GHOST BUSTER

ANDY FLIND

Spooky feelings all around you? Track down their source!

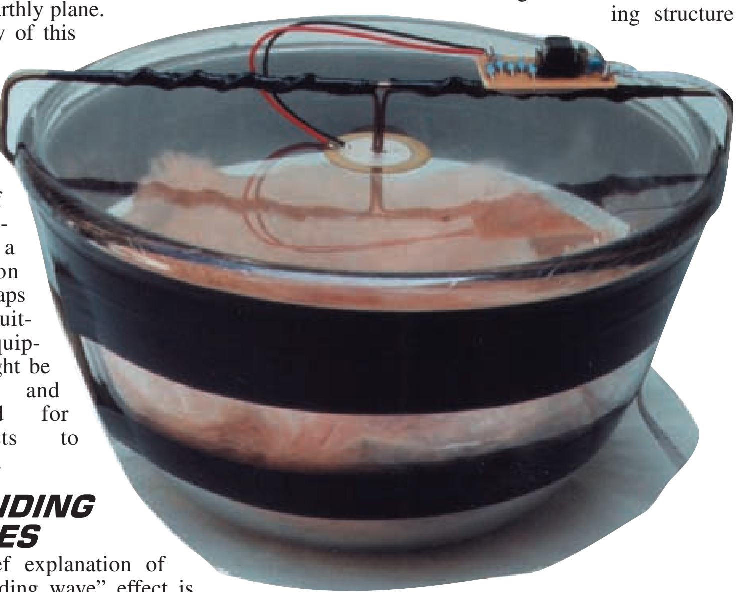
SOME time ago, an interesting manuscript was received at the *EPE* Editorial office. The author, Vic Tandy, had apparently heard that his workplace was haunted, but as a confirmed sceptic in ghostly matters had dismissed it as colleagues' imagination. Until that is, he had occasion to work late one night.

Suddenly he experienced all the phenomena associated with the supposed haunting: the hair standing on the back of the neck, a feeling of being watched by another "presence", a deep sense of unease . . .

Some time later, quite by accident, he discovered the presence of strong sub-audio "standing waves" in the air of the affected premises. The source of these was subsequently traced to an extractor fan. Modifications were made to prevent the formation of the standing waves from this fan and the apparent "haunting" promptly ceased.

The obvious conclusion was that serious ghost hunting enthusiasts should include a test for such standing waves to the "armory'' of physical checks they already use in order to establish that the "ghost" they are investigating is not due to some simple physical effects generated on this earthly plane.

A copy of this manuscript was sent to Andy Flind, the author of this article, with a suggestion that perhaps some suitable equipment might be designed and presented for enthusiasts to construct.



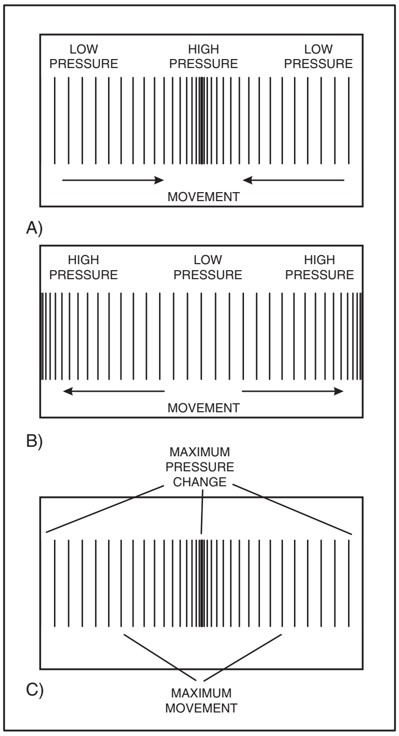


Fig.1. Simplified explanation of standing wave effect.

STANDING WAVES

A brief explanation of the "standing wave" effect is appropriate before continuing. Any hollow space filled with air will have at least one, and often several, resonant frequencies. Usually we're not aware of this because the spaces we occupy are often relatively small, not well-shaped for efficient resonance and contain carpets, curtains and other soft furnishings, which tend to damp down any oscillation of the air contained in them.

Rooms without such furnishings often demonstrate some resonance though, which explains why bathrooms have always been so popular with would-be opera stars! Larger rooms, such as concert halls, often suffer from resonance to the point where it causes serious problems, and there is a whole science devoted to the control of its effects in such places.

Here though, we are describing resonance at audio frequency. Some sizes and shapes of space will have resonances below the audio range. Such low frequencies cannot be heard, but may have other undesirable manifestations, such as the ghostly effects described earlier.

BAD VIBRATIONS

The author recalls hearing some years ago of a case where the staff of a large office building suffered endless headaches and nausea, leading to high sickness rates which caused their employer much difficulty. The cause was eventually traced to a strong vibration in the building structure at just seven hertz, which was duly fixed, curing the sickness problems.

A "standing wave" consists of a body of air literally expanding and contracting, bouncing back and forth at a resonant frequency determined by its elasticity and the physical dimensions of the space in which it is confined. It follows that at some points within the space it will be moving a great deal, whilst at others it will be more or less still, but experiencing pressure changes.

FUNDAMENTAL WAVEFORM

There will be a fundamental frequency, but other, higher "harmonic" frequencies may also be present. Fig.1 shows one possible form of this effect.

In Fig.1a the air is moving towards the centre, leading to high pressure here and low pressure at the walls. In Fig.1b it is bouncing back again, causing low pressure at the centre and high pressure at the walls. It can readily be seen that there are points where there will be large movements of the air but little pressure change, and other points where there will be less movement but large pressure changes.

There would have to be some motivating cause for the oscillation, which could take almost any form. Extractor fans, resonant vibrations of the building structure, perhaps some effect due to wind, might all serve as prime movers. Logic suggests that in all cases, an area of little movement but high pressure change should be found close to at least one of the boundaries, or walls of the space.

"MIC"-ING THE BOWL

In constructing a device to detect such waves, three problems had to be tackled. The first concerned the microphone. An ordinary electret or similar microphone cannot be used as most of these do not operate much below 100Hz. In fact it would be a disadvantage for a microphone intended for audio use to operate below the audio frequency range, so even the best professional microphones would be unlikely to do so.

A suitable microphone had to be designed and constructed for the job. It seemed, too, that it should be simple and inexpensive to make, as well as being very sensitive at low frequencies.

After numerous experiments with various techniques the design shown in Fig.2 was arrived at. This consists of a 7-inch (18cm) diameter Pyrex glass mixing bowl with some wadding glued inside it for damping, and a cling-film (yes, cling-film) diaphragm stretched across the top. Cling-film sticks quite well to glass, but plastic insulation tape was added to secure it, see photograph opposite.

A "bridge" of stout iron wire from a coat-hanger was bent to fit across the top above the cling film and taped into place on the bowl. Some single-core insulated wire was shaped to form a "nib" pointing down into the centre of the diaphragm. This was taped to the bridge, slipping a piezo disc sounder beneath it to act as a transducer to sense vibrations picked up by the film diaphragm. These transducers make excellent microphones, with a high output and good sensitivity well into the audio range.

A pinhole was pierced in the cling-film close to the edge of the bowl to allow air pressure inside to equalise slowly with the general atmospheric pressure outside. This arrangement detects pressure change rather than movement, as variations in air pressure cause changes in the volume of air behind the diaphragm, moving the diaphragm as they do so.

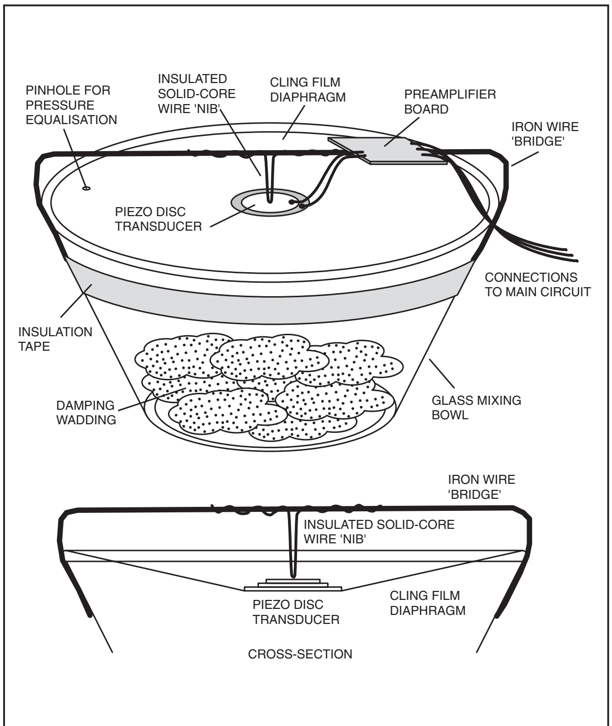


Fig.2. Suggested method of construction for a simple, low-frequency microphone using a piezoelectric disc transducer, a coat-hanger and a glass mixing bowl.

COMPONENTS

Resistors

R1 to R4	1M (4 off)
R5, R6	10k (2 off)
R7, R10, R11, R14, R18, R19, R24	10k (7 off)
R8	100k
R9	47k
R12	1k
R13	27k
R15, R17	2k2 (2 off)
R16, R25	1k2 (2 off)
R20	560Ω
R21	82k (2 off – see text)
R22	22k
R23	33k
R26	390Ω

All 0·6W 1% metal film.

See SHOP TALK page

Potentiometers

VR1	10k 22-turn cermet preset, vertical
VR2, VR3	10k rotary carbon, lin (2 off)
VR4	10k rotary carbon, log

Capacitors

C1, C3, C5, C6, C8, C9	100n ceramic, resin-dipped (6 off)
C2	22n ceramic, resin-dipped
C4	10µ radial elect. 16V
C7	470µ radial elect. 16V

Semiconductors

TR1	BC184L *npn* transistor
IC1, IC2	TL082 f.e.t. dual op.amp (2 off)
IC3	LP2950 micropower +5V voltage regulator
IC4	3914 linear bargraph display driver
IC5	OP296 CMOS dual op.amp
IC6	7556 CMOS dual timer
IC7	LM358 dual op.amp

Miscellaneous

S1	s.p.s.t. toggle switch
S2	s.p.d.t. toggle switch
X1	10-segment l.e.d. bargraph display
MIC1	piezo disc sounder, 27mm 1·8kHz resonance (see text)

Printed circuit boards, available as pair from the *EPE PCB Service,* code 326 (Mic.) and 327 (Main); 8-pin d.i.l. socket (4 off); 14-pin d.i.l. socket; 18-pin d.i.l. socket; 20-pin d.i.l. socket; 7-inch (18cm) diameter glass mixing bowl, cling film etc.; 9V battery, battery holder and connector; plastic case (see text); control knob (3 off); connecting wire; solder, etc.

Approx. Cost Guidance Only **£30** ***excl. case, bowl & hanger***

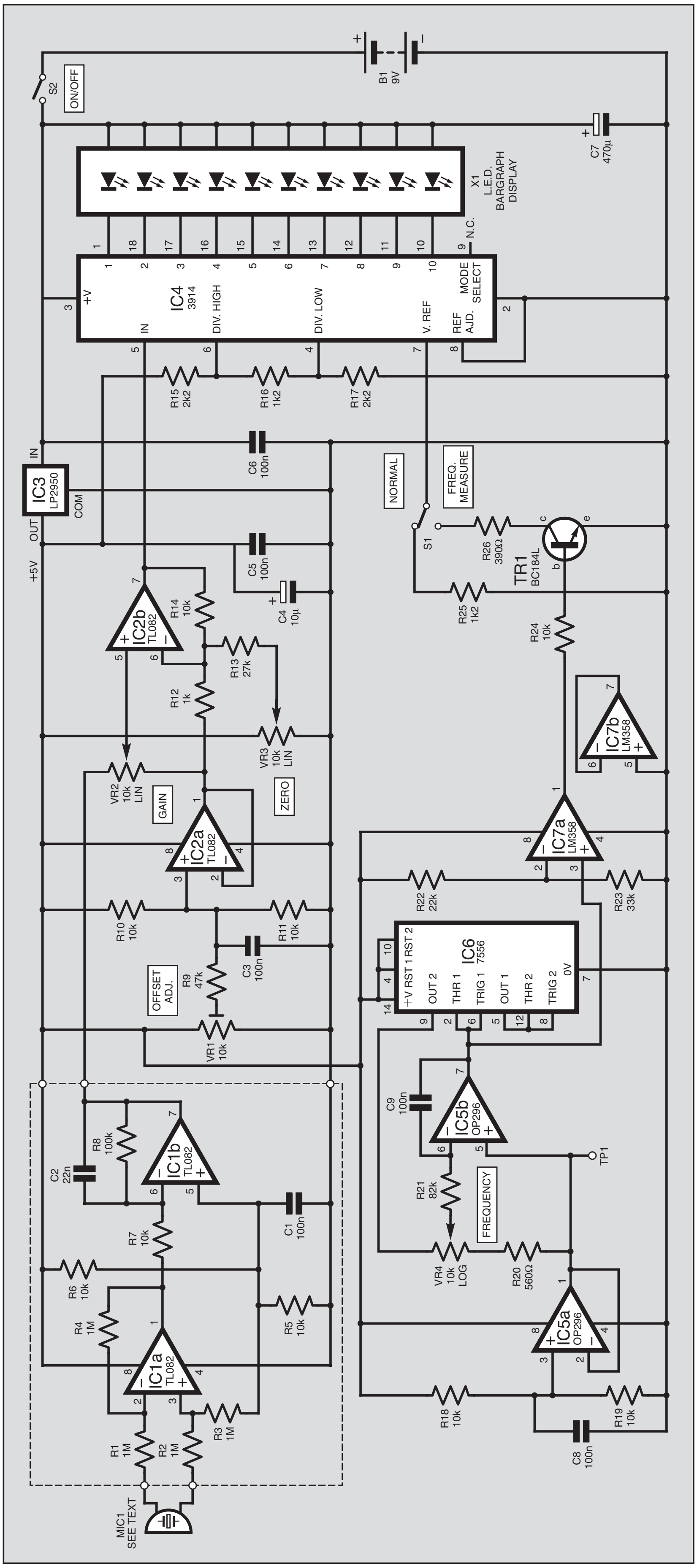


Fig.3. Complete circuit diagram for the Ghost Buster.

HIGH IMPEDANCE

Although the piezo disc makes a fine microphone, it has a very high impedance. Because of this the first stage of any circuit must also have a very high input impedance, plus some ability to cancel out mains "hum" which may be induced into the wires leading from it.

To achieve this, the first part of the circuit, shown in a dotted box in the full circuit diagram of Fig.3, is a differential amplifier with an input impedance of about two megohms, built around op.amp IC1a. IC1b provides a gain of about ten, and capacitor C2 provides frequency attenuation above about 100Hz. Without this capacitor the "microphone" was found to operate up to 4kHz, but we're not really interested in such frequencies with this project.

The output from IC1b has a low impedance and a relatively high level so it can be connected to the rest of the circuit through ordinary unscreened cable. This part of the circuit is constructed on a separate printed circuit board and mounted directly on the "microphone" for two reasons.

First, although the differential input cancels out most of the mains "hum", it is still advantageous to keep the leads to the piezo disc MIC1 as short as possible. Second, it may be desirable to place the rest of the electronics a short distance away from the "microphone" so the ability to connect it through a length of ordinary wiring is useful.

This "microphone" assembly is extremely sensitive and operates well at frequencies extending to below 1Hz, detecting the sub-audio frequencies required by this project with no difficulties whatsoever.

DISPLAY SOLUTION

The next challenge was to find a simple and inexpensive way of displaying sub-audio frequencies detected by it since they cannot be heard. An oscilloscope can be used, but not every ghost hunter is going to possess one of these, and even those that do may be unwilling to lug it to the investigation site and find a suitable power supply.

The solution adopted is the use of a 10-segment bargraph display (X1) with a 3914 linear driver (IC4). The illuminated segment is adjusted to be approximately central when there is no input, and to move up and down when a signal is applied.

Op.amp IC2a generates a low-impedance voltage of about half the supply. A small offset adjustment through preset VR1 allows it to be set to exactly the same value as the average d.c. voltage from the output of IC1b. This allows adjustment of the gain control VR2 without affecting the average value at the output.

Op.amp IC2b provides further voltage gain of just over ten, with a user-adjustable "zero" control, VR3, and the output is applied to the bargraph driver IC4. This is configured with resistors R15, R16 and R17 to have a full-scale span of about 1V, centred around 2·5V.

Leaving pin 9 (mode select) unconnected invokes "dot" mode, where only one segment is illuminated at a time. Connecting pin 7, V_{ref}, to ground via resistor R25 causes the l.e.d. segment current to be set to about 10mA.

IC4 and the bargraph X1 are powered directly from the 9V battery supply voltage. Everything else is powered with a regulated 5V supply from IC3, which is an LP2950 low drop-out, micropower voltage regulator, much better suited to battery operation than the standard 78L05 type.

SPECTRE

The last problem to be overcome was the provision of some way of determining the frequency of signals detected. Their waveform and level might be unsuitable for squaring and feeding into some sort of frequency measuring circuit, and in any case it is difficult to measure really low frequencies in real time.

Again, a requirement was that the method used should be simple and inexpensive. The technique adopted is to flash the illuminated segments of the bargraph, with a fairly short duty cycle, at a frequency that can be manually adjusted by the user. If the flashing is at a rate similar to the detected frequency, the illuminated segment will appear to stand still or travel very slowly up and down the display. This method isn't perfect but it works and with care will usually give a good idea of the detected frequency.

The oscillator is a type used by the author in several previous designs because its output can be directly proportional to the position of the variable resistor used to control it. It is constructed around IC5 and IC6.

Op.amp IC5a provides a low-impedance voltage of half the supply. IC5b is configured as an integrator, where the rate of change of output is directly proportional to the input voltage applied to resistor R21 from frequency control VR4.

The output from IC5b is connected to the inputs of the first half of the 7556 dual timer IC6, so that the output of this goes high when the input falls below a third of the supply voltage, and low when it rises above two thirds of it. The output from the timer, at pin 5, is of opposite polarity to the feedback needed by the integrator to form an oscillator, so it is applied to the inputs of the second timer which simply inverts it, providing the required feedback from output pin 9.

An OP296 precision op.amp is used for IC5 as this was found to produce a much more linear output than other types, especially at low frequency. The output from IC5b is an almost perfect triangle wave. With the values shown the frequency range extends from around 5Hz to 75Hz. The reasoning for this range being that higher frequencies will be audible and lower ones can be simply counted as the illuminated bargraph segment travels up and down!

A logarithmic (log) potentiometer is used for frequency control VR4 as this type provides some useful expansion of the low frequency end.

A comparator, IC7a, is used for picking off the positive tops of the triangle waveform to give drive pulses of around a seventh of the total cycle time to transistor TR1. This controls the l.e.d. current-setting input, V_{ref}, of IC4 through resistor R26, which has a lower value than R25 and gives a higher l.e.d. current so that the short pulses do not result in the l.e.d.s appearing too dim.

MICROPHONE BOARD

There are two printed circuit boards for this design, which are available as a pair from the *EPE PCB Service*, codes 326 and 327.

The physical construction of the microphone has been described earlier. Its electronic circuit is assembled on the p.c.b. whose layout details are shown in Fig.4.

Construction should begin with the fitting of the five solder pins for external connections, followed by the resistors, capacitors and IC1. As usual, the author recommends the use of d.i.l. (dual-in-line) sockets for all integrated circuits wherever possible.

For testing this circuit, IC1 should be inserted and the board powered with a supply of 5V. The drain from the supply should be in the region of 3mA. The voltage at the output should be around 2·5V d.c., half the supply.

The piezo disc can be connected, and if the centre of this is pressed with an insulated object it will be possible to observe the change of output voltage with a meter as the pressure is applied and released. If the test works, this p.c.b. is ready for use and can be fitted to the "microphone" to complete it.

Various means can be used to fix it in position, such as a drop of glue, double-sided adhesive foam etc. The author is particularly fond of Blu-Tack for such tasks.

MAIN BOARD ASSEMBLY

Construction should now proceed with the main p.c.b., whose layout details are shown in Fig.5. Before describing this, it should be pointed out that the frequency-determining part of the circuit is entirely optional. If this feature is not required then resistor R18 and everything else physically beneath this level on the board (as viewed in Fig.5) can be omitted, with the exception of R25 and capacitor C7.

The suggested assembly procedure is to fit the single link, followed by the solder pins for external connections, there are

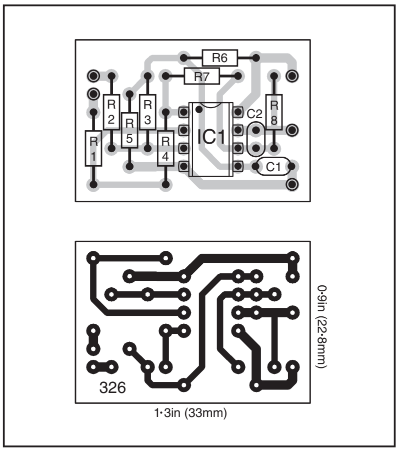
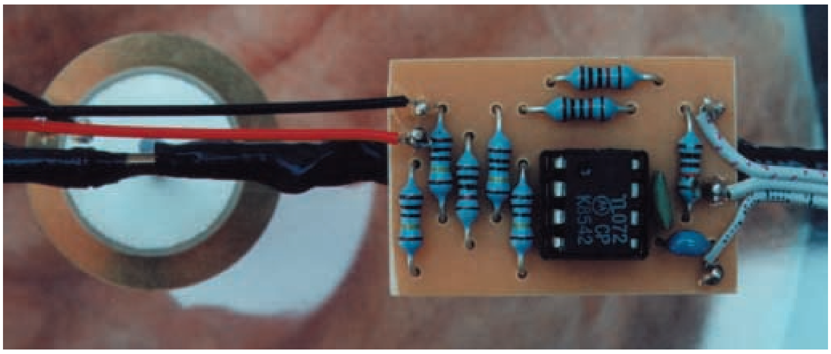
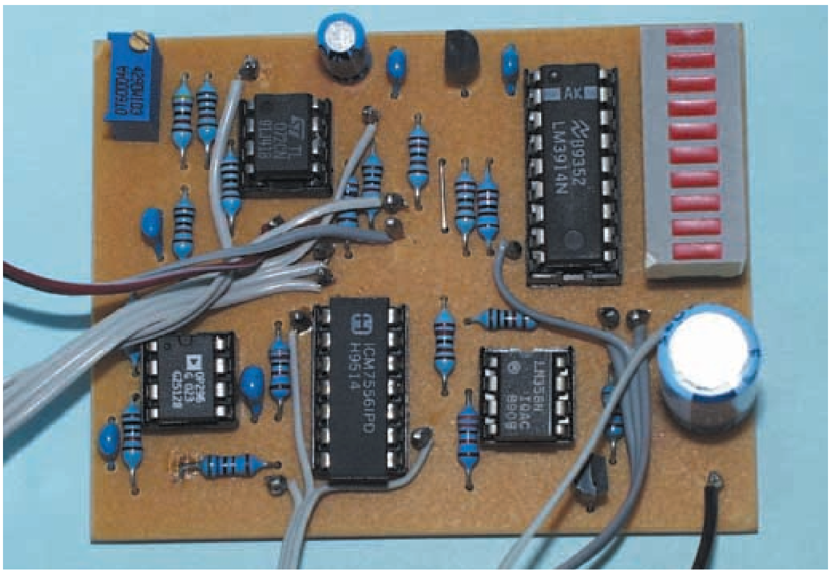


Fig.4. Microphone preamplifier printed circuit board component layout and full-size copper foil master.



The completed preamplifier circuit board suspended above the "microphone".



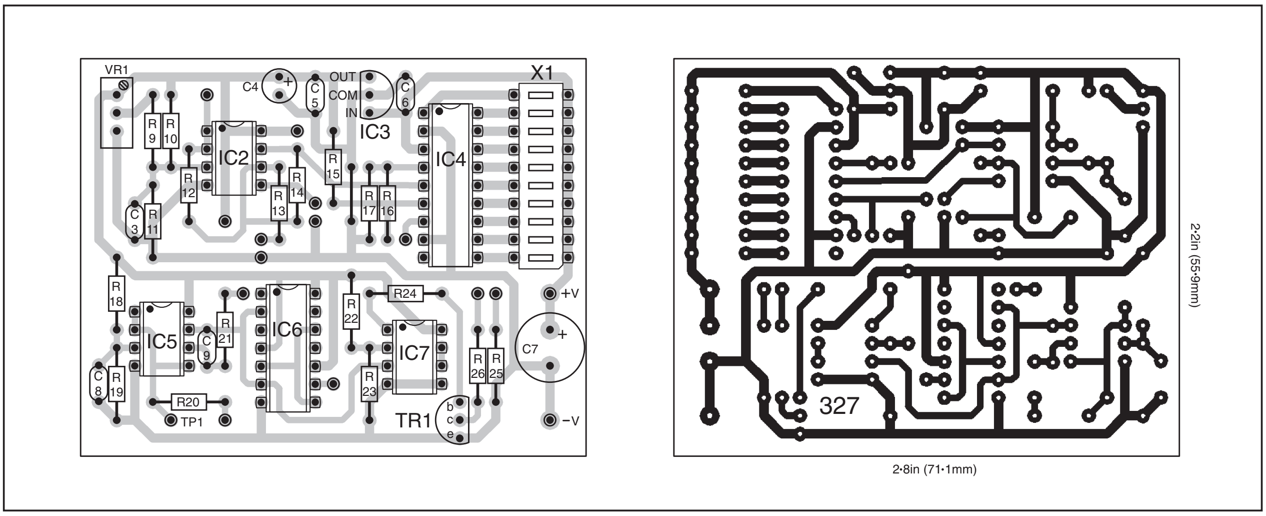


Fig.5. Main printed circuit board topside component layout and full-size underside copper foil master pattern.

fifteen of these. Next all the resistors should be fitted, followed by d.i.l. sockets for IC2 and IC4 to IC7. A 20-pin d.i.l. socket is also recommended for the bargraph l.e.d. display X1.

The five 100n ceramic capacitors should now be fitted, followed by the two electrolytics C4 and C7, observing their correct polarity. Finally, preset VR1, transistor TR1 and the regulator IC3 should be fitted, after which the p.c.b. is ready for testing.

FIRST CHECKS

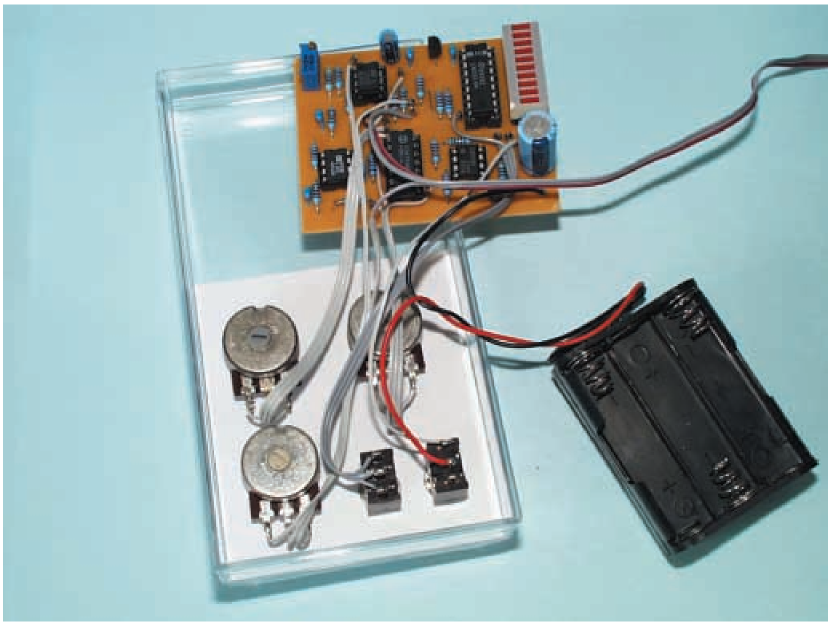
A check without any of the i.c.s inserted (except regulator IC3) should be made. When the board is connected to a 9V supply, there should be a brief surge as capacitor C7 charges, after which the current drain should settle to about 2mA. If so, the 5V regulated output can be checked, this should appear at pin 8 of the sockets for IC2, IC5 and IC7, and at pin 14 of the socket for IC6. These are the top-right pins as shown in Fig.5.

The 9V supply should appear at pin 3 of the socket for IC4, and of course at all the right-hand side pins of the socket for the bargraph display. If this checks out, VR2 should be temporarily connected, just two wires from the wiper and the bottom, or counter-clockwise end, to the board, and IC2 inserted.

This should take the supply current to 4mA or 5mA, and the voltage at both outputs of IC2, pins 1 and 7, should be in the region of 2.5V d.c. Adjusting preset VR1 should cause a small variation of this.

Next IC4 and the bargraph display X1 should be fitted. The bargraph used in the prototype has a small bevel on one corner and the product markings, on the right-hand side when fitted to the p.c.b. (as shown in Fig.5), denotes the anodes of the l.e.d.s.

If there is any doubt regarding polarity, though, it would be wise to check this before fitting it. A temporary wire link can be used to connect the solder pin adjacent to pin 8 of IC4 (from pin 7) to the pin above resistor R25. When powered, one or two segments of the display should illuminate and the supply current will be somewhere around 25mA to 35mA.



ALIGNMENT SETTING

The three leads of the microphone p.c.b. can now be connected, two (power supply) to the main board, the third to the top (clockwise) connection of VR2. The piezo transducer should be disconnected for this test, as it will make reading of the d.c. voltages to be checked difficult.

A digital voltmeter should be connected across VR2 top and bottom (not the wiper) and preset VR1 carefully adjusted for a reading as close to zero as possible. The purpose of this is to cancel out any d.c. voltage discrepancy here, so that the average output will be unaffected by gain adjustment with control VR2.

Following this, the Zero control VR3 should be temporarily connected. This control should adjust the illuminated segment of the bargraph up and down its range. The centre should correspond roughly to the centre of the range of VR3.

It may prove easier to check this with VR2 turned to minimum as stray noise may cause the display to jump about a bit with the gain turned up. Variation of VR2 should not cause any change in the average position of the display set with VR3, though. If it does, the adjustment of VR1 should be re-checked.

It is now possible to connect up the piezo transducer and try out the complete amplifier section. This is a very experimental project, and some care may be needed to operate it. It has been found helpful to stand the microphone on a piece of foam plastic to insulate it from vibrations in the surface it is placed on. It may take some time to settle following large changes in air pressure due to wind, extractor fans etc.

Another factor that has been found to affect it is shining an incandescent light directly on it, the cause of this is not fully understood but is likely to be a change in the tension of the cling-film caused by heat. Sunlight would presumably have a similar effect, but wind would usually make outdoor use difficult anyway, and the unit is not intended for this.

Apart from these limitations, the prototype usually settles reasonably quickly and works well. Finding a source of low frequency sound can be difficult, though, since loudspeakers are not very effective at the low frequencies this project is designed to detect, and ghosts are notoriously difficult to find!

Meanwhile, the author has found that in a small room, the door can be held slightly ajar and pulled back-and-forth at four or five hertz, and the project responds to this very well. Waving a hand up and down over the diaphragm will also generate an output, indicating that it is operating correctly and with good sensitivity.

FREQUENCY GENERATOR

Moving on now to testing the frequency generator section, it is suggested that IC4 should be removed first, to allow the supply current to be checked more readily. This should leave an overall drain of about 9mA before any of the i.c.s of this section are fitted.

Frequency control VR4 should be connected first. This is a log type, to provide some expansion of the scale at lower frequencies. IC5 and IC6 should be fitted next. These are both micropower types and will make almost no difference to the power consumption.

Control VR4 should be turned fully clockwise (highest frequency) and the average d.c. voltage at the clockwise end of VR4 and pin 3 of the socket for IC7 should both read about 2·5V. If VR4 is turned fully anti-clockwise (lowest frequency) these voltages should show a slight flicker on an analogue meter. If an oscilloscope is available, the waveforms can be checked visually, square wave from VR4 and triangle wave at IC5 pin 7.

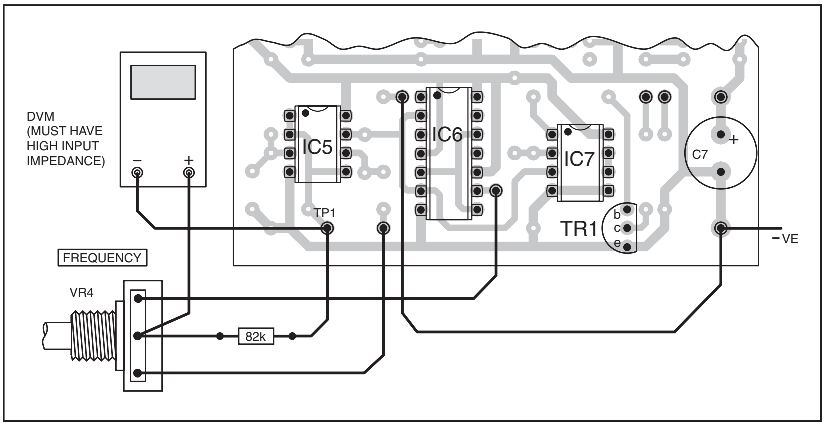
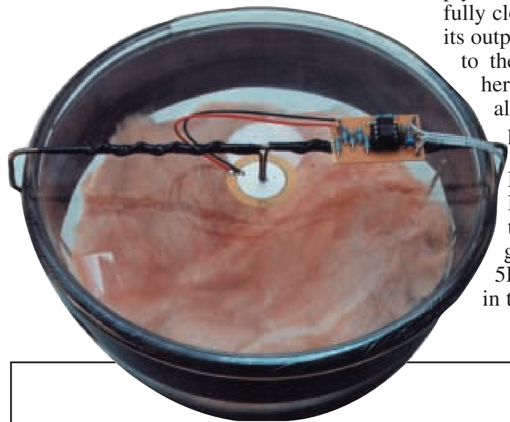


Fig.6. Interwiring connections for frequency calibration using a digital voltmeter (DVM).



Fitting IC7 should now increase the supply current by about 1mA, and with VR4 fully clockwise, the average d.c. voltage at its output pin 1 should be around 0·5V due to the duty cycle of the output pulses here, which is about 7:1. These can also be observed on a 'scope as short positive-going pulses.

If the lead from the pin above R25 is now moved to the one above R26 and IC4 is refitted, and VR4 turned fully anti-clockwise, the bargraph display should flash at about 5Hz with an average supply current in the region of 20mA.

PHANTOM DISPLAY

This completes the testing of the frequency checking part of the circuit. It should be possible to try it out by placing a finger on one input to inject some 50Hz "hum", adjusting Gain control VR2 for a suitable "spread" on the bargraph, then carefully adjusting VR4 around 3/4 travel.

A point should be found where the bargraph display keeps "moving" slowly from a single point at one end through the "spread" to a single point at the other end and back again. This is the frequency indication for 50Hz.

Calibration of the frequency checker is most easily carried out with a frequency meter hooked up to the top of VR4, but it is appreciated that not every constructor will have such an instrument. Another way is to temporarily connect the circuit as shown in Fig.6.

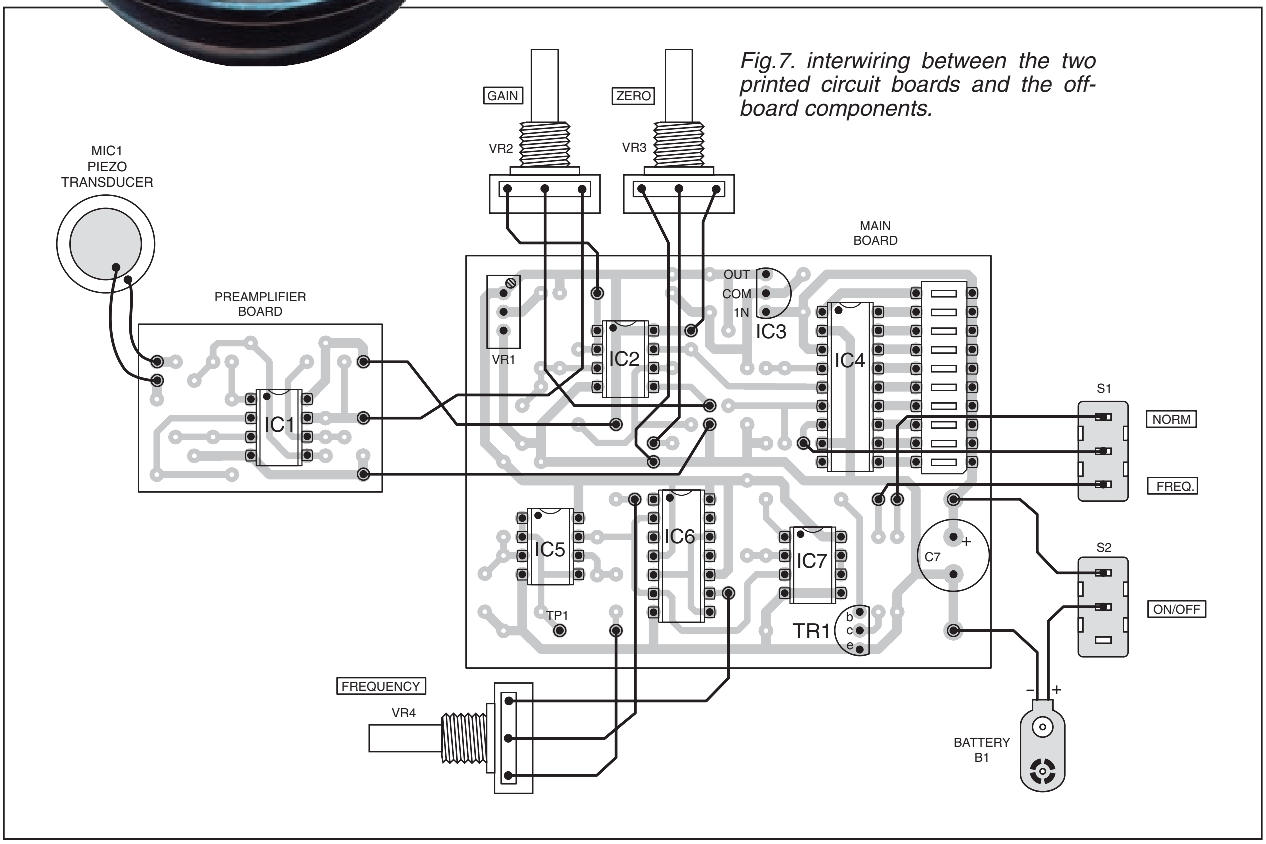


Fig.7. interwiring between the two printed circuit boards and the off-board components.

Pin 7 of IC4 should now be connected to resistor R25 or left open for this procedure, to avoid overloading IC4 and the bargraph display.

As shown in Fig.6, connecting resistor R21 to the battery negative causes IC6 output pin 9 to go high and remain there. The extra 82kΩ resistor between VR4 and test point TP1 simulates the load of R21 on VR4.

The voltage from VR4 can now be measured with a high impedance meter such as a DVM, allowing this control to be calibrated using the values shown in Table 1. Although not as accurate as a frequency meter due to component tolerances, when this procedure was tried on the prototype the errors were surprisingly low, within two per cent.

HOUSING PREFERENCE

The unit can be housed in any manner preferred. The connections between the two boards and the controls are shown in Fig.7. As this is an experimental project, there was no attempt to make it look "commercial" in a smart housing. Using a mixing bowl from the kitchen to make the "microphone" would make this difficult in any case!

The main p.c.b. must be visible since the bargraph is mounted directly onto it, so the prototype is housed in the transparent plastic case which the author had in his "spares box". An alternative approach would be to cut a window in one of the more common grey plastic boxes.

An alkaline PP3 battery could be used as the power supply, but where long periods of surveillance are to be undertaken a pack of six AA cells would be better due to the current consumption of the display. The "microphone" stands on a piece of plastic foam, but could be suspended on elastic for greater isolation from surface vibration. It is unlikely this will be necessary in most situations, however.

A small plug and socket arrangement could be used to connect the microphone assembly to the main section if this is thought more convenient.

Table 1. Frequency Calibration

FREQUENCY	VOLTAGE
5	0·14
10	0·27
15	0·41
20	0·55
25	0·68
30	0·82
35	0·96
40	1·09
45	1·23
50	1·37
55	1·50
60	1·64
65	1·78
70	1·91
75	2·05

Remember to disconnect IC4 Pin 7 from resistor R26 when using this calibration procedure.

TRACING APPARITIONS

A final interesting option would be to use John Becker's *Micro-PICscope* (April 2000) for displaying the output, but it must be pointed out that this will only be suitable for displaying steady standing wave frequencies.

Unlike a conventional oscilloscope, *PICscope* works by storing the incoming waveform as a series of digital values, then outputting these to the display. As such, it is not a "real-time" instrument, and will miss many of the transients picked up by the microphone and readily displayed by a normal scope or the bargraph display.

It is likely that most of the commercial miniature l.c.d. scopes work in a similar manner. However, where a steady standing wave frequency is thought to be the source of the effects being investigated, the *PICscope* could prove to be a useful tool if used in conjunction with this project.

HAUNTING REFRAIN

So "Who Ya Gonna Call"? Now you know - happy ghost hunting! □

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