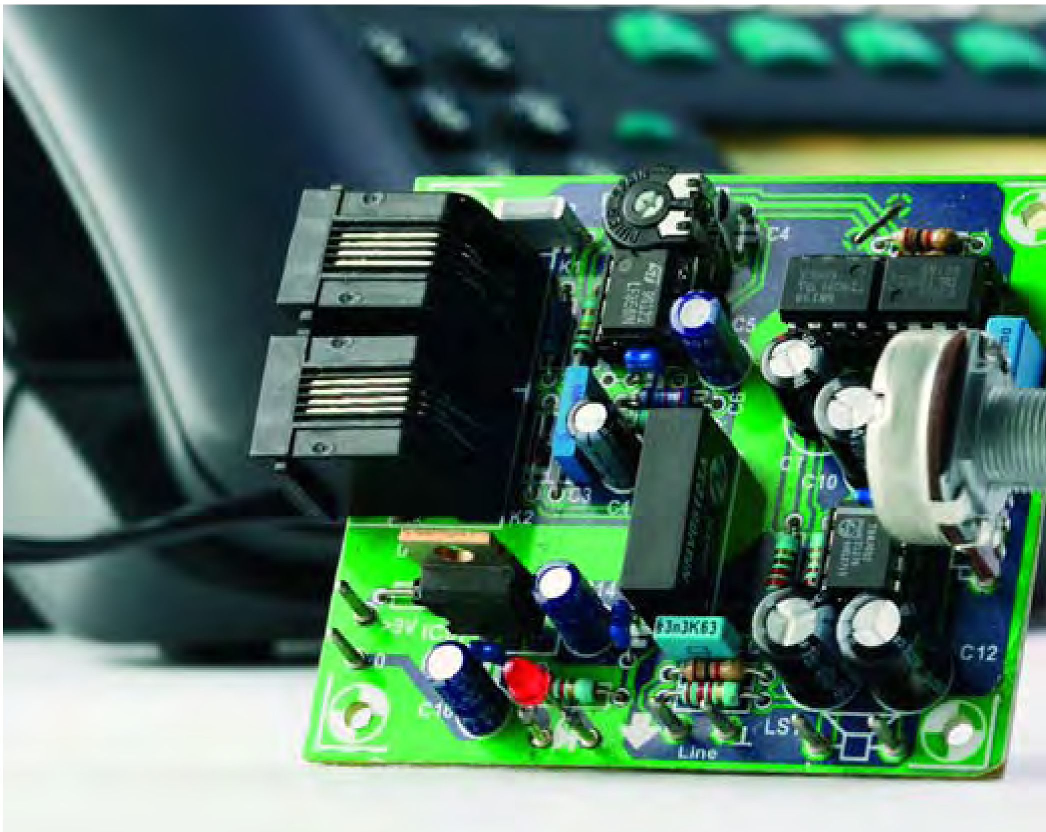
Telephone Eavesdro



Galvanic isolation is a special feature of this telephone amplifier, which includes a line output connection for a hi-fi system.

From an idea by
Markus Müller

Although in some countries, including the UK and Germany, analogue telephone connections are something of a dying breed, most residential customers use analogue apparatus, even in cases where the underlying connection is over ISDN.

There is little reason to change: first, ISDN telephones are rather expensive, and second, ISDN connection starter packs generally include an a/b adaptor which allows the connection of old analogue telephones to the ISDN system. What a lot of analogue telephones lack, and which most modern ISDN devices provide, is a loudspeaker.

The experienced *Elektor Electronics* reader will have no difficulty in adding a loudspeaker. Several designs for telephone amplifiers have appeared previously in *Elektor Electronics*, but there has never been a circuit to which we cannot make some improvements or add new and interesting features.

High Voltage

The amplifier described here has the special feature, not shared by any of its predecessors, of a line output. This means that it can be connected to an ordinary hi-fi system. This requires, as a glance at the circuit diagram in **Figure 1** will show, complete galvanic isolation between the telephone network and the mains. Now we shall look at the parts of the circuit in turn.
The amplifier has two RJ45 telephone-style sockets connected in parallel at its input, to simplify adding the circuit into an existing cabling arrangement.
An analogue telephone connection works essentially as shown in **Figure 2**. In the quiescent state the exchange provides a DC voltage of nominally 60 V between the a-wire and the b-wire. The actual voltage level varies significantly with the distance from the exchange and can be as low as 40 V or as high as 80 V. To ring the telephone to signal an incoming call, the exchange superimposes an AC voltage of up to 75 V on the DC level. The peak value of the ringing voltage can thus be over 120 V. Despite the low current available, this is dangerous: not just to humans, but also, in particular, to connected electronic devices. When the receiver is lifted, a current of between 10 mA and 30 mA flows and the DC voltage falls to around 12 V. The analogue voice signal is superimposed on this voltage.
Private telephone exchange systems and a/b adaptors can work at much lower DC voltages (often 24 V) because the distance to the telephone itself is much shorter.

Amplification and filtering

Of course, the telephone amplifier must be designed to work at any of these voltages. It is the noble duty of input capacitor C2 to isolate these DC levels from opamp IC1 (an LF356). A high-voltage type is essential, and the component recommended in the parts list can easily cope with 400 V.
Next we must ensure that the AC component is also reduced to a level

pper an advanced amplifier with line output

safe for the input to IC1: this is achieved using two Schottky diodes, D1 and D2, which limit the incoming voltage to between –0.3 V and 15.3 V. The current which flows is limited to a safe value for the diodes (and for the exchange) by R3. The reduced AC voltage (whether it be a ring signal or a voice signal) is taken to the inverting input of inverting amplifier IC1 via R4. Since the useful signal can vary considerably in level, the gain of the amplifier can be adjusted between 0 and 2 (which is slightly lower than might be expected, on account of C2 and C4) using potentiometer P1. At the same time, a DC voltage of 6.8 V is applied to the non-inverting input of the amplifier by voltage divider R1/R2. This voltage can be measured for test purposes at the output of the opamp. This voltage, which is a little less than half the supply voltage, is used at another point in the circuit where it is not allowed to exceed 7 V. The output swing of the opamp is such that this small asymmetry does not matter.

Since the telephone voice signal is not exactly high-quality audio, we can take some liberties with it in the interests of reducing the effects of interference and noise. The input capacitor, along with R3 and R4, forms a high-pass filter with a cut-off frequency of 100 Hz, while C3 and R3 form a low-pass filter with a corner frequency of about 17 kHz. And last but not least, C4 also attenuates higher frequencies above about 10 kHz (or at least those which the opamp is capable of amplifying).

Galvanic isolation

To protect the output stages and any electronics that may be connected to them, two type 6N138 linear optocouplers are used to provide galvanic isolation up to 2.5 kV. Since the performance of the optocouplers is not very dependable (in that their characteristics vary considerably from one device to the next), we use the rather elegant combination of two 6N138s shown to achieve repeatable opera-

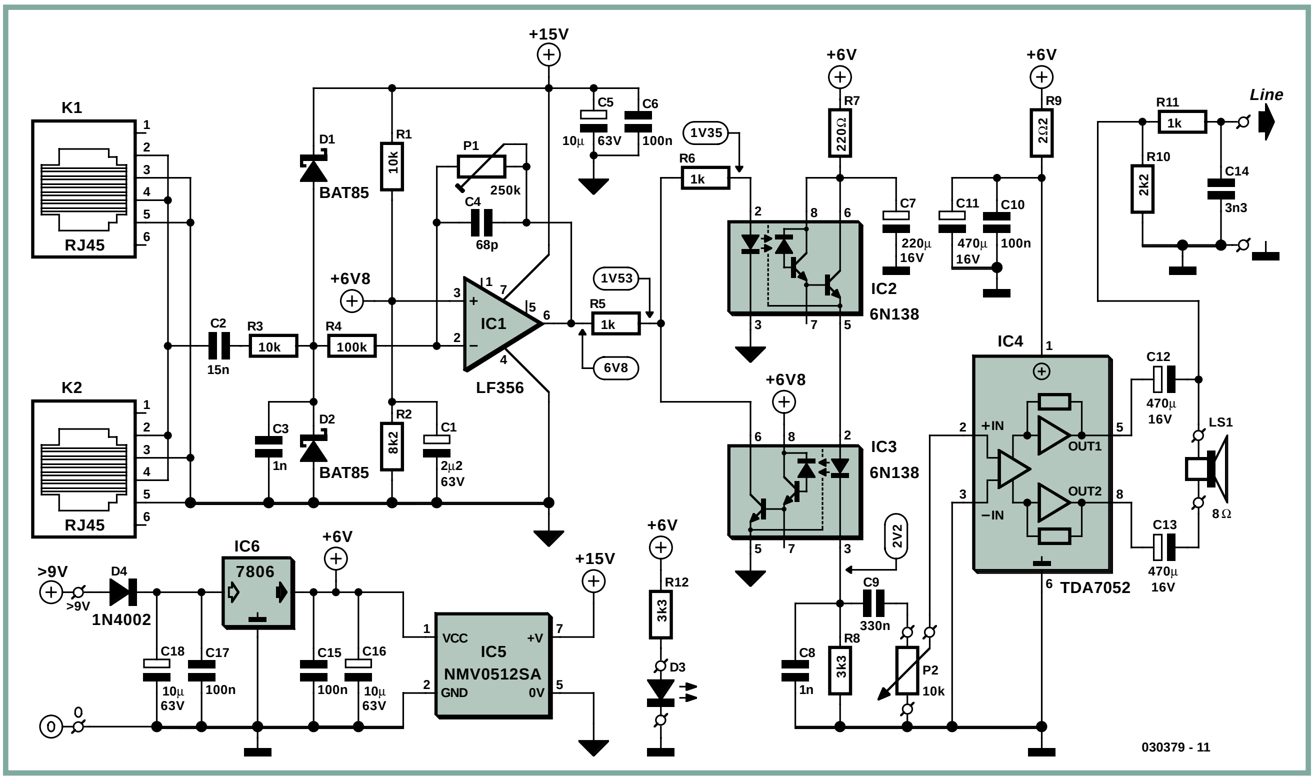


Figure 1. The telephone and audio parts of the circuit are kept strictly separate.

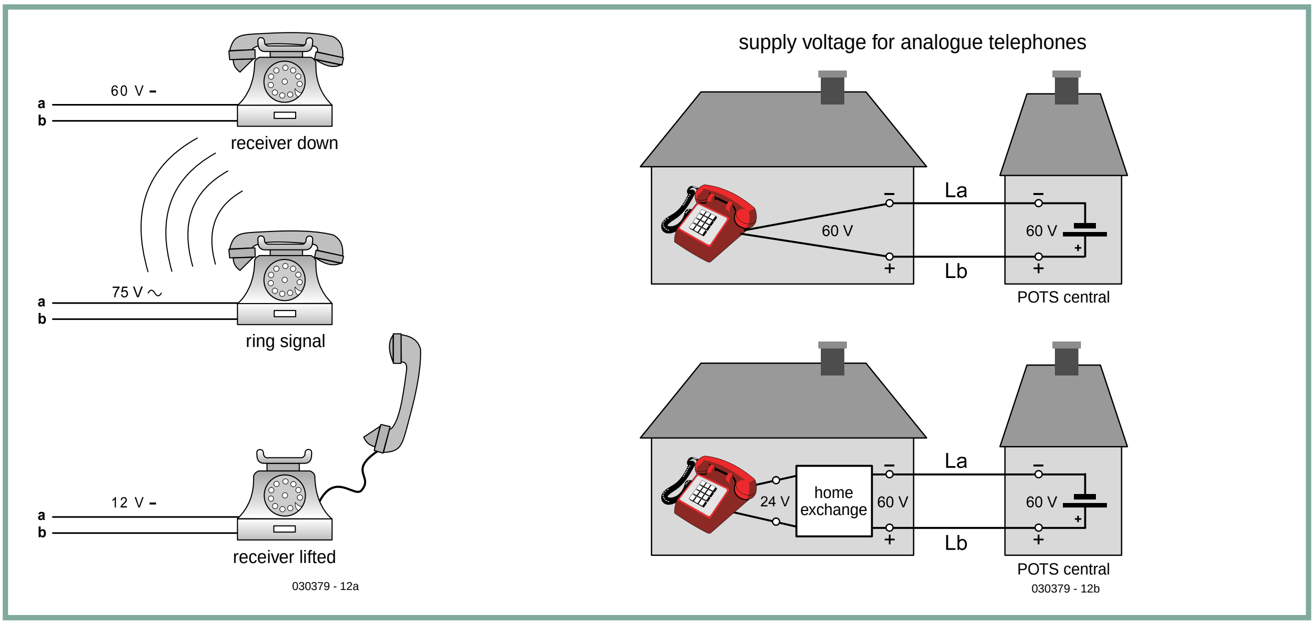
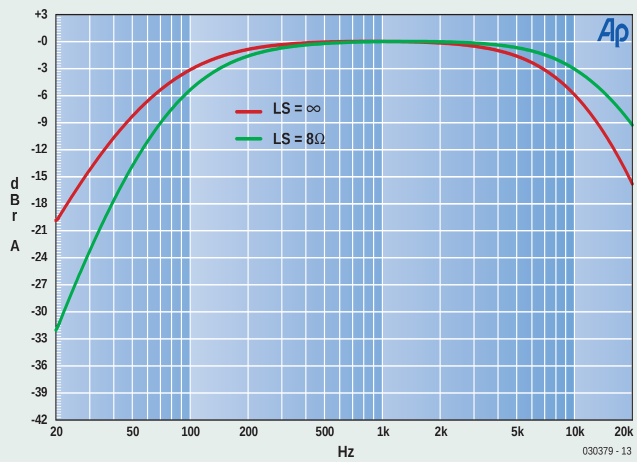


Figure 2. AC and DC voltages on an analogue telephone line.

Measured characteristics

Characteristic curve A shows the frequency response of the telephone amplifier. The measurement was made at the line output, and thus corresponds to the values for the loudspeaker output. The upper frequency range is shown for the two extreme settings of P1, and the effect of capacitor C4 is clearly visible. The –3 dB frequency of 9.9 kHz (at –20 dB) falls to 6.8 kHz when P1 is set to maximum. At the low-frequency end the effect of the loudspeaker is significant. With the loudspeaker connected the corner frequency is 140 Hz, whereas without the loudspeaker it is 100 Hz. Since the output impedance of the TDA7052 amplifier effectively attenuates the output signal by about 1 dB, we have artificially superimposed the curves so that they may be compared more easily.



Here are some of the characteristics as measured on the prototype:

Line output (LS1 not connected)

Sensitivity	Full drive, 1 V line level	60 mV
Maximum output level	THD+N = 1 %	1.6 V
Maximum bandwidth		100 Hz to 9.9 kHz
Minimum bandwidth		140 Hz to 6.8 kHz
Minimum THD+N	B = 22 Hz to 22 kHz	0.26 %
THD+N	B = 22 Hz to 22 kHz, LS1 = 8 Ω	1 %
Signal-to-noise ratio	250 mV in, 1 V out, B = 22 Hz to 22 kHz	55 dB
Signal-to-noise ratio	250 mV in, 1 V out	57 dBA

With LS1 (8 Ω) connected

P_{max} (THD+N = 1 %)	Voice signal	750 mW
Minimum THD+N	B = 22 Hz to 22 kHz	0.6 %
Signal-to-noise ratio	at 500 mW, B = 22 Hz to 22 kHz	55 dB
Signal-to-noise ratio	at 500 mW	57 dB

Quiescent current consumption		72 mA
Current consumption at P_{max}		0.3 A
Current consumption when overdriven	maximum	0.4 A
Minimum supply voltage		9 V

tion. The optocouplers have a Darlington pair at the output and are connected so that the current flowing through the output of IC2 is coupled back via IC3 to the input of IC2. Although this arrangement is slightly noisy, the circuit has adequate bandwidth and the gains in terms of linearity and low distortion more than compensate.

The current though IC2 is translated into a voltage for the following output amplifier by R8. C9 removes the DC component of the signal on R8, and also forms a second high-pass filter with a relatively low corner frequency of approximately 40 Hz. This makes the overall frequency response of the amplifier fairly flat. C8 also reduces interference from the power supply, a point which we shall return to later.
As we stated earlier, the gain of the input stage of the circuit is approximately 2. The attenuation in the optocoupler is approximately 4.7, and so the overall gain up to the volume control potentiometer P2 is around 0.4. This attenuation is not a problem since the gain of IC4 (in bridge mode) is 39 dB. The optimum voltage at the output of the optocouplers, in terms of minimising THD+N, is around 100 mV. At this voltage distortion (the second harmonic is below –53 dB) is comparable with the signal-to-noise ratio of –55 dB. At maximum volume (P2 at maximum), IC4 is overdriven.

Output amplifier

The familiar Philips TDA7052 is used as an output device in this telephone amplifier. This 1-watt bridge-mode amplifier has a low quiescent current and is thus suitable for battery operation. It is powered from the same supply as optocoupler IC2. Bridge-mode amplifiers have the advantage, when used with a single (asymmetrical) supply, that they can be connected to the loudspeaker without coupling capacitors; here, however, we go so far as to fit two such capacitors — and for a good reason!

The electrolytic capacitors form a high-pass filter with a corner frequency of slightly less than 100 Hz, thus removing the lowest frequencies. In theory the corner frequency when using an 8 Ω loudspeaker is 85 Hz, but this value depends, of course, on the impedance of the loudspeaker. In principle a single electrolytic would work

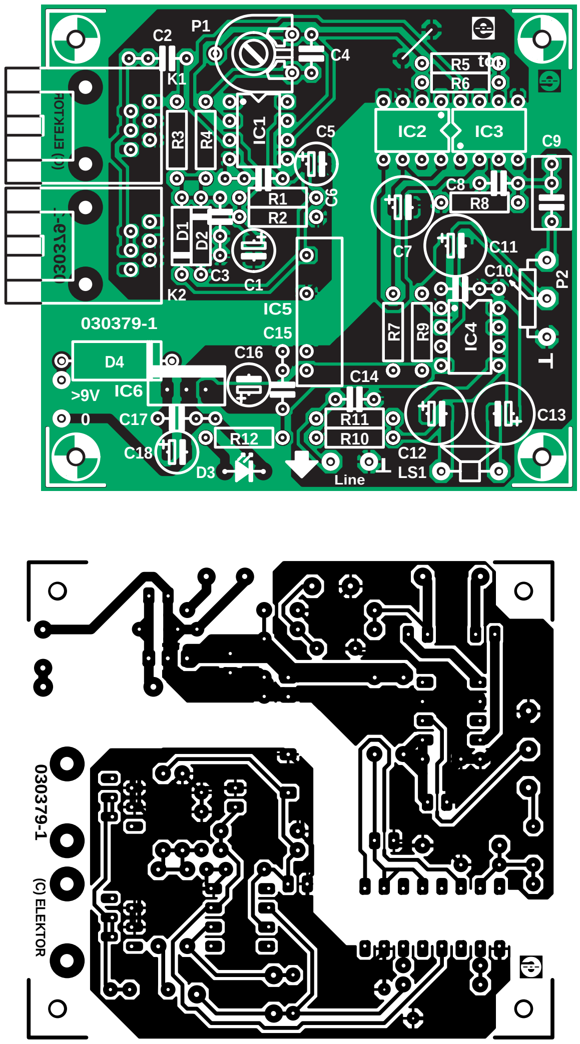


Figure 3. The printed circuit board for the telephone amplifier has two ground planes with a minimum separation of 6 mm between them.

COMPONENTS LIST

Resistors:
R1,R3 = 10kΩ
R2 = 8kΩ2
R4 = 100kΩ
R5,R6,R11 = 1kΩ
R7 = 220Ω
R8,R12 = 3kΩ3
R9 = 2Ω2
R10 = 2kΩ2
P1 = 250kΩ preset H
P2 = 10kΩ logarithmic potentiometer, mono

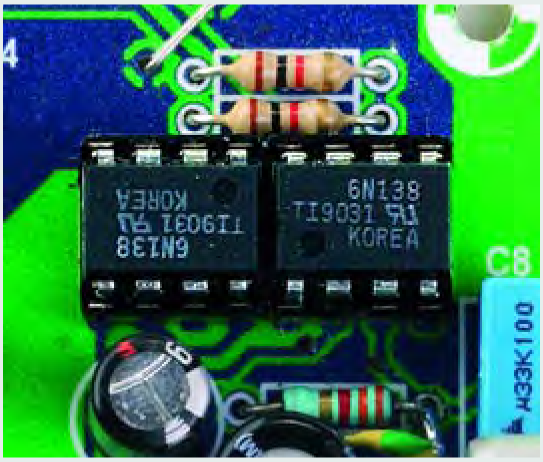
Capacitors:
C1 = 2µF2 63 radial
C2 = 15nF 400V
C3 = 1nF 400V
C4 = 68pF
C5,C16,C18 = 10µF 63V radial
C6,C10,C15,C17 = 100nF
C7 = 220µF 16V radial (max. diameter 8mm)
C8 = 1nF ceramic (5mm lead pitch)
C9 = 330nF
C11,C12,C13 = 470µF 16V radial (max. diameter 8mm)
C14 = 3nF3 (5mm lead pitch)

Semiconductors:
D1,D2 = BAT85
D3 = LED, low current
D4 = 1N4002
IC1 = LF356
IC2,IC3 = 6N138 (Farnell # 325-831)
IC4 = TDA7052
IC5 = NMV0512SA, C&D Technologies/Newport Components (Farnell # 589-822)
IC6 = 7806

Miscellaneous:
K1,K2 = RJ45 socket
LS1 = 8Ω / 1W miniature loudspeaker
Solder pins
PCB, order code **030379-1** (see Readers Services page)

Optocoupler tolerances

Optocouplers have wide tolerances. If possible, use a type 6N138 with a current transfer ratio (CTR) of between 250 % and 450 %, as otherwise IC2 and IC3 may attenuate the signal too much. If the voltage across R8 is a few tenths of a volt too low (a tolerance of 10 % is allowable), its value can be increased to raise the voltage, and vice versa. The circuit is so simple that if necessary other standard optocouplers with a Darlington output, such as the IL300, can be used with a suitable adjustment to the resistor value. The CTR of IC2 is easy to calculate: CTR = (U_{R8}/R8) / (U_{R6}/R6). Changing R8 naturally affects the gain of the circuit, although for reasonable adjustments this should not cause any problems.



just as well, but here the required capacitance is obtained using two capacitors in order to prevent a DC level appearing on the line output, which is taken from one of the amplifier's outputs. Because of this, the gain at the line output is only 33 dB. R10 ensures that the two electrolytics remain charged so that there is no 'click' when an external amplifier is connected to the line output. R11 makes the output short-circuit-proof, and C14 provides additional filtering to remove high-frequency interference. To prevent undesirable coupling through the power supply connections, the optocouplers and the amplifier are separately smoothed (by R7 and C7, and R9, C10 and C11 respectively).

Power supply

There is little point in galvanically isolating the telephone line from the audio electronics if their power supplies are not also kept separate. To this end we use a NMV05125SA DC-DC converter which converts an input voltage of 6 V to an output voltage of 15 V while providing galvanic isolation up to 3 kV.
The input voltage is a little higher than the maximum value of 5.5 V specified in the data sheet, but is clearly within the 'absolute maximum rating' of 7 V. In practice, it works well, and thanks to the low load, the output voltage is slightly higher than the 14.4 V that one would expect with an input voltage of 6 V. The converter presents a rather aggressive load to the fixed voltage regulator, resulting in an output ripple voltage of 0.1 V_{pp}. According to the manufacturer's data, the converter switches at a frequency of approximately 120 kHz. However, in our laboratory prototype the frequency appeared to be a little higher: we measured the ripple frequency to be approximately 300 kHz. This does not affect the performance of the telephone amplifier, but it does simplify the measures we need to take in the circuit to suppress interference.

The fixed voltage regulator is the common-or-garden 7806, with its input protected from reverse polarity connection by a diode. The regulator has a drop-out voltage of 3 V, and so the input voltage obtained from a mains adaptor must be at least 9 V. Of course, the telephone amplifier can also be powered from a battery, although the current consumption is quite high. We measured a quiescent current consumption of 72 mA on the prototype (even using a low current LED for power indicator D3), with peak current up to 0.4 A (using an 8 Ω loudspeaker); battery operation is thus only appropriate if the device is to be used occasionally. In any case, a PP3-style battery will not last long, and it would be better to use four AA cells with IC6 replaced by a wire link and D4 ideally replaced by a Schottky diode such as the 1N5822 (40 V, 3 A). At 0.4 A this Schottky diode drops only 0.3 V, considerably less than the 0.8 V drop of a 1N4002.

Keep your distance

The steps we have taken to achieve galvanic isolation are clear in the printed circuit board layout of **Figure 3**. As can be seen, the ground planes for the telephone and audio parts of the circuit are separated. Populating the board should present no difficulties. Do not forget the wire links (the circuit will work without them, but will be more susceptible to interference). Sockets should be used for the amplifiers but not for the optocouplers, so that the isolation voltage is not compromised.

The connection points for the external components (potentiometer, line socket, loudspeaker and power supply socket) lie around the edge of the board and should be fitted with terminal pins.

The circuit can be built into an ordinary plastic enclosure, but a metallic screen (a piece of tin or unetched printed circuit board) should be fitted directly under the printed circuit board, taking care not to cause a short circuit. The screen should be connected to the metal enclosure of potentiometer P2 and to ground. P2 should be fitted as close as possible to its connection points on the board, and its connection wires twisted.

For best audio results a small, good-quality loudspeaker should be used inside a large enclosure rather than in the electronics box, with the loudspeaker being located a few metres away from the telephone to prevent feedback. Alternatively, the line output can be connected to a hi-fi system.

The circuit discussed in this article is not approved for connection to the public switched telephone network (PSTN) in the United Kingdom.

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