Direct Injection Box

Clean up your on-stage sound with this low-cost, high and low impedance splitter.

By Andrew Armstrong

EVEN WITH the large number of electric musical instruments in use today, sound is still frequently transferred from instrument to PA system by means of a microphone. Electric guitarists often regard their stage amplifier as part of the instrument and wish the sound to include the distortions, cabinet resonances and even the microphone in the case of tube amplifier. This demands a microphone placed directly in front of the musician's loudspeaker, with all the consequent problems of distortion and increased risk of feedback.

Microphones have to be used in any case for vocalists and acoustic instruments, which makes it all the more important to avoid using them on electric instruments wherever possible so as to keep the risk of feedback to a minimum. Electric keyboards can usually be fed directly into the PA system, but an on-stage amplifier may still be required so that the sound can be heard by the musician and acoustic instruments may also need local amplification in the noisy environment of an amplified band.

The solution to some of these problems is a direct injection box, a unit which takes the incoming signal from the instrument (or from the microphone in the case of an acoustic instrument) and splits it to produce two outputs, one of which is fed to the main PA while the other is taken to a nearby amplifier and speaker controlled by the musician. A DI box (as they are generally known) usually has a high impedance input, a low impedance output for the mixer which is sometimes balanced, and either a high or low impedance output for the stage amplifier.

Well Balanced Design

This design is based around a very low noise dual op-amp which allows it to be used at low signal levels without significant noise problems. The gain is normally set at unity but a voltage gain of 2:1 can be achieved by making a few component changes. The unit operates from a single 9V battery and powers up automatically when a jack plug is inserted into the input socket. In addition, a low-voltage detector is included which lights an LED when the battery needs replacing.

The unbalanced output can be taken from the output of the first op-amp which gives a reasonably low impedance driver, or, if preferred, can be connected directly to the input. The advantage of this arrangement is that the unbalanced output will then continue to operate even if the unit develops a fault or the battery runs down. The input impedance of the DI box circuitry is quite high and will not excessively load a connection made in this way.

The mixer output is balanced and can either be used directly with high impedance balanced inputs or set at 600R by adding two 300R resistances. A circuit for a low impedance balanced input has also been included, as an add-on, to enable the unit to be used with equipment which does not already have a balanced input.

The normal type of balanced line to use for audio work is 600R. To be completely correct, the source resistance for each signal connection should be 300R and each one should be terminated with a 300R resistance to ground at the receiving end. In many cases, a high impedance is used at the receiving end and the sending end impedance is just 'low'.

As long as the signal level is suitable, this unit may be used as a proper 600R driver. The 5532 op-amp specified has very low noise, typically 5 $nV/\sqrt{Hz}$, so very low level signals may be used without a severe signal-to-noise penalty. The voltage swing which the op-amp can drive into 600R is somewhat less than it could drive into 10k for example, so, taking account of the reduced efficiency when operating from a single 9V supply rather than a dual 15V supply, signals of over two volts peak to peak may clip. When the battery is exhausted, the 5532 may only manage two volts peak to peak into a high impedance. This should be adequate for most purposes, but if it is not, the project may easily be adapted to give more output.

If the box is operated with 300R output resistors into a terminated 600R line, the output signal will be potted down by 2:1. To compensate for this, voltage gain is provided by the addition of optional components R4 and C2. Equally, if the input signal is of a very low level, adding these components will boost it to a level considerably above the of the interference picked up on the line. This is particularly useful to prevent buzz from phase controlled lights being audible on microphone circuits. For the purpose of driving a balanced line, a voltage gain of two times is required.

In order to gain the greatest benefit from the DI box, its output should be fed into a balanced (or differential) input. Unfortunately, the equipment you use it with may not have a differential input, but read on.

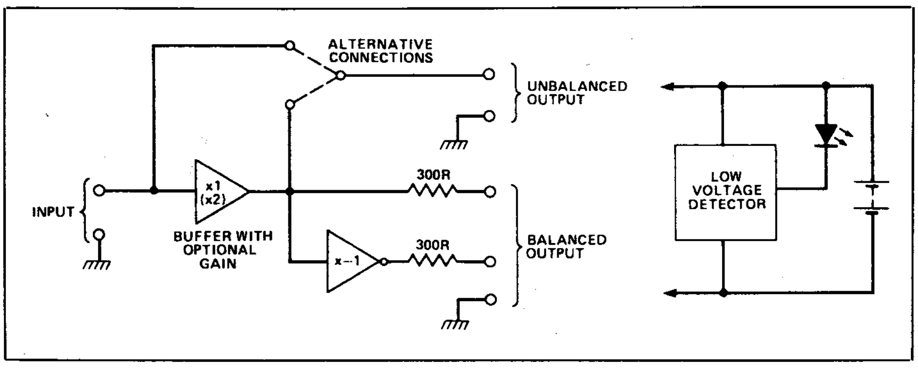

Fig. 1 The block diagram of the direct injection box.

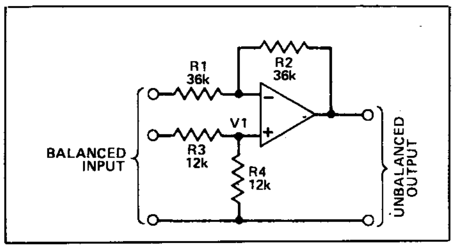

Fig. 2 A standard differential input arrangement.

The circuit in Fig.2 shows the conventional configuration of a differential receiver. Most text books show all four resistors in the circuit to be of equal value, but that is not always the best way to do things. At first glance, it would appear that the impedance on the non-inverting input is R3 + R4, while that on the inverting input is R1. This is not so. If the op-amp is working linearly (ie not clipping) then for all practical purposes, the voltage on the inverting input of the op-amp is the same as that on the non-inverting input.

First of all, the differential impedance of the circuit shown is correct, but the common mode impedance is not balanced. The addition of 300R load resistors will swamp any differences and the best performance will be obtained. The second reason is that the op-amp would be required to drive heavy currents into its feedback resistors if low value resistors were used around the op-amp, and this would restrict the output swing.

Power Consumption

The one drawback of the excellent NE5532 dual op-amp is that its current consumption is quoted as eight milliamps typical, sixteen maximum. If the DI box is to be used with reasonably large signals and not into a low impedance load, it may be preferable to use the LM358 op-amp in order to cut the power consumption. The gain bandwidth product of this device is only 1MHz, so there is not a lot of scope for providing voltage gain without the risk of slight degradation of sound quality.

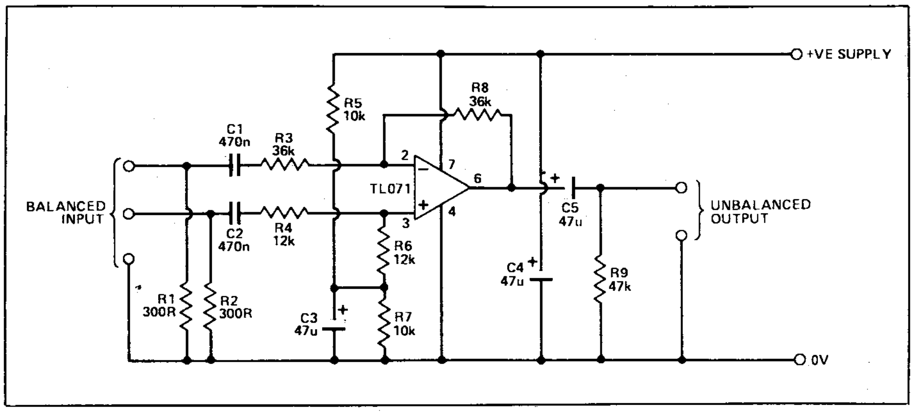

Fig. 3 A practical circuit for a differential input stage.

The non-inverting input has half the positive signal voltage, and since the inverting input has the same signal present, resistor R1 has a voltage across it equal to half the positive input signal plus the negative input signal. The signals are meant to be balanced, so the voltage across R1 is 1.5 times the negative input signal. The current flowing in this resistor is therefore 1.5 times as high as would be expected if R1 were feeding a virtual ground point, so the apparent impedance is 1/1.5 times the value of R1. Therefore R1 should have a value of 1.5 times the desired input impedance. Another way to visualize this is to think of the virtual ground point as being one third of the way along the resistor from the inverting op-amp input to the input signal.

The component values shown in this circuit are for a 48k input impedance, 24k on each line. should a 600R input impedance be required, it is best to use 300R resistors to load the input, rather than using very low value resistors around the op-amp. There are two reasons for this.

How it Works

IC1A works as a buffer with selectable gain, R4 and C2 being added only if voltage gain is required. The offset voltage on the inputs is minimized by having a similar net DC resistance on each input. The output of this buffer drives the in-phase output and also a unity gain inverter, IC1B, which in turn drives the other output. Both outputs have their impedance set by series resistors and are DC blocked by electrolytic capacitors. The capacitors are polarised by load resistors R11 and R12

The low battery detector is based on a purpose designed IC which contains a very low current band gap voltage reference, a comparator, and a current limited output drive circuit. For this reason, the LED needs no current limiting resistor.

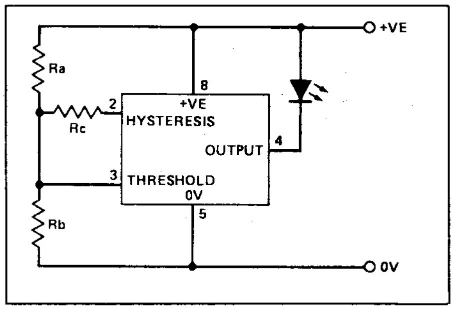

Fig. 4 The low voltage warning circuit using the 8211 micro power sensor.

Another alternative would be the TL072 which has a gain bandwidth product of 3MHz and a noise figure of $18nv/\sqrt{Hz}$, both of which are quite acceptable. This is a BiFET device, so it would be possible to use a very high input impedance if necessary, a megohm for example. The maximum current consumption of this is 5mA total, so the battery life should be reasonable.

If the application requires substantial voltage drive into a 600R load, the DI box may be constructed with 25V rated electrolytic capacitors and powered from two 9V batteries in series. There is not room in the case of the prototype unit for another battery, so a large sized case would have to be used. The low battery warning would have to be recalculated to work at a different voltage as well, of course, in order to give warning before the unit stopped working correctly, rather than afterwards.

Low Battery Alarm

This part of the circuit uses the 8211 micropower sensor. This handy chip draws a quiescent current of about 25uA and provides a current limited LED drive which switches on when the voltage on its threshold input falls below 0.15 volts. Referring to Fig. 4, the threshold voltage for the LED to switch off is given by the formula:

$$V = 1.15 \times \frac{Ra + Rb}{Rb} \text{ volts}$$

Hysteresis is added by Rc (R14 in the final circuit), but if this is not required pin 2 should be left open circuit.

The addition of hysteresis does not affect the switch off voltage but the switch on voltage is lowered. This voltage is calculated from the formula:

$$V = \left(\frac{Ra \times Rc}{Ra + Rc} + Rb\right) \times \frac{1.15}{Rb}$$

The component values specified in the circuit diagram give nominal switching voltages of 6.55 (off) and 5.60 (on). If this end of life voltage is too low, it may be raised by reducing Rb in the sensing circuit.

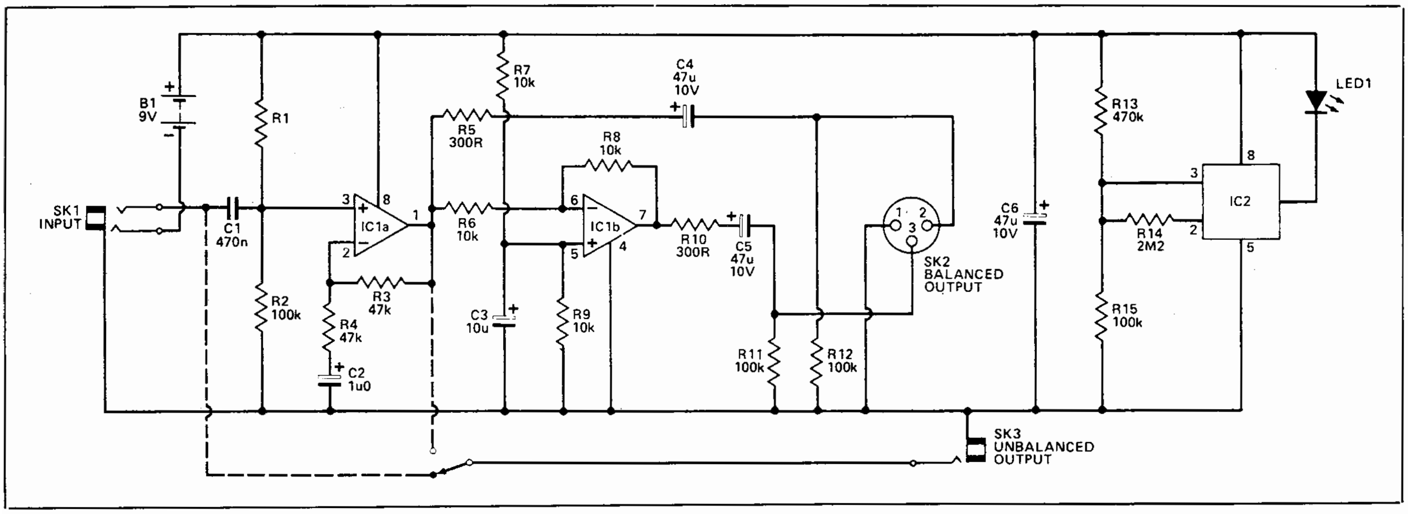

Fig. 5 Complete circuit diagram of the direct injection box.

Construction

Before starting to assemble the DI box, you must decide which of the various circuit options you wish to incorporate. Some of these will affect your choice of components while others, like the choice of unbalanced output take-off point, will only involve wiring changes. The components which may be affected are all marked in the parts list. SK1 is specified as a stereo jack socket even though the signal is mono, the extra connection is used to connect the battery negative to the PCB when the input is plugged in. The rest of the assembly is straightforward; Fig. 7 shows the suggested layout within the case.

Testing

If a regulated power supply is available it should be used for initial testing. Set the power supply to about 4V, if the LED does not light, then reverse its connections and try again. Once the LED works, increase the voltage until the LED goes off, then reduce it until the LED switches on again. Measure the voltage and check that it is about 5.6V. Individual units may vary due to component tolerance, but if the voltage is not acceptable the value of R13 or R15 should be changed.

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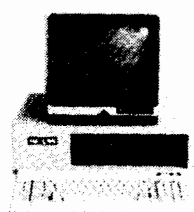

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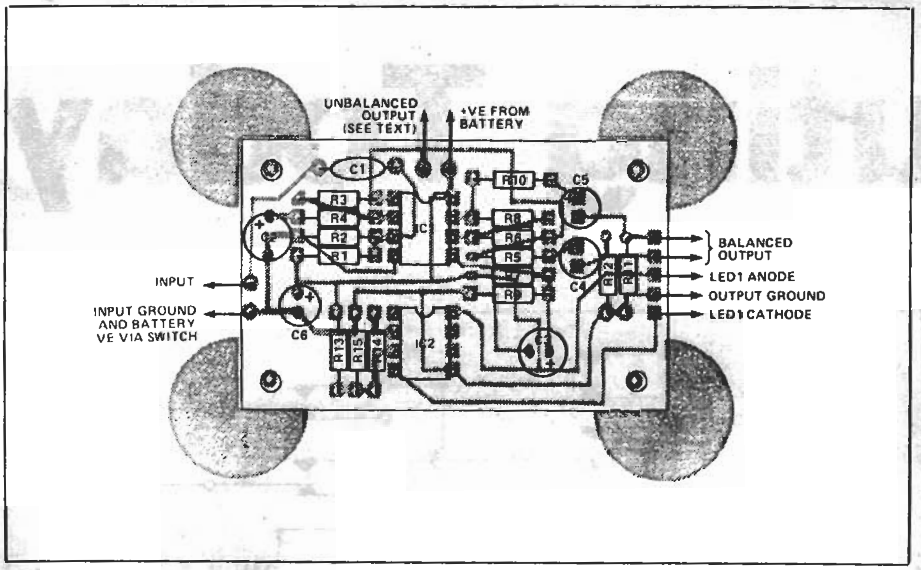
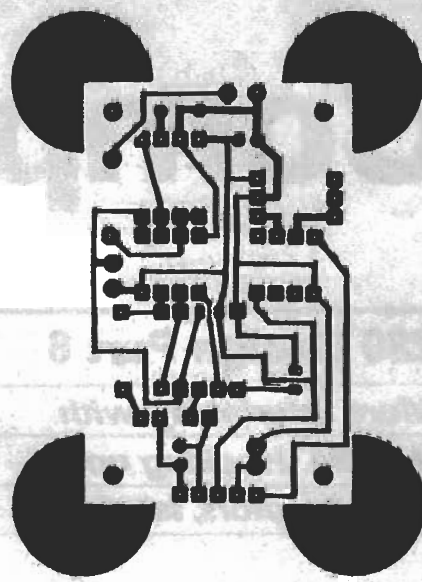


Fig. 6 The component overlay for DI box.



PCB for the DI box.

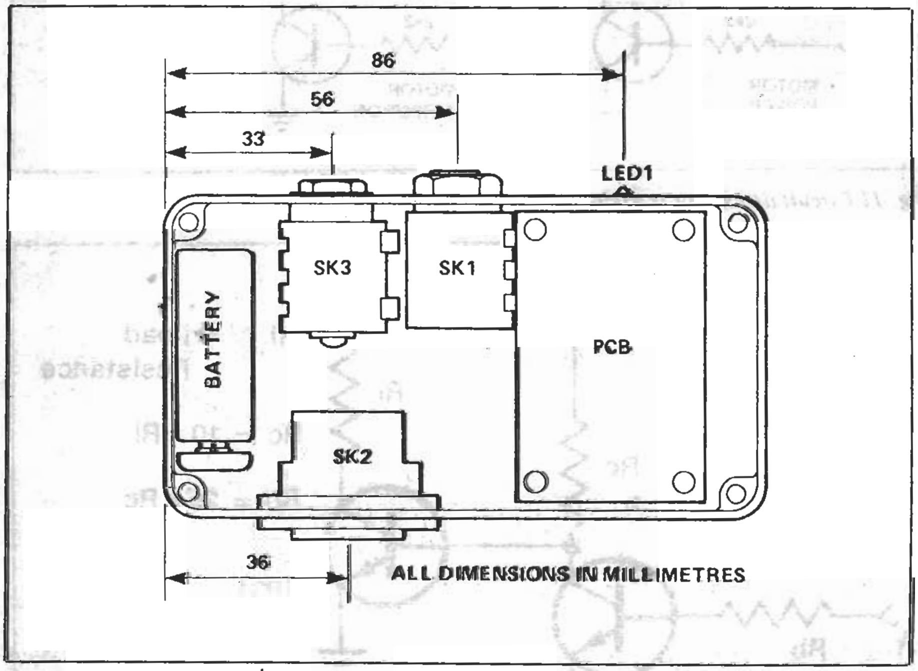


Fig. 7 Layout of the major components within the case.

Now apply 9V, either from a battery or from the power supply, and use a voltmeter to check that the op-amp output pins are at about 4.5V and that the outputs are at 0V. If they are not, the most likely fault is a reversed electrolytic capacitor. Finally, connect up a signal source and a suitable amplifier and check that everything works correctly and that the sound is what it should be.

A practical circuit for a differential input is shown in Fig. 3. The 300R input resistors are optional but should be included if the input is connected to a 600R balanced output. The power may be drawn from any DC source with a voltage in the range 6-30V or a dual rail supply could be used and the biasing component omitted. If the arrangement is to be battery powered, it might be an idea to include a low voltage monitor of the type used in the main DI box.

Parts List

Resitors
(¼ W 5% unless otherwise stated)

R1,2,11,12,15	100k
R3	47k
R4	47k (see text)
R5,10	300R 1%
R6, 8	10k 1%
R7,9	10k
R13	470k
R14	2M2 (see text)

Capacitors

C1	470n polyster
C2	1u0 tantalum (see text)
C3	10u 10V radial electrolytic
C4,5,6	47u10V radial electrolytic

Semiconductors

IC1	NE5532 dual op-amp
IC2	ICL8211 micropower sensor

Miscellaneous

SK1	¼" stereo jack socket
SK2	XLR 3-pole chassis plug (XLR-3-32 or equivalent)
SK3	¼" mono jack socket

PCB: die cast box, approx 110 x 60 x 30mm; panel-mounting bush for LED1; battery connector; nuts and bolts to mount SK2 and the PCB.