LONDON OPERATIONAL AMPLIFIER BOARD

099.910 4mm version 099.911 2mm version

INTRODUCTION

The London Operational Amplifier Board is designed to fulfil the requirements for teaching analogue electronics in the University of London syllabuses. It covers study of the operational amplifier in the Analogue Electronics option of the A level Physics syllabus and in the AS Electronics Syllabus. The use of the London Operational Amplifier Board is not confined to these syllabuses. The board is suitable for a wide range of syllabuses including the Revised Nuffield Advanced Physics. In particular, the provision of the power amplifier on the board enables it to drive useful loads such as a lamp or a loudspeaker.

The Revised Nuffield Advanced Physics Teachers' and Students' Guides for Unit I give invaluable explanation about operational amplifiers and hints for experimental work.

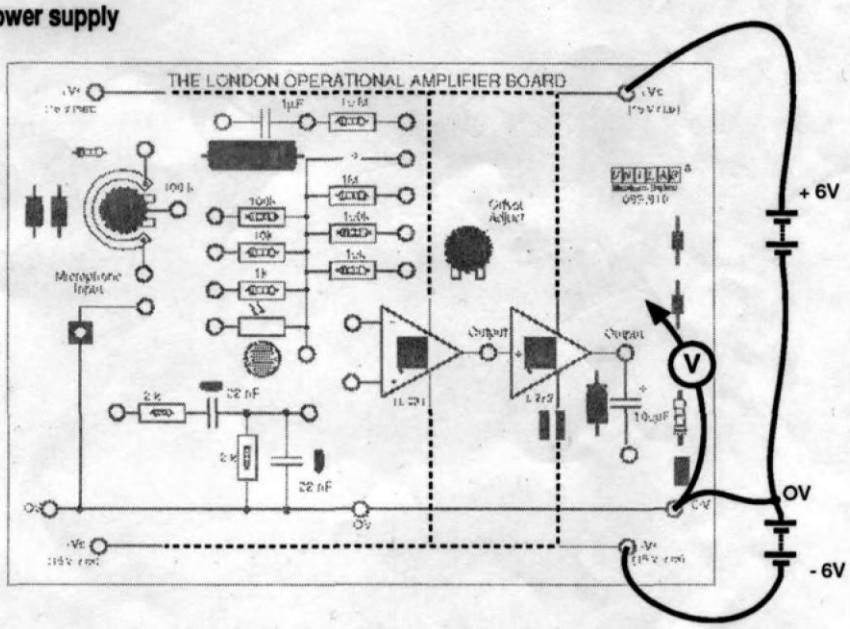
POWER SUPPLIES

No special power supplies are required for use with the Board. For many experiments, a four cell holder with four x 1.5V cells (092.023) is adequate and will provide ± 3V. For experiments where the power amplifier is used, it is better to use two sets of four x 1.5V dry cells to give ± 6V. If mains powered operation is required, a power supply such as the Unilab Variable Dual 15V Regulated Power Supply, (022.110), may be used.

If dry cells are used as the power supply, they should be tested before use. Short circuit each cell in turn through a 10A meter. (This test must not be performed on rechargeable cells.) Adequate cells give a short circuit current of at least 1A.

First connect the power supply. Figure 1 shows the connections together with a voltmeter connected to the 0V line. It is useful to leave a voltmeter permanently connected to the circuit to test the power supply as well as to carry out other measurements. If at any stage an experiment fails to work, the first test that should be made is to check that +Vs is positive and that -Vs is negative.

Fig 1 Connecting the power supply



The power supply is connected to both operational amplifiers. In figure 1, the dotted lines show how these connections are made.

In the circuits that follow, no power supply is shown, in common with standard operational amplifier convention.

INTRODUCING AMPLIFIERS

We are used to encountering the term *amplifier* in connection with high fidelity equipment or perhaps a public address system. For these purposes, an amplifier is used to make a sound louder. This is a useful context in which to introduce the operational amplifier.

A note on loudspeakers and microphones. For the experiments that follow it is assumed the 65 Ω Loudspeaker, (011.140), is used together with the Moving Coil Microphone, (035.142). In fact better results can be obtained by using the 65Ω Loudspeaker as both microphone and loudspeaker. (This loudspeaker works well as a microphone.) For very effective demonstrations, use the 8Ω loudspeaker, (011.142), as the loudspeaker. Note that crystal microphones, e.g. 035.141 should <u>not</u> be used.

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Figure 2 shows a failed attempt to make a public address system or intercom. A microphone is connected directly to a loudspeaker. When a sound is made near the microphone, an electrical signal is produced. This electrical signal is connected to the loudspeaker and should make the coil move. In fact the electrical signal produced by the microphone is not large enough to drive the loudspeaker. Such an intercom will *just* work. Shouting loudly in the microphone will produce a faintly audible sound in the loudspeaker. It is best if the loudspeaker and microphone are connected together by very long cables and in separate rooms to test this.

Fig 2 A failed attempt to make an intercom

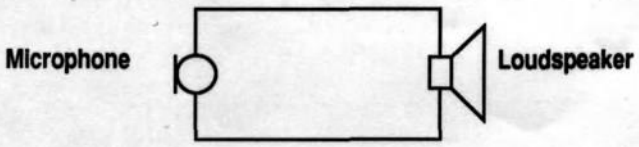
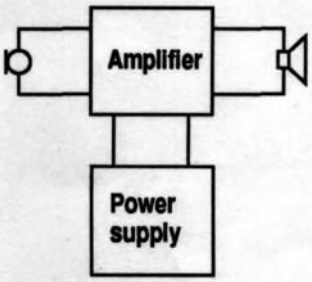


Fig 3 A block diagram of an amplifier

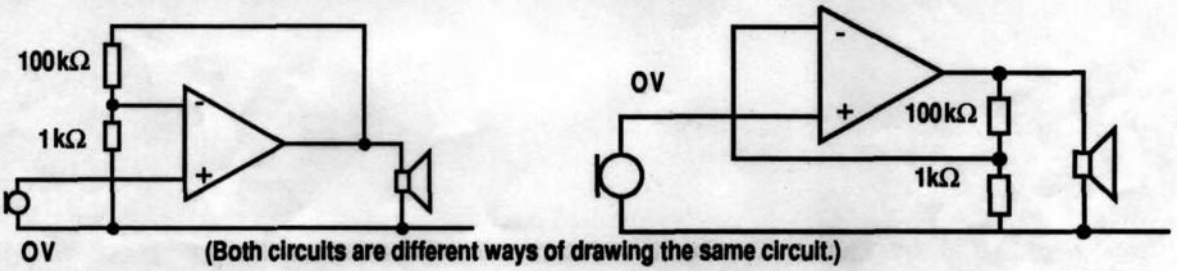


Since the microphone is not capable of driving the loudspeaker directly, some intermediate device is required. A transformer may suggest itself. But a transformer gives a reduced current at the same time as a larger voltage or vice versa. What we need is a device that will give out both a larger voltage and a larger current, that is more power than the input it receives from the microphone.

Figure 3 shows the block diagram of the system we require. The microphone is connected via an amplifier to the loudspeaker. The power supply for the amplifier, as its name suggests, is the source of the power for the loudspeaker.

Figure 4 shows a very simple way of making an audio amplifier with the London Board. Two ways of drawing the same circuit are given. Both are in common use.

Fig 4 A simple audio amplifier

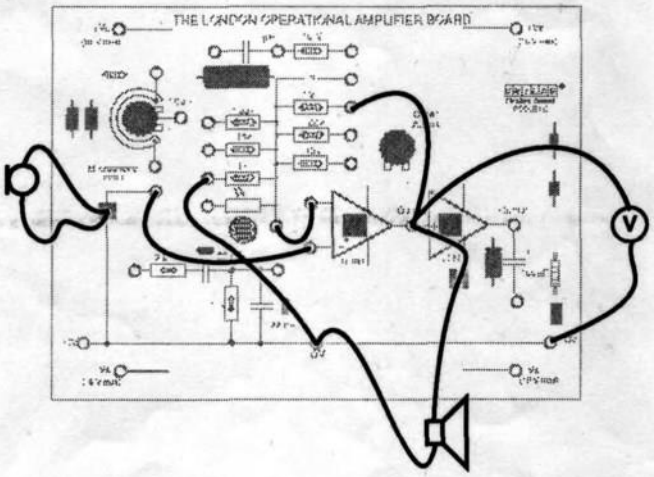


(Both circuits are different ways of drawing the same circuit.)

SETTING THE OFFSET ADJUSTMENT.

When the circuit of figure 5 is first set up, it may not amplify if the offset adjustment is incorrectly set. The voltmeter shown in the circuit can be used to make the adjustment. Set the circuit up as in figure 5. Then adjust the offset control until the output of the first operational amplifier is zero. The circuit should then amplify. Further adjustment of the offset is usually unnecessary.

Fig 5 A simple audio amplifier: The connections to the board



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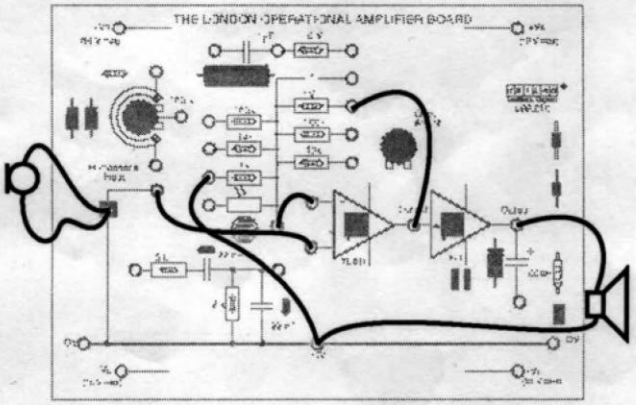
USING THE POWER AMPLIFIER

Fig 6 Using the power amplifier



The first operational amplifier on the Board is a TL081 operational amplifier. It is capable of driving a loudspeaker with a reasonable volume. But the L272 power operational Amplifier is capable of supplying much larger currents. When the circuit of fig 5 is working, transfer the loudspeaker connection to the output of the power amplifier (fig 6). Significantly more current is available from this amplifier (1 A max) and a significantly louder sound can be made. A large 8Ω loudspeaker is particularly effective in this circuit.

At some stage it may be noticed that acoustic feedback occurs if the microphone is too near the speaker. Sound picked up by the microphone is amplified and fed to the loudspeaker. From there it gets back to the microphone. Continuous howls occur if the *loop gain* of the circuit is more than 1 (i.e. if a signal is larger once it has been all round the loop than when it set out). For oscillation to occur it is also necessary that the *phase shift* of a signal having travelled around the circuit is a multiple of 2π, so that it is in phase with the next signal setting out. These two conditions are worth mentioning if the Wien oscillator is to be studied later.

The circuit of figure 6 is the standard method of using the power amplifier. First set up the desired circuit with the first operational amplifier on the board, enclosing that amplifier only in the feedback circuit. Then use the power amplifier to boost the output from the first stage. The power amplifier has a voltage gain of 1. It gives the same output voltage as the input voltage. But it is capable of supplying much larger currents.

CHANGING THE GAIN OF THE AMPLIFIER

The circuit of figure 6 can be used to investigate the factors affecting the gain of the operational amplifier. Change the input resistance from 1 kΩ to 10 kΩ (fig 7a). The gain of the amplifier decreases. Experiment with a range of input resistors. Use the LDR on the board as a variable resistor. The gain of the circuit is then controlled by the level of illumination of the LDR (fig 7b). Insert the 100 kΩ variable resistor in series with the 1 kΩ resistor to make a circuit with variable gain (fig 7c). Figure 8 shows how this circuit is set up on the board.

Fig 7a

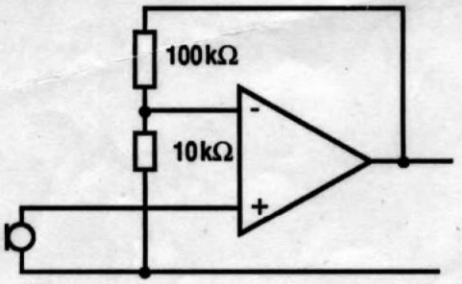


Fig 7b

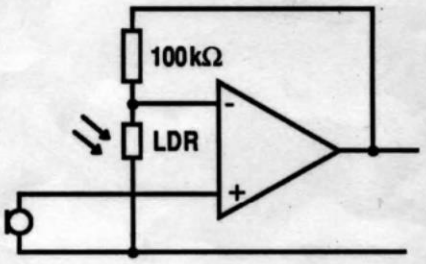


Fig 7c

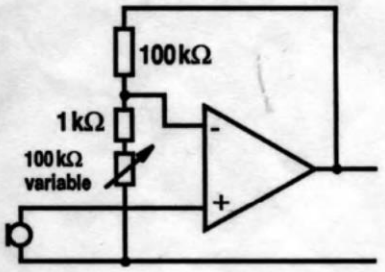
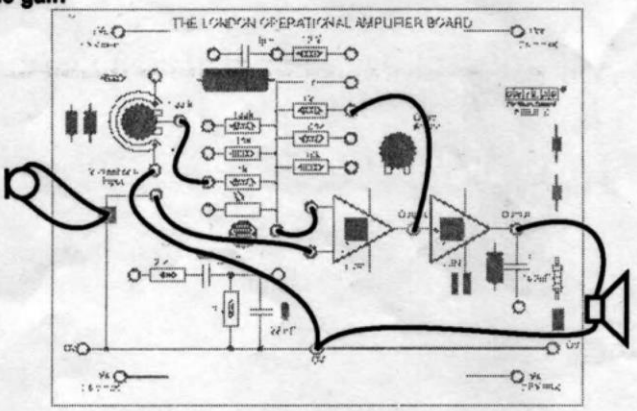


Fig 8 Audio amplifier with variable gain



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A series of such experiments shows that the gain of this circuit is controlled by the pair of resistances connected to the amplifier. If we label the resistances R_1 and R_2 (figure 9), the gain of the circuit, $V_{out}/V_{in} = 1 + R_2/R_1$.

Fig 9

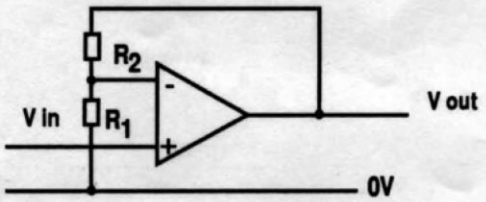
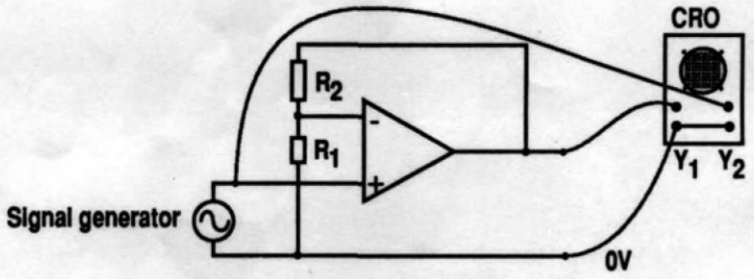


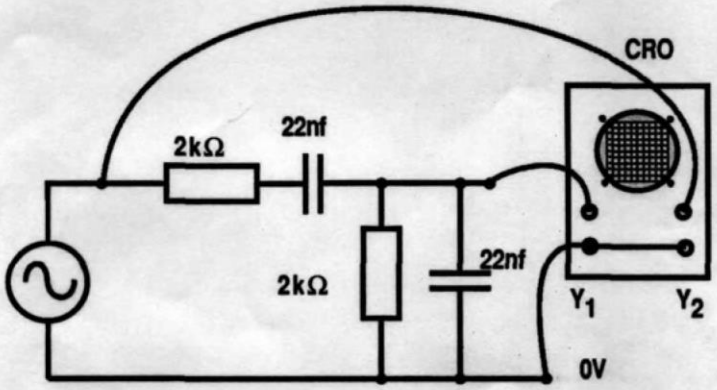
Fig 10 Measuring the gain of an amplifier



A common method of measuring the gain of an operational amplifier circuit uses two voltmeters (fig 22). The method is described in the Revised Nuffield Advanced Physics Students' Guide 2 pp106ff. Alternatively an oscilloscope and signal generator may be used in an a.c. method. A double beam oscilloscope makes this particularly easy (fig 10). Measure the ratio of the heights of the output signal to the input signal.

INVESTIGATING A FREQUENCY DEPENDENT NETWORK

Fig 11 Investigating the Wien network



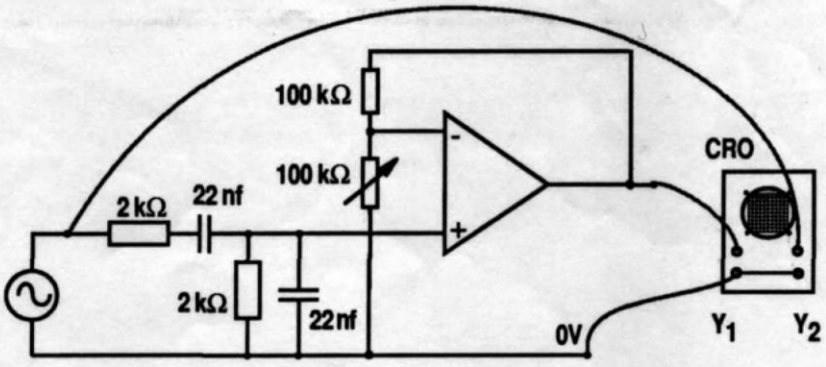
A Wien (pronounced *veen*) network is fitted to the London Operational Amplifier Board. This network has characteristics that depend on the frequency of alternating signals applied to it. Fig 11 shows a circuit that can be used to investigate the Wien network. It may be useful to compare this circuit with figure 10. Both the amplifier of fig 10 and the Wien network of fig 11 process an alternating signal. The amplifier increases the size of the signal: the Wien network decreases the size of the signal. But whereas the action of the amplifier is independent of frequency (except at comparatively high frequencies) the Wien network's response varies with frequency. At a frequency given by $f = 1/2\pi RC$, where $R = 2k\Omega$ and $C = 22nF$ for the circuit on the Board, the output of the Wien network is in phase with the input. And at that same frequency, the gain of the Wien network is a maximum of 1/3. (This 'gain' is of course a loss. The output of the Wien network is less than the input. But we should expect the circuit to introduce losses since it contains no amplifier.)

It is instructive to take measurements over a wide range of frequencies and plot a graph of gain against frequency.

MAKING AN OSCILLATOR

At one frequency only, f_{max}, the gain of the Wien network is 1/3. At other frequencies, the gain is less than this. Let us consider what will happen if we connect an amplifier to the Wien network which has a gain of 3. This means that at f_{max}, the whole circuit will have a gain of 1. Fig 12 can be set up to check this. The 100kΩ variable resistor can be adjusted around the mid position (50kΩ) so that the gain of the amplifier compensates for the loss of the Wien network at f_{max}.

Fig 12 An amplified Wien network



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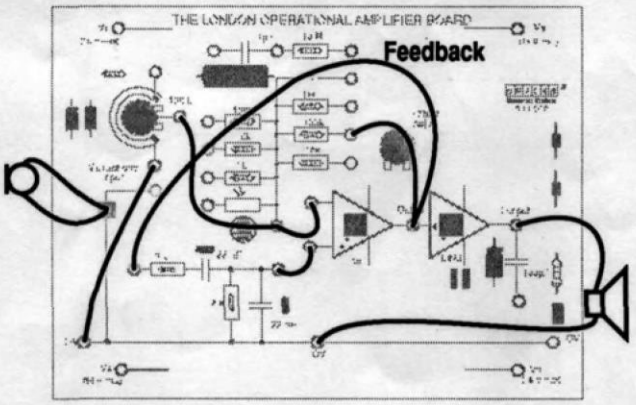
The circuit of fig 12 can easily be converted to an oscillator. Since the output is the same as the input, the output can be connected to the input to provide the circuits own input. No input from the signal generator is required, the circuit will oscillate at f_{max}. Slight adjustment of the 100kΩ variable resistor will be required so that the circuit is just on the point of oscillating. The layout of this circuit is shown in fig 13. The loudspeaker is connected to the power amplifier to enable the oscillating signal to be heard.

This circuit has electrical feedback that is similar to the acoustic feedback observed earlier. The conditions for oscillation are the same, that is, the loop gain must be greater than 1 and the phase shift around the loop must be an integer multiple of 2π. This latter condition is achieved because the amplifier introduces no phase shift and nor does the Wien network at f_{max}.

Fig 13 A Wien Oscillator



FURTHER INVESTIGATIONS

The above instructions introduce common amplifier and oscillator concepts and give familiarity with the London Operational Amplifier Board. Such a sequence might be considered an adequate introduction to operational amplifiers for many pupils. But further investigations into other circuits are possible. The diagrams below give arrangements for further investigations. For most of the circuits, the layout of the board is given and it is left to the reader to draw the conventional circuit diagram.

Two additional points about the board are worth noting. First, a space is provided on the resistance ladder for the connection of an additional component. This is to suit the needs of individual schools and courses. Secondly, a coupling capacitor is connected to the output of the power amplifier. This may be used ensure that no direct current passes through the output load and for teaching about coupling capacitors.

Fig 14 Inverting audio amplifier

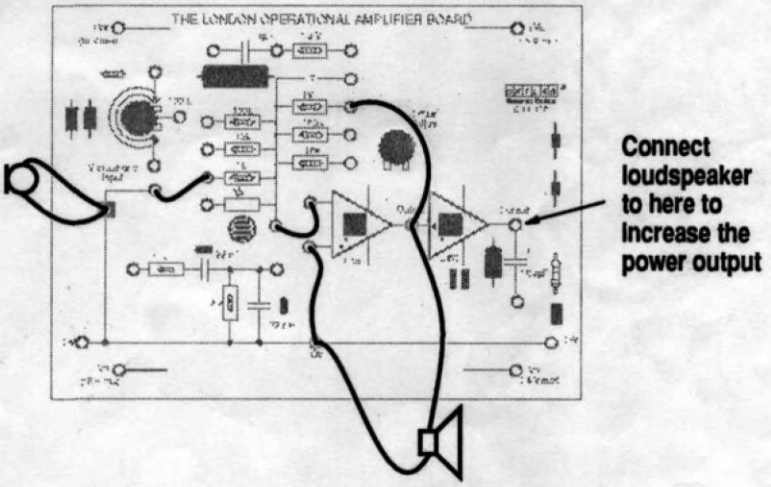


Fig 15 The voltage follower

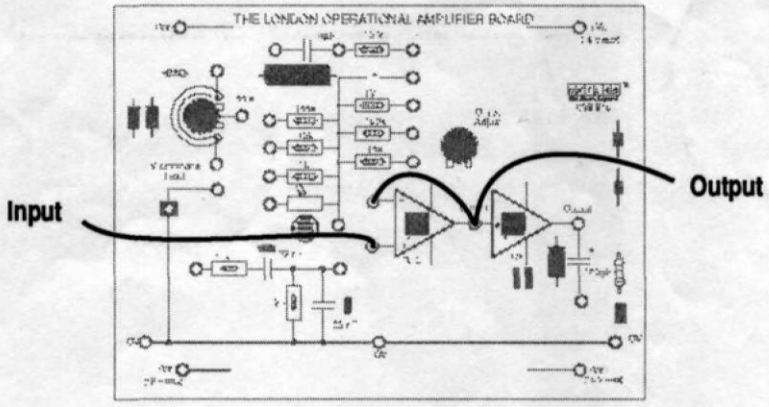


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Fig 16 The voltage follower used to measure the p.d. across a capacitor, i.e. to measure the charge on a capacitor. This is a simple coulombmeter

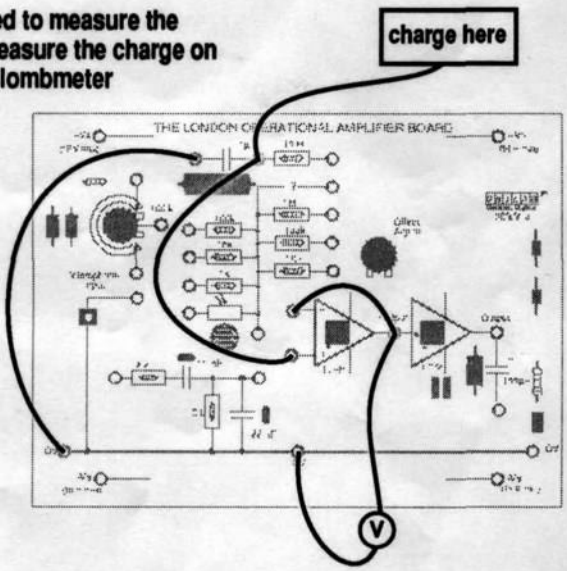

Fig 17 The voltage follower measuring the p.d. across a known high resistor:- i.e.as a nanoammeter

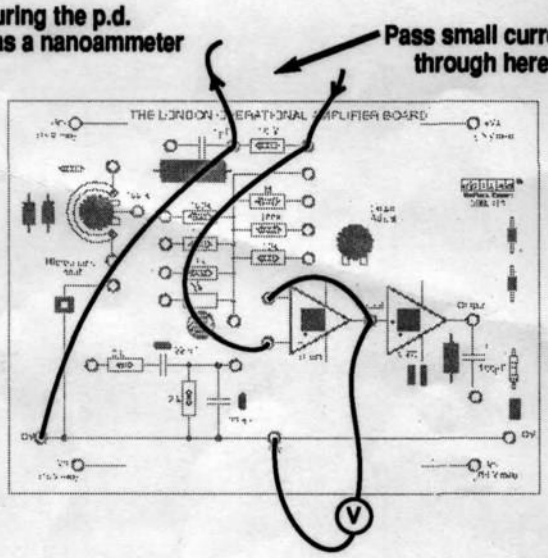

Fig 17a Measuring the ionisation current of a flame

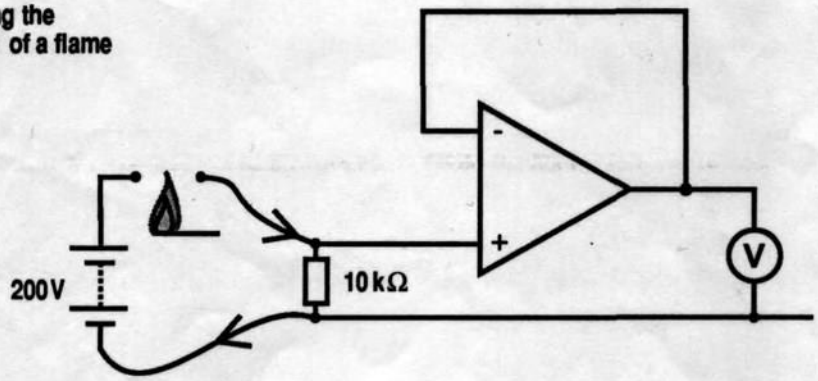

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Fig 18 Comparator used to control a lamp

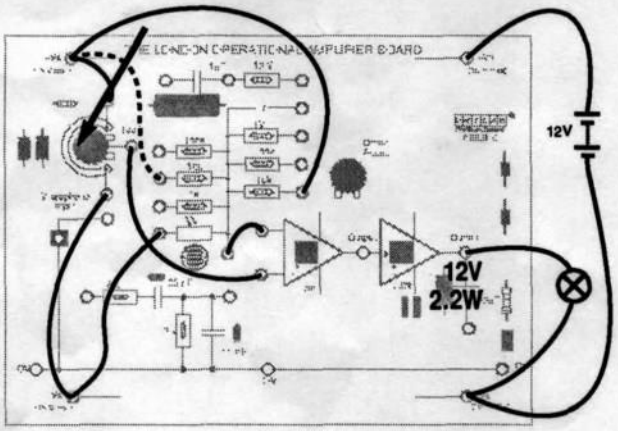


Fig 18 a

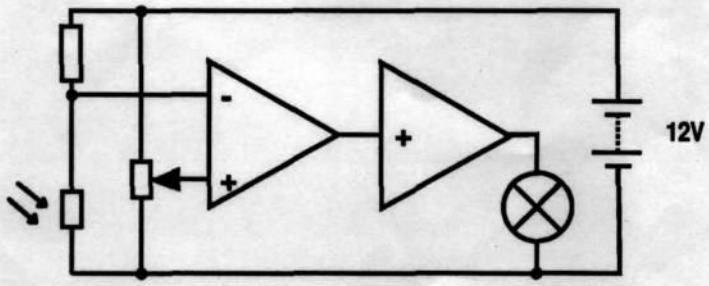


Fig 19 Investigating the Schmitt trigger.

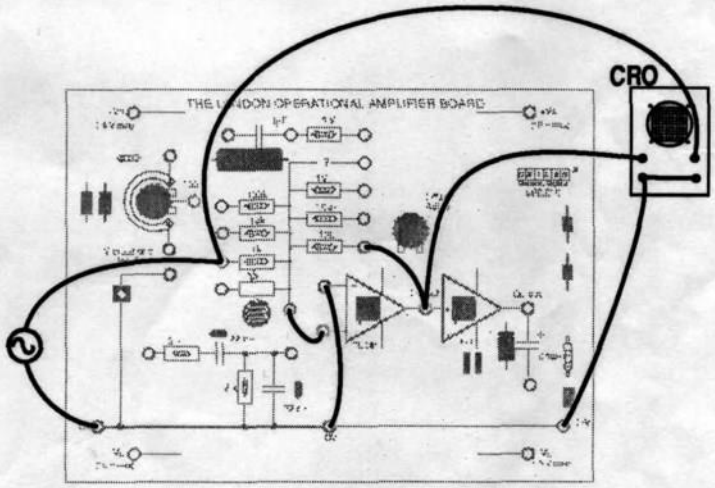
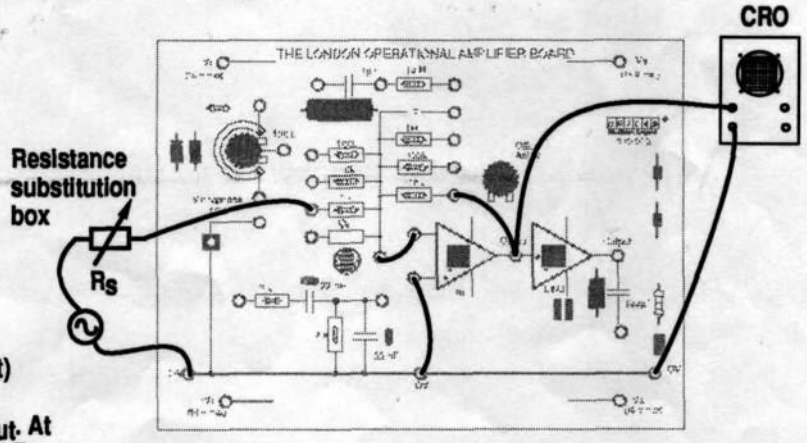


Fig 20 Measuring the input resistance of an amplifier.



Signal Generator (use low impedance output)

Set R_S to zero. Measure V_{out}. At this point input resistance = R_S

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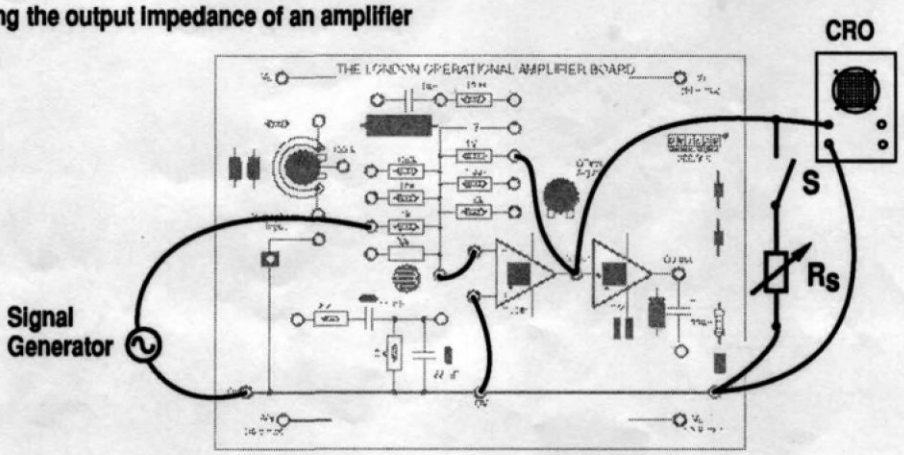
Fig 21 Measuring the output impedance of an amplifier

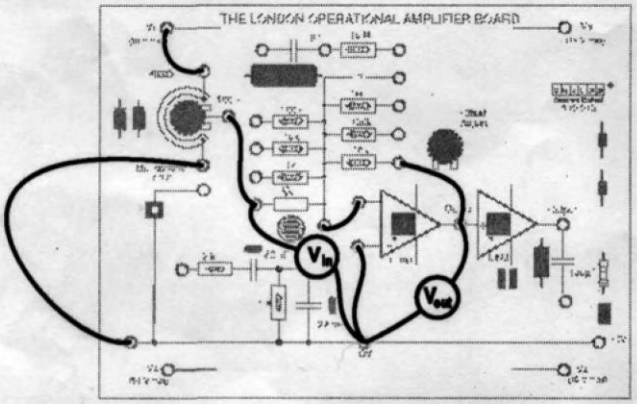


Close S, adjust R_S so that signal is not quite distorting. Measure Vout. Open S measure Vout.

$$V_{out} = V_{out} \times \frac{RS}{RS + \text{Internal Resistance}}$$

N.B, Only at high gains is the output resistance significant. at low gains it is too small to measure.

Fig 22 Using voltmeters to measure the gain of an amplifier.



ASSOCIATED EQUIPMENT

011.140	Loudspeaker (65 ohm)
011.142	Loudspeaker in enclosure (8 ohm)
022.110	Variable Dual 15 V Regulated Power Supply, 1.5 A
035.142	Moving-Coil Microphone (dynamic)
092.023	4 Cell Holder, for SP2

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