PROJECT

Build a Seismograph Part 1

Watching for earthquakes around the world.

TONY HOPWOOD and ANDY FLIND

The theory of the seismograph is simple enough. A freely suspended mass will tend to remain still as the earth trembles under it, and the relative motion between the support frame and mass can be detected and recorded by mechanical or electronic means to give the profile of a seismic event.

There are two basic types of seismometer. Portable "velocity type" instruments designed to respond to vertical or transverse waves shorter than two seconds period, and longer period fixed instruments. The most spectacular traces are recorded by long-period instruments which can detect the surface waves arriving from earthquakes anywhere on the planet, so that's what I built.

A seismometer tuned to over six seconds period has the big advantage of discriminating against short wave local disturbances like traffic, while still able to detect the short sharp transients that signify the onset of a distant earthquake.

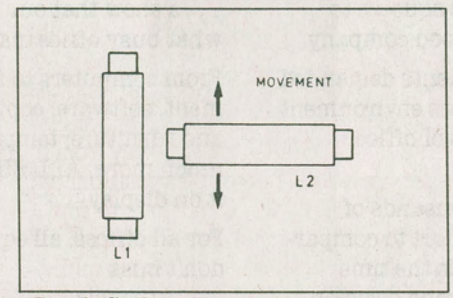


Fig. 1. Coil position and movement.

It was decided to build a "garden gate" type — a horizontal pendulum tuned to an eight second period, with the beam set North/South to be most sensitive to East/West transverse waves. Short period instruments are usually electrodynamic with a moving magnetic mass exciting a fixed coil to convert seismic motion into voltage. As the period increases, this gets more difficult, and involves coils with thousands of turns of fine wire to give adequate signal as well as precision temperature compensated spring suspensions.

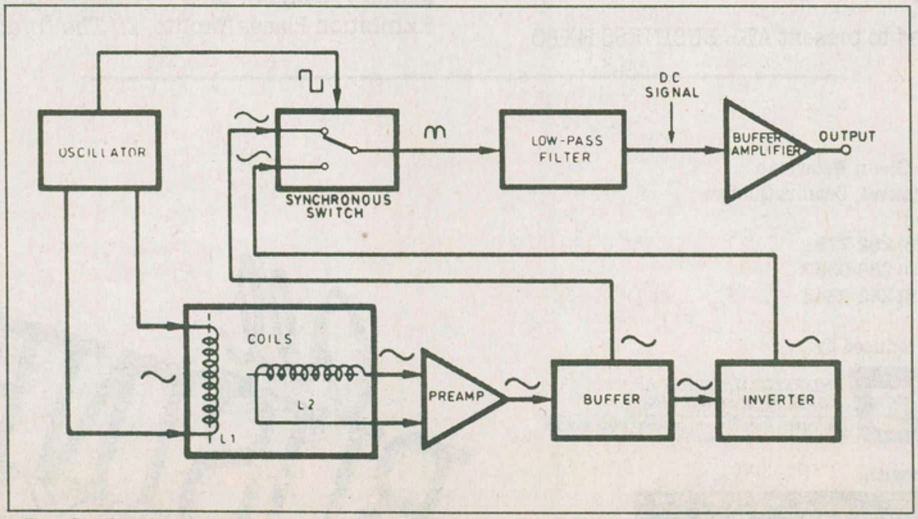


Fig. 2. The electronics block diagram for the Seismograph.

A simpler way is to use electronics to sense the deviation of a long period seismic beam fro its mechanical null — so with the help of Andy Flind, an

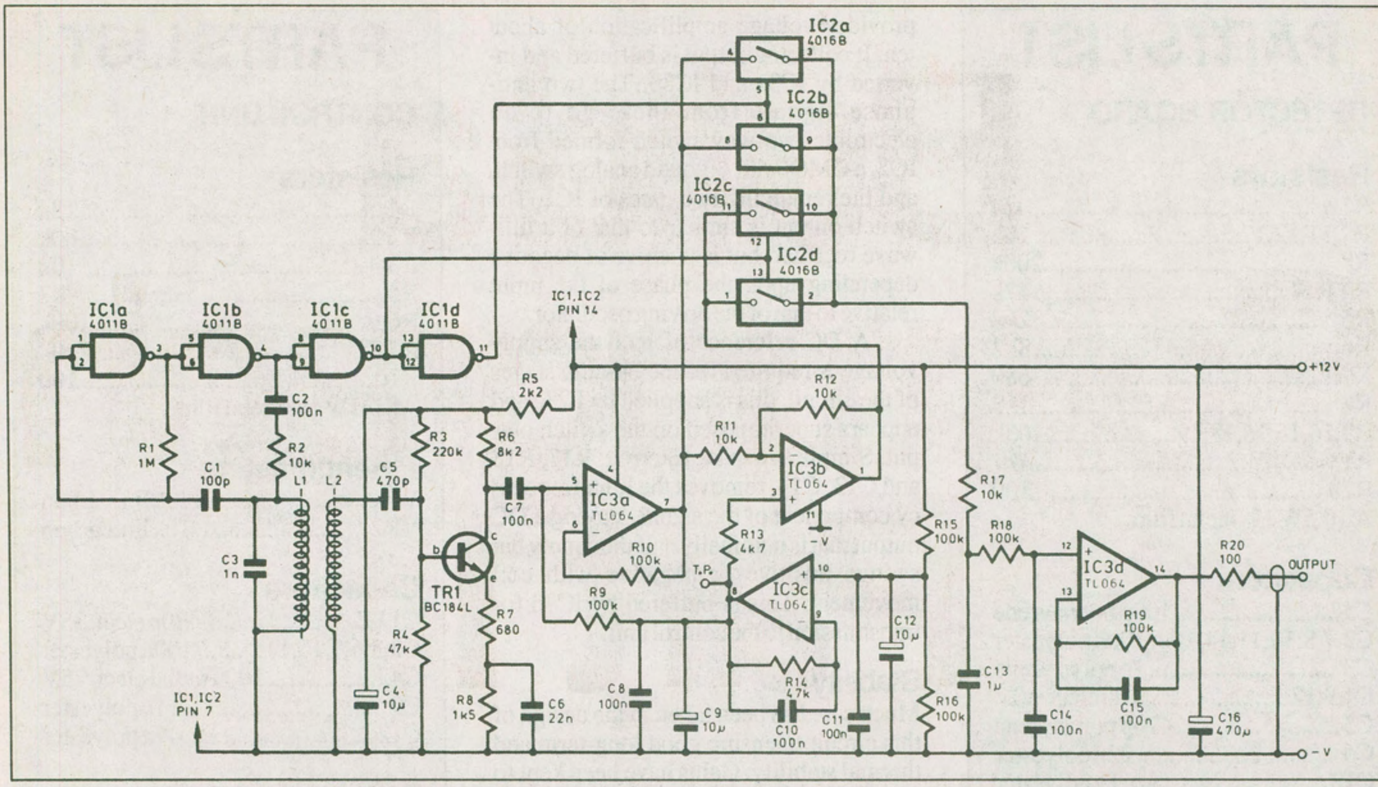


Fig. 3. Circuit diagram for the detector stage of the Seismograph. The coils L1,2 are wound on ferrite rod and are interchangeable.

electronic pickoff system was developed which gave high sensitivity and stability without needing any precision mechanical fitting.

Construction is split between electronics and mechanic (to be described next month) and can be tackled in any order, although some thought should be given to the siting of what is rather a large instrument before final construction is started.

Electronics

The electronics of this project are designed to sense tiny movements of the Seismograph's main beam while imposing practically no friction. As well as being sensitive, the circuit needs good long-term stability, a feature not often required of DIY circuits.

There are various transducers capable of detecting movement. The best known, the variable resistor, is unsuitable because of its high level of friction. Various optical and capacitive sensors, often used in industry, were rejected because they involve electromechanical "follower" mechanisms that would be difficult to make. Linear Hall-effect devices were considered, but they are expensive, their long-term drift characteristics were unclear, and they draw a fairly high operating current. The possibility of battery operation was considered desirable for this project.

The system chosen uses two coils would on short lengths of ferrite rod. One of these is energized with a sinewave current. The other is placed at right-angles about five to ten millimeters away from it, as shown in Fig. 1. If the coil positions are carefully adjusted, it is possible to find a "null" point where induced voltages in the second coil cancel to zero. Small displacements then result in output voltages, which are amplified and detected to indicate the movement.

As a bonus, the phase of the induced output depends on the direction of movement away from null. In one direction it is in phase with the energizing signal, in the other, opposite to it. If a synchronous detector is used, driven by the oscillator, the direction of movement will be indicated by positive or negative output.

Block Diagram

A block diagram of the system is shown in Fig. 2. An oscillator drives one coil and a synchronous electronic switch. The output from the second coil is amplified, buffered and inverted before going to the switch.

The various signal waveforms in the circuit are shown, and it will be seen that the switch output is similar to that from a full-wave rectifier. The remaining AC component in this is removed by passive low-pass filtering, and a DC amplifier and buffer complete the circuit.

While the effect is not completely linear, it is good enough over the range of movement needed. It takes only a small energizing current from a simple oscillator, is extremely sensitive, yet is easy to mount and set up. Careful design of the electronics provides good long-term stability. Additionally, it's cheap and easy to make.

Disadvantages? Well, the coil on the beam needs two wires to energize it, but these, if thin and placed close to the fulcrum, do not impair performance.

Practicalities

An instrument of this type is often sited some distance from occupied buildings to minimize disturbance and vibration from human activities. However, it would be useful to have the output available in the workshop or laboratory. With this in mind, the circuit is split into two sections, a "Detector" board for the Seismometer itself, and a "Control" unit, containing the power supply and output processing circuitry.

Connections between the two units consist of a single-ended low voltage supply, and one low-impedance signal lead that uses the negative supply as "common". This arrangement means that con-

PARTS LIST

DETECTOR BOARD

Resistors

R1	1M
R2,11,12,17	10k
R3	200k
R4,R14	47k
R5	2k2
R6	8k2
R7	680
R8	1k5
R9,10,15,16,18,19	100k
R13	4k7
R20	100

All 0.5W 1% metal film.

Capacitors

C1	100p polystyrene
C2,7,8,10,11,14,15	100n polyester
C3	1n polystyrene
C4,9,12	10u elect. 50V
C5	470p polystyrene
C6	22n polyester
C13	1u polyester
C16	470u radial elect. 16V

Semiconductors

TR1 .... BC184L, 2N3904 npn
IC1. 4011B CMOS quad NAND gate
IC2 4016B CMOS quad analog switch
IC3 .... TL064 quad op amp

Miscellaneous

14-pin DIP sockets; Veropins; 8mm ferrite rod, 10cm length; 32 gauge enamelled copper wire; heatshrink sleeve (see text); PCB

nections between the two can normally be made using the cheapest three-core cable available; screening and similar precautions are unlikely to be necessary.

Circuit

In the detector circuit diagram, Fig. 3, the coil L1 is driven by a simple oscillator formed by two NAND gates IC1a and IC1b. The coils each have an inductance of about 2.5mH, so with C3, 1nF, the frequency is about 100kHz. This is low enough for simple processing but high enough for the characteristics of the ferrite. With L2 positioned as described, an output only appears when it moves away from the "null".

As the small movements to be detected produce small signals, TR1 provides voltage amplification of about ten. It collector output is buffered and inverted by IC3a and IC3b. The two antiphase signals from these go to an electronic two-way switch formed from IC2, a CMOS 4016B quad analog switch, and the remaining two gates of IC1. The switch output is similar to that of a full-wave rectifier, but is positive or negative depending upon the phase of the input relative to that of the driving oscillator.

A DC reference of half the supply voltage is required for the op-amp stages of the circuit, this is supplied by IC3c and appears superimposed on the switch output. Simple low-pass filtering, R17, R18 and C13, C14, removes the high frequency component of the signal, leaving a DC output that is nominally half the supply but swings positive or negative with coil movement. This is buffered by IC3d for transmission to the control unit.

Stability

Much care has been taken in the design of this circuit to ensure good long-term and thermal stability. Gains have been kept to conservative values and impedance matching resistors are used in all op-amp input stages. Experience with the prototype over the last three to four months suggests that these measures are more than adequate.

Supply

The "Control" part of the circuit, Fig. 4, provides a regulated supply for the detector and processes its output. A 12-0-12 volt 100mA transformer and bridge rectifier produces two supplies, positive and negative. These are regulated with three- terminal 100mA regulators IC1 and IC2 to give +12 volts and -5 volts relative to the "common rail". This rail is also the negative supply and common for the detector, and is intended to be grounded.

The purpose of the negative supply is to enable the output to swing below as well as above the grounded common, since many chart recorders require such a signal. The signal processing part of the circuit begins with low-pass filter R9 and C11, which removes any noise induced in the connecting lead between the units, although the low output impedance of the detector unit should minimize such interference. The signal is then amplified by IC3b, a non-inverting amplifier with a voltage gain set at about two.

The other half of IC3 (IC3a) provides a reference voltage controlled by VR1 and VR2, "coarse" and "fine" zero adjusters. It will be recalled that the input is a voltage that varies about a nominal value of six volts; the effect of R7 is to shift the output downwards by six volts to swing about the "common" rail.

PARTS LIST

CONTROL UNIT

Resistors

R1	18k
R2	180k
R3,4	10k
R5	4k7
R6,9	100k
R7,8	220k
R10	100

All 0.5W 1% metal film

Potentiometers

VR1	10k lin. carbon
VR2	10k lin. carbon

Capacitors

C1,C5	470u elect. 35V
C2,3,6,7,10,11	100n polyester
C4,8	100u radial elect. 25V
C9	1u polyester
C12	47n polyester

Semiconductors

D1-4 .... bridge rectifier, 50V 1.5A
IC1 ..... 78L012 12 volt pos. regulator
IC2......... 79L05 5 volt neg. regulator
IC3 CA3240E, dual MOSFET op amp

Miscellaneous

SK1	4mm socket red
SK2	4mm socket black
SK3,SK4	phono sockets
T1	transformer 12-0-12V 100mA
S1	SPST toggle switch

PCB; 8-pin DIP socket; case 150X80X50mm; control knobs

Construction

Construction can start with the Control unit, since the 12V supply will be needed for testing the detector. After ensuring that the board fits the slots of the moulded case, the transformer should be mounted on it. The holes for this are not provided as their spacing will vary with different makes of transformer. Its position can be seen from the layout Fig. 5, and the mounting screws should connect its metalwork to the large grounded area of copper on the PCB.

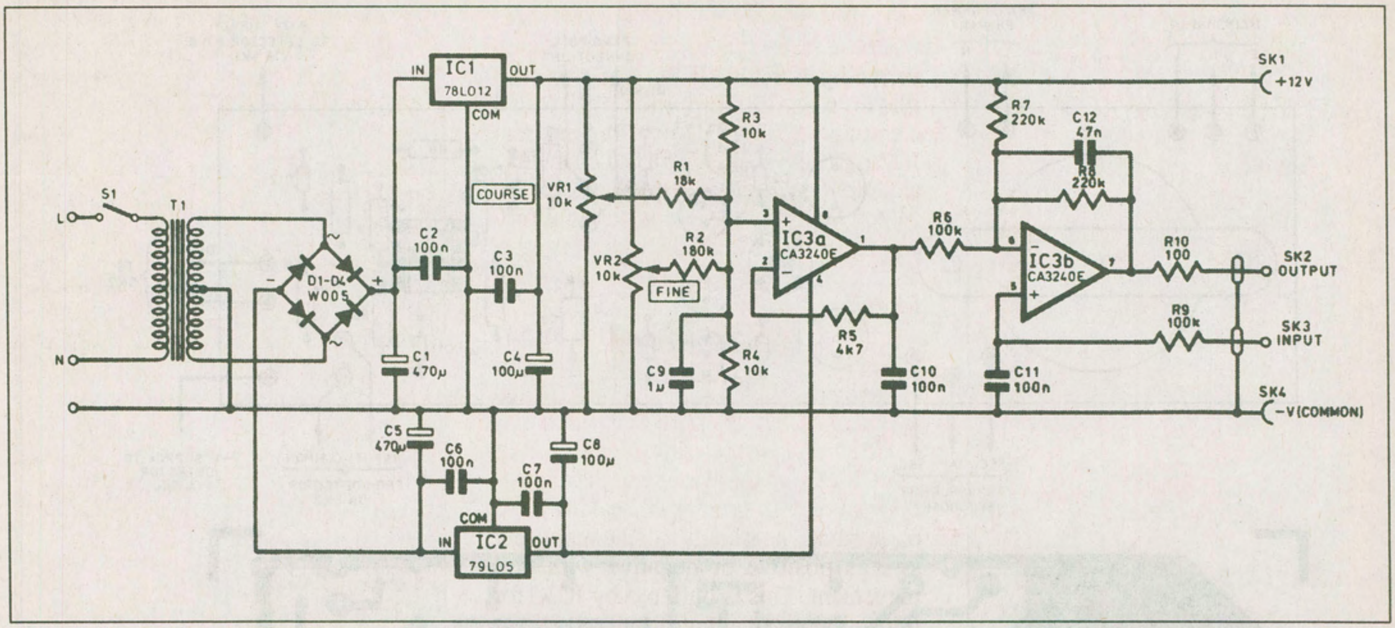


Fig. 4. Circuit diagram for the control stage of the Seismograph.

The bridge rectifier and 470uF capacitors C1 and C5 should be fitted, taking care with polarity, and the unit powered up. Since this implies connection to live mains, the usual precautions should be taken to avoid inadvertent personal contact.

A check should reveal about 17 volts across each capacitor. If this seems OK, C2, C3, C4 and C6, C7, C8 should be added (with the power disconnected of course), with the regulators IC1 and IC2. Check the polarity of the two 100uF capacitors. If the unit is energized again, the 12 volt positive supply should now appear across C4 and the 5 volt negative across C8.

With the power supplies operating correctly, the remaining components can be fitted. A socket is recommended for IC3; these cost only pennies and make trouble-shooting far simpler.

Resistors R1 and R2 are not mounted on the PCB R6 sets the circuit gain. If it is desired to experiment with this, R6 may be mounted on Veropins for easy access, or even replaced by a variable component. The stage gain is given by R8/R6. With the value given, the sensitivity of the prototype was about 50mV per thousandth of an inch of movement when the coils were 5mm apart, half this at 10mm apart.

Testing

The board is now ready for final testing. Two 10k resistors should be connected from the supply rails to the input as shown in Fig. 6, and one pot and the 18k resistor to the zero-setting connections. IC3 should be inserted. If the unit is energized and the output monitored, the pot should provide output adjustment of plus and minus 2.5 to 3.0 volts (2.8 on prototypes).

A "wet" finger across one of the 10k resistors should produce movement in the appropriate direction and the 180k resistor across either should cause a shift of about 0.7 volt. A quick retest of the supply volts, +12V and -5V, and a check that nothing is overheating completes the job. The transformer and IC2 run slightly warm; this is normal.

Coils

The coils are needed to test the detector PCB, so these can be wound next. Each consists of 250 turns of 32 gauge enamelled copper wire, layer-wound over 4cm of a 5cm length of ferrite rod. The ferrite is cut to length by notching around it with a fine-toothed file and snapping it. A layer of insulation tape keeps the wire from touching the ferrite.

Once wound, the wire must be secured to prevent movement, which would affect stability in this project. There are various ways to do this; for the prototype heatshrink sleeving over each coil provided both security and protection to the windings, but a dip in potting resin might be even better. None of the coil dimensions is critical in any way, as only one coil is resonant and the frequency only has to be approximately correct.

Detector Board

Construction of the detector board begins with the fitting of all components as shown in Fig.7, save the three ICs. Sockets should be used for these; they should not be inserted

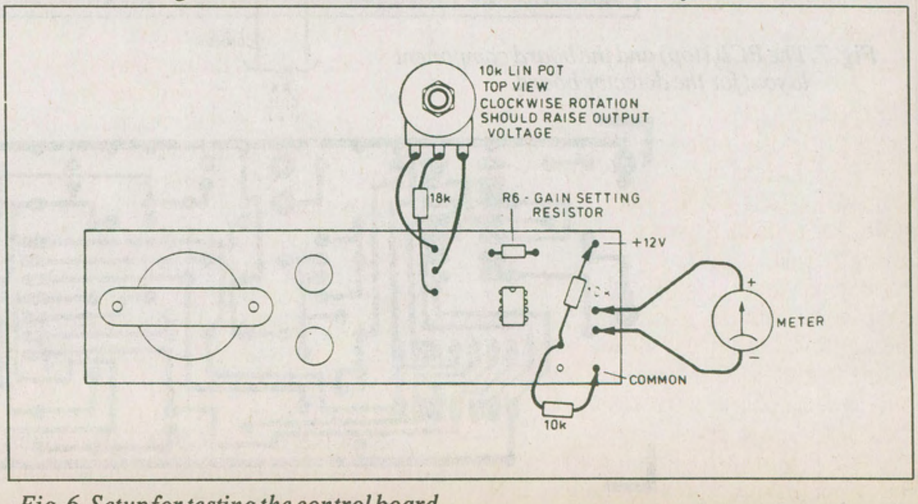


Fig. 6. Setup for testing the control board.

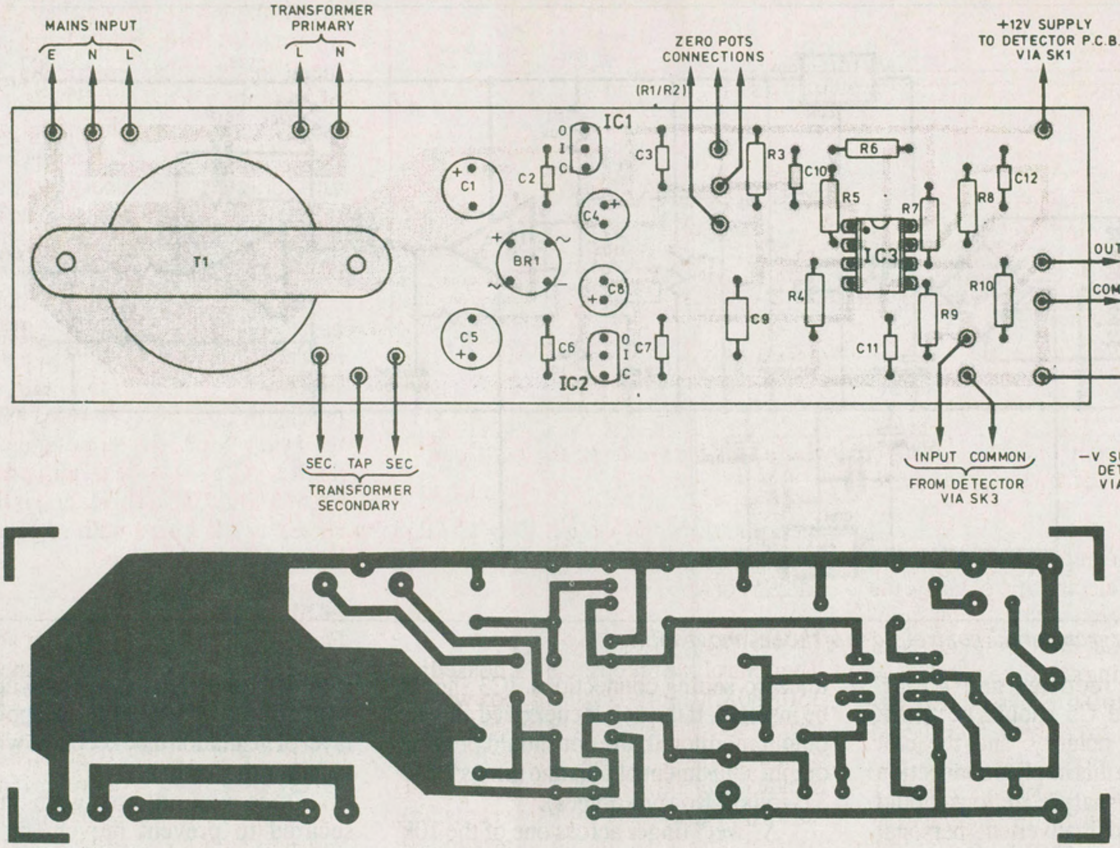


Fig. 5. Control unit PCB and component layout.

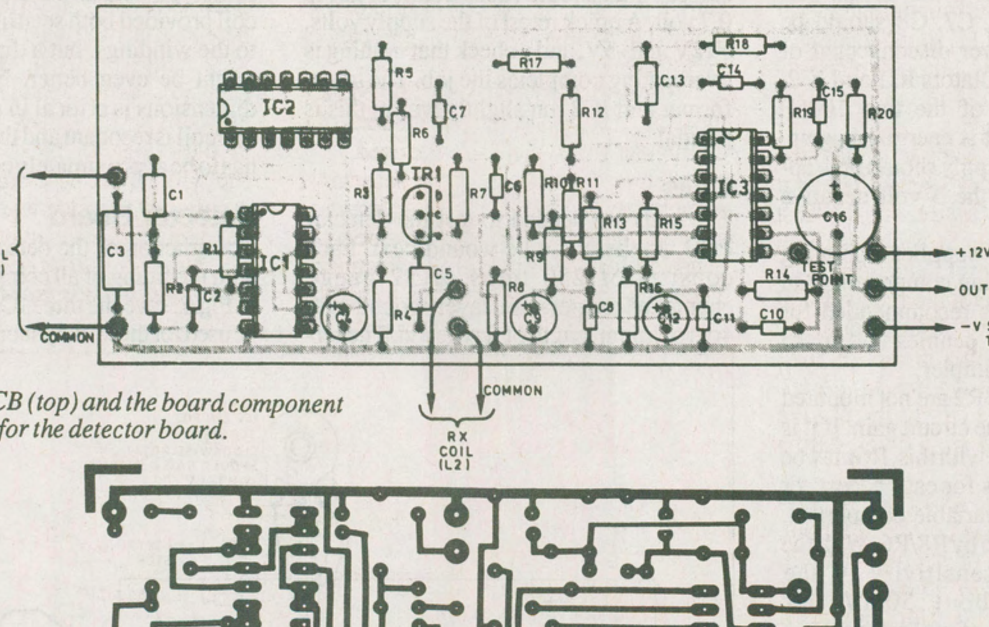
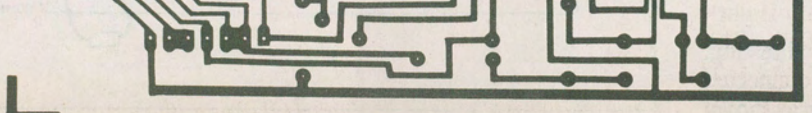


Fig. 7. The PCB (top) and the board component layout for the detector board.



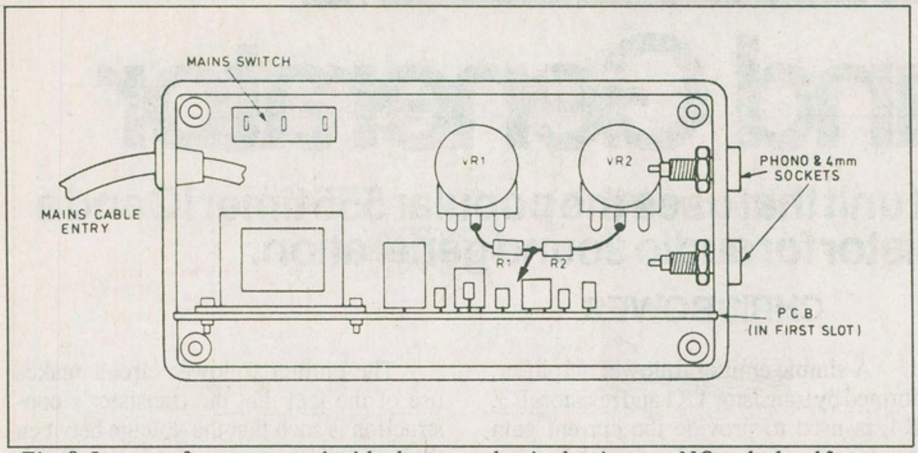


Fig. 9. Layout of components inside the control unit plastic case. NOte the lead from junction of the two resistors to the board.

yet.

following a careful physical check, including correct electrolytic polarity, the board can be powered with a 12 volt supply, still without ICs. Following the usual electrolytic charging surge the supply current should settle to 0.6 to 0.7mA. Any significant variation from this value should be investigated before proceeding. Assuming it is correct, the voltage at TR1 collector should be about 6 volts above the negative (common) supply. If so, IC1 should be inserted and the TX coil connected. This will push the supply current to around 1mA and the four output pins of IC1, pins 3, 4, 10 and 11, should appear to be at about 6 volts DC although in reality they will be switching from rail to rail at the operating frequency.

Next insert IC3. This will raise the supply current to about 1.8mA. The first three outputs, pins 1, 7 and 8, and the "test point" (driven from pin 8), should all be at 6 volts, set by divider R15 and R16. If so, IC2 can be inserted and the receiver coil L2 connected. The output should be monitored and the coils placed at right angles to each other, 5mm to 10mm apart. Careful adjustment of their relative positioning should locate a 6 volt output point, the "null".

Alternatively, the meter can be connected between the test point and output, where the null will give an output of zero volts with movement to either polarity. If the coils are around 5mm apart, a sideways movement of 2mm to 3mm should cause an output change of one volt, with polarity depending upon direction. The final current drain will vary slightly but should be about 1.8 to 1.9mA. This low supply current will allow long-term use from batteries if necessary, especially if the p.s.u. board is replaced with a circuit incorporating one of the new C-MOS micropower regulators such as the RS LP2951 or MAX666CPA.

Housing and Mounting

The control and output board is housed in a 150X80X50 mm ABS plastic box with internal slots for the PCB Input and output connections are made through phono sockets, while the 12 volt supply is available from red and black 4mm sockets. The "coarse" and "fine" zero adjusters and the mains switch are situated on top of the box. Wiring between these components is shown in Fig. 8. A 100mA cartridge fuse could be incorporated into the case if preferred.

The detector board is not housed, as in most cases it will be incorporated into the equipment with which it is to be used.

Setting up and use of the detector is straightforward as it is very tolerant of misalignment, much of which can be compensated for with the "zero" adjustment. The coils are not too sensitive to nearby metal, though obviously they should not be mounted hard against large structural metal components. In particular, any form of mounting that involves a complete metal loop around wither of the coils must be avoided as this would act as a "shorted turn" drawing much energy from the system. If twists of wire are used, they must be of insulated wires. Nylon cable ties would be fine, or perhaps glue.

For the Seismograph installation, it is best to install the transmitter coil L1 on the moving beam, with a twisted pair of thin wires connecting it to the PCB, with the flexing portion of these wires as close to the beam's fulcrum as possible. At this point it will have the least influence on the beam action. The receiver coil is best connected to the board with screened lead, kept as short as possible.

Adjustment

For correct adjustment a meter should be used to set up the detector, connected between output and the "test point". It should have a range of plus and minus one volt, and the coils should be adjusted for an output as close to zero as possible. If desired a 100-0-100uA meter can be fitted together with a suitable series resistor, say 10k, for continuous local indication.

In areas of high interference it may prove necessary to screen the signal lead between the two units. Two-core screened wire could be used, with the negative supply (common) connected to the screen and the 12 volt positive supply and signal to the cores. In most installations this shouldn't prove necessary though, simple 3-core cable or telephone wire, etc. should be adequate even over long distances.

Next Month: Mechanical assembly, setting-up and seismic recording. ■

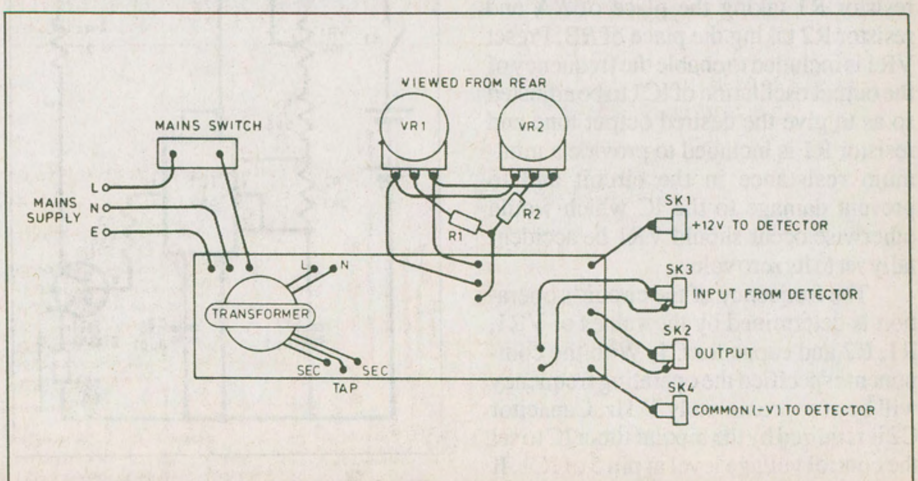


Fig. 8. Interwiring from the board to case mounted components.