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# The Mk IIIC Vertical Component Force-Balance Seismometer System. Part 2: Detailed Description, Calibration, Maintenance and Repair

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# 1. TECHNICAL DESCRIPTION

A general description of the seismometer system is given in Part 1 of this report (AWRE Report O24/83). Here a detailed description is given of the system. Repair, maintenance and calibration are discussed in sections 2 to 4.

The Mk IIIC system is designed for unattended operation in any one of three situations:-

(a) As part of an array where the seismometer system is emplaced in a shallow hole in the ground (usually referred to as a pit) at distances of up to 25 km from the recording laboratory. Two wires are sufficient to carry dc power for the system electronics from the laboratory to the pit and the FM output from the pit to the laboratory.

(b) As part of the Blacknest array which has pits where power is available from the mains and private wire telephone lines for transmitting the FM output from the pit to the recording laboratory. Some of the systems in this array are located in fibreglass lined pits which have metal pads keyed into a concrete base. At pits without pads the seismometers are emplaced in metal tubes sunk into the ground.

(c) As an element of UKNET (see section 1.2 of Part 1 (AWRE Report O24/83)). Block diagrams showing the units required for each type of installation are given in figure 1.

The seismometer can be divided up into five units:-

(i) Unit No. 1: Seismometer, preamplifier and pressure jacket.

(ii) Unit No. 2: Main electronics can.

(iii) Unit No. 3: Power/tone interface box.

(iv) Unit No. 4: Seismic monitor box.

(v) Unit No. 5: Battery power supply.

A photograph of the complete system is shown as figure 2.

A description of these units is given below and their weight and dimensions in table 1.

## TABLE 1

### Weight and Dimensions of System Units

| | | | |
|---|---|---|---|
| Unit No. 1 | Dimensions: | Cylinder of height | 39 cm |
| | | diameter | 20 cm |
| | Weight | 13.4 kg | |
| Unit No. 2 | dimensions: | Cylinder of height | 46 cm |
| | | diameter | 18 cm |
| | Weight | 2.3 kg | |
| Unit No. 3 | Dimensions: | 41 × 28 × 13 cm | |
| | Weight: | 7.0 kg (maximum including two mains power units) | |
| | | 5.0 kg (for battery operation) | |
| Unit No. 4 | Dimensions: | 17 × 12 × 8 cm | |
| Unit No. 5 | Dimensions: | (Two units each 66 × 53 × 34 cm) | |
| | Total weight when activated: | 212 kg | |

## 1.1 Unit No. 1: Seismometer, preamplifier and pressure jacket

The Willmore Mk IIIC is a modified version of the Mk IIIA. The Mk IIIA is a conventional type of short period seismometer with a velocity transducer; it is manufactured by Sensonics Ltd and is described by Willmore (1). Operating and servicing instructions for the Mk IIIA are supplied by the manufacturers (2).

To convert a Mk IIIA to a Mk IIIC the following modifications are made:-

(a) The period lengthening mechanism consisting of a gear train and two springs is removed.

(b) Three plates of the capacitance transducer are added: the two outer plates are fixed to the frame, the inner plate to the suspended mass.

(c) A signal transformer and preamplifier are fitted to the frame close to the capacitance plates.

(d) A gear box and dc electric motor are added to the mass centering mechanism to allow recentering to be carried out without removing the seismometer covers.

(e) The original instrument top plate is replaced by a plate on which are mounted the transformer, preamplifier and recentering motor.

(f) The original base plate is replaced by a more rigid plate that incorporates feet, a cable gland and clamp.

(g) The two original coils are replaced by coils of different diameters.

(h) The original case of the instrument is now only used as a cover; the original feet are removed, the holes sealed and the case inverted over the modified instrument to rest on the new base plate.

(i) The signal and power cables come out through the new base plate and terminate in a printed circuit edge connector.

Photographs of the modified instrument are shown in figures 3(a), (b) and (c). A detailed description of this seismometer is given below and its specifications are listed in table 2.

TABLE 2

Specifications of the Willmore Mk IIIC and the Output Signals from the Complete System

| | |
|---|---|
| Inertial mass (including capacitor plates) | 1.30 kg |
| Natural frequency | 1.6 Hz |
| Residual damping factor (mechanical) | 0.01 critical |
| **Capacitance Transducer** | |
| Space between capacitor plates | 1 mm |
| Capacitance | 10 pF |
| **Velocity Transducers** | |
| Number of transducers | 2 (one at top and one at bottom of mass) |
| Number of coils per transducer | 1 main and 1 subsidiary |
| Resistance of main winding | Instruments A to F: 5000Ω<br>Instruments G to L: 4100Ω |
| Motor constant of main winding | Instruments A to F: 160 V/m/s (160 N/A)<br>Instruments G to L: 120 V/m/s (120 N/A) |
| Resistance of subsidiary winding | 400Ω |

Main winding of upper coils is usually used for feedback signal.

Subsidiary winding of lower coil is used for calibration.

| | |
|---|---|
| **Frequency Modulated Signal** | |
| Centre frequencies of the carriers | 270 and 2160 Hz |
| Deviation | ±33% for 10 V analogue signal |

Analogue Signals

Acceleration response (ACC) - response flat from 0 to 0.05 Hz

| | |
|---|---|
| Sensitivity at zero frequency: | $1.34 \times 10^4$ V/m/s$^2$ |
| Maximum signal at zero frequency: | $7.5 \times 10^{-4}$ m/s$^2$ |

Velocity response (VEL) - response flat from 0.067 Hz to 100 Hz

| | |
|---|---|
| Sensitivity at 1 Hz: | $10^5$ V/m/s |
| Maximum signal at 1 Hz: | $10^{-4}$ m/s |

Velocity response (VBB) - response flat from 0.08 to 4 Hz

| | |
|---|---|
| Sensitivity at 1 Hz: | $9.5 \times 10^5$ V/m/s |
| Maximum signal at 1 Hz: | $1.05 \times 10^{-5}$ m/s |

Long period narrow band response - response 6 db points 17 and 43 s

| | |
|---|---|
| Sensitivity at 0.05 Hz: | $1.65 \times 10^6$ V/m |
| Maximum signal at 0.05 Hz: | $6.1 \times 10^{-6}$ m |

Power requirements of system: 2.1 W at 30 V dc and a current of 70 mA to give electronic circuit power rails of ±12 V dc.

### 1.1.1 Clamping

For transporting the seismometer the inertial mass is clamped to the frame. The mass can be unclamped by unscrewing a slotted screw which is positioned in the frame plate immediately above the top of the mass. Access for the 1/8 in. diameter screwdriver is obtained through a clearance hole in the centre of the top plate between the preamplifier and the recentering motor and clearance holes through the capacitor plates. The screw should be rotated anticlockwise four turns or to its maximum extent, whichever is the greater. Similarly clamping is effected by screwing clockwise to its maximum extent - in both operations the force required is that of the fingers only. The screwdriver should not be gripped in the palm of the hand as this may cause fracture and displacement of the capacitor plate insulators.

### 1.1.2 Capacitance transducer

The outer capacitance plates (upper and lower) are mounted on the frame but electrically insulated from it, using glass spacers and nylon screws. A similar arrangement is also used for fixing the inner capacitor plate to the inertial mass but here the nylon screws are also used to clamp one end of each of three spokes. The purpose of the spokes is to restrain the motion of the mass to the vertical direction only and also maintain the alignment of the clearance gaps between the magnets attached to the mass and the circular coils attached to the frame. To allow for any small deviation of the centres of the magnets from the centres of the coils, the coil formers have been redesigned to give greater clearance.

### 1.1.3 Coils

The internal and external diameters of the Mk IIIA coil are 2.710 and 2.890 in. and the clearances between the coil former and the magnet are 0.010 in. (outer gap) and 0.017 in. (inner gap). By increasing the internal diameter to 2.730 in and reducing the external diameter to 2.850 in. the clearance gaps have both been increased to 0.027 in. This reduction in the thickness of the coil reduces the available number of winding turns. The subsidiary coil (400 Ω) is wound with the same number of turns as on the standard coil to give a motor constant of ~ 10 N/A but the number of turns of the main coil is reduced to give a resistance of 5 kΩ (motor constant 160 N/A) or 4 kΩ (motor constant 120 N/A) instead of the standard coil value of 8 kΩ (200 N/A).

In practice, the main coil of one former is used for the feedback and the subsidiary coil of the second former is used for calibration purposes. Although only one former could be used for both purposes, the use of two coil formers not only retains the geometrical design symmetry of the Mk IIIA seismometer but also eliminates the coupling due to the transformer effect between them during calibration.

### 1.1.4 Recentering mechanism

The mass centering mechanism as fitted on the Mk IIIA is used but to allow remote operation a worm gear assembly is mounted to the shaft and this is driven from a geared down 6 volt motor. In practice, this has proved to be the least reliable component in the whole seismometer system due mainly to the variation of the amount of friction in the gears and bearings, coupled with the requirement to reduce the backlash in the system.

### 1.1.5 Capacitance plate drive transformer

The primary of this transformer is energised by a constant amplitude (10 volts pk to pk) constant frequency (50 Hz) sine wave generated from an oscillator circuit in the main electronic unit. The turns ratio is 1:1+1 with the centre tap of the secondary winding connected to earth. This allows the two capacitor plates to be excited antiphase with one plate in-phase with the single-sided drive input waveform. A derivation of the sensitivity of the capacitance transducer is given in appendix A of Part 1 (AWRE Report O24/83).

### 1.1.6 Preamplifier

The signal picked off from the centre plate of the capacitance transducer is fed directly to the input of a charge amplifier. The circuit diagram is shown as figure 4. This is a low noise amplifier with low input impedance and has a gain in the bandpass (150 to 500 kHz) of ~ 20. The gain is determined by the ratio of the transducer capacitance to the feedback capacitor multiplied by the ratio of the two resistors connecting the feedback capacitor between the preamplifier output and the zero volt rail. The transfer function is given in appendix A of Part 1 (AWRE Report No. O24/83).

### 1.1.7 Pressure jacket

The purpose of this jacket is to prevent changes in atmospheric pressure from being transmitted to the inertial seismic mass of the seismometer. Such changes would cause the buoyancy of the mass to change - the inertial mass floats in the air. Increases in pressure would cause the mass to rise and vice versa. Whereas this effect can be neglected when the instrument is used to record short period signals, the effect is very important when used for long period recordings. To overcome this effect not only is the pressure jacket made airtight (using an "O" ring seal) but the walls are made very rigid with a wall thickness of 5 mm. The original jackets used a threaded hole at the top to give provision for evacuating the complete seismometer assembly. In operation this has been found to be unnecessary and the threaded hole is used for connecting a large eyebolt (using a second small "O" ring) that facilitates carrying and lowering the assembly into seismic field pits made from 8 in. diameter steel tubes. The jackets for the original batch of six seismometers were made of brass. Subsequent manufacture has been of mild steel. The reason for this change is to reduce the effect on the inertial mass (which contains a powerful magnet) of any stray or continuous electromagnetic fields.

### 1.1.8 Internal polystyrene cover

A thin cover made from sheet expanded polystyrene is fitted around the seismometer to fill the space between the instrument and the pressure jacket. Apart from a possible benefit by reducing thermal convection inside the jacket, this cover does give some protection against accidental damage when carrying the seismometer inside the jacket as the seismometer is not fixed to the pressure jacket base but simply rests on its feet.

### 1.1.9 External polystyrene cover

This cover fits over the complete seismometer and pressure jacket and acts as a thermal shield from draughts when the system is emplaced in a seismic vault or an ROC post and prevents convection currents when the assembly is operated inside a steel tube seismic pit.

## 1.2 Unit No. 2: Main electronics can

The unit has a cylindrical case and is fitted with a handle. When installed in a steel tube type pit the unit should be attached to a hook on the inside of the tube by a short length of chain fitted to the handle so that the can is above and clear of the seismometer. For ROC post installation the unit is best left lying on its side.

The can has three Plessey type 100 connectors fixed to its top plate; these are:-

(a) A 12 pin plug for power and signal connections to the seismometer.

(b) A 2 pin plug for raw dc input power and signal output (FM tones) connection to the interface unit.

(c) A 12 pin socket for optional connection to the seismic monitor box.

Attached beneath the top plate is a signal transformer and a chassis holding four printed circuit board connectors. The transformer superimposes the signal outputs of the system (FM tone) into the incoming dc power lines. (A similar transformer is used in the power/tone interface unit (Unit No. 3) to recover the FM signals.)

A photograph of the chassis and its four printed circuit boards is shown in figure 5(a).

The wiring diagram for the complete unit is shown in figure 5(b). The four printed circuit boards are described individually below.

### 1.2.1 6002 power card

Mounted on this card are three independent circuits.

#### 1.2.1.1 Power circuit (see figure 6(a))

The circuit receives a nominally constant, floating input of between 28 and 38 volts dc and converts it to a regulated floating +12 and +24 volts dc. The +12 volt output is then earthed to the system frame to give a regulated ±12 volts for all the electronic circuits. This circuit is based on that which is in use at the short period array sites at EKA and GBA but has been modified to allow greater power output.

The bridge rectifiers on the input are not required for the operation of the circuit but are retained to protect the circuit in the event of an accidental reversal of the leads at the battery. Similarly the 39 volt Zener diode is retained for use with the array configuration where the input voltage is obtained by adjusting the current down long lengths of field cable using a high voltage source.

The TIP 32A transistor enables the LM305 voltage regulator to operate at the required current output and the output voltage (+24 volts) is set by the trim pot. This regulated output is divided by the LM308N operational amplifier to give a precise ±12 volts (±2%). The two complementary transistors (2N3702, 2N3704) following the amplifier are used as a current boost and the feedback is connected from their output. (This boost circuit is needed to allow the symmetry of the rails to be maintained when the loading on the outer rails is not equal.)

1.2.1.2 Drive oscillator (see figure 6(a))

This is a Wien bridge type of oscillator and uses two operational amplifiers with added components to give amplitude stability. The basic circuit is made to be just positively unstable. When the negative peak amplitude exceeds the volts drop of the diode, plus the turn on voltage of the Zener diode, current flows through the 5K6 Ω resistor and develops a potential between gate and source of FET2 and so increases its resistance. This increases the fraction of the signal from IC1 to be applied to the non-inverting input of IC2 and so opposes the main signal on the inverting input, thus reducing the output from IC2. To enable the gain to be reduced over the whole cycle a capacitance (2.2 μF) is added, resulting in a time constant of 12 ms which is long compared with the oscillator output period of 20 μs. The purpose of the other FET is simply to balance the attenuator arms in an attempt to compensate for temperature effects.

1.2.1.3 Automatic mass recentering circuit (see figure 6(b))

The purpose of this circuit is to monitor continuously the average long-term position of the inertial mass relative to the instrument frame and to initiate and terminate any corrective action necessary to maintain this position within preset limits. Drift of the mass position is due mainly to the effects of temperature on the spring suspension. Re-positioning is achieved by using the output signal from this circuit to drive an electric motor to the shaft of which is attached an auxiliary spring connected to the mass. Once initiated this corrective action takes a few minutes to complete during which time the seismometer system is effectively out of commission, but in operation this automatic action is rarely required after a few days following installation.

If uncorrected, the offset position of the mass has two bad effects:-

(a) The linearity of the basic transducer becomes worse when the capacitances are not equal.

(b) The dynamic range is reduced due to the voltage offset in the electronics.

Note that although the effect of the negative feedback is to "strengthen the spring", that is its polarity is such that its effect is to recentre the mass, this should only occur dynamically for signals and not occur as a standing direct current as the power developed in the feedback coil can cause thermal air currents to be generated within the seismometer. For a mass on a spring the displacement of the mass is proportional to ground acceleration, therefore this ACC signal is proportional to the offset of the mass, that is the offset of the capacitance displacement transducer.

The first stage (IC6) is a second order low-pass filter with a pass band from dc to 20 s period and enables the mass offset signal to be passed while rejecting high frequency seismic signals. The following four stages (IC8, IC9, IC10 and IC12) determine not only when the drift signal is outside its allowed limits, but also give the polarity required to recentre the system. Both IC8 and IC9 are connected as Schmitt triggers fed from a common input signal. The voltage thresholds of the two stages are ±3 and ±1 volts and the "hysteresis loop" relationship between the stage outputs (±12 volts) to the inputs is shown in figure 7. IC10 is an inverting summing amplifier giving an output of - (A + B) where A is the output of IC8 and B is the output of IC9. (Note A and B can only be +12 or -12 volts.) The inverter stage IC12 reverses the polarity of the output of IC10 to give +(A + B).

Suppose the mass is off centre to give an output from IC6 of - 4 volts. Both A and B are +12 volts which will be summed to give -12 volts at output of IC10 and +12 volts at the output of IC12. (The voltage power rails are ± 12 volts which restricts the sum to ±12 volts.) The requirements to operate the mass recentering mechanism is determined whenever either output (of IC10 or IC12) goes to +12 volts. Assume the mass is slowly recentering; the input signal (ACC) will slowly decrease but the hysteresis loops will remain locked to +12 volts until the input signal not only goes through zero but reaches a value of +1 volt when IC9 operates and its output B changes polarity. Now the sum (output of IC10) goes to zero as does the output of IC12 and the recentering mechanism is stopped.

Now suppose the mass drifts of its own accord in the same direction so as to increase the positive input voltage. When $V_{in}$ reaches +3 volts IC8 operates and its output (signal A) goes to -12 volts. The output of IC10 (-(A + B)) goes to +12 volts and that of IC12 goes to -12 volts. Originally the +12 volts from IC12 triggered the recentering mechanism (to make $V_{in}$ change from -4 to +1 volt). Now IC10 is +12 volts and operates the mechanism in reverse to decrease the value of $V_{in}$ and continues to do so until $V_{in}$ goes through zero to -1 volt when IC9 operates to change its output B from -12 to +12 volts so enabling the outputs of IC10 and IC12 to revert to zero and stop the mechanism.

If after the initial recentering at +1 volt (when A was +12 volts and B was -12 volts) the seismometer mass had drifted through zero to $V_{in}$ = - 1 volt, then IC9 would operate to make B go to +12 volts and the mechanism would be triggered to operate in the initial direction, ie, to make $V_{in}$ go through zero to $V_{in}$ = +1 volt.

The operation can be summarised in five steps as follows:-

(a) The circuit triggers the recentering mechanism whenever the mass drifts to make the ACC output change by 2 volts from its last recentred value.

(b) The mass is always recentred to make the ACC output pass through zero and finish at 1 volt offset from zero.

(c) If A and B are both positive, then the mass must move to give a final ACC value of +1 volt.

(d) If A and B are both negative, then the mass must move to give a final ACC value of -1 volt.

(e) If A and B are different polarities, then the mechanism does not operate.

Because the corrections made to the mass position are very small (the ±2 volt allowable drift range can be shown to be equivalent to ±12 nm ($12 \times 10^{-9}$ m) displacement of the mass) it is not surprising that the recentering mechanism must be operated in a manner that will give minute but definite increases to the force on the mass. Despite using a large ratio step down gear train and a subsequent worm gear drive, direct operation of the small dc motor is too fast to enable the recentering process to be operated in a controlled manner. Further but controlled reduction in speed is achieved by the technique of pulsing the motor at a time interval of ~ 10 s with a pulse of 12 volts amplitude but with a duration of ~ 0.1 s.

The pulse circuit is made from the four NOR gates of a Cosmos digital integrated circuit (IC5) and the circuit only operates when the recentering mechanism has been triggered (when IC10 or IC12 give +12 volts which then supplies the power for IC5). Two of the gates are connected as inverters and with R18 and C20 form an astable (free running) multivibrator at a period of ≈ 10 s. Of the remaining two gates, one pair is used as an inverter and connected with R16 and C16 + C16A to give a monostable "one shot" circuit with a pulse length of ≈ 0.1 s. (R16 is connected in parallel with a preset variable resistance mounted on the can top plate. This allows this time constant to be adjusted to obtain optimum recentering speed when in the automatic recentering mode.) This is gated by the output of the astable multivator to give the required pulse once per 10 s.

To convert the polarity of these pulses (all positive at +12 volts relative to the 0 volt rail) into the polarity that is required to drive the motor the correct way to recentre the mass, a second digital-integrated-circuit (IC7) is used in conjunction with a differential amplifier (IC11). IC7 consists of four independent NAND gates. These are connected to give two independent AND gates (NAND gate + invertor). The pulse derived above using the multivibrators is common to one input of both gates. The second input of the second gate is connected to the output of IC12 which is of opposite polarity to the output of IC10. Thus, when the mass is recentering only one or other of the AND gates is transmitting the pulses - the other AND gate giving zero volts output. Because the outputs of the AND gates are connected differentially to the amplifier IC11 the output from IC11 will be positive pulses if IC12 was +12 volts (and IC10 gives -12 volts) and will be negative pulses if IC12 was -12 volts (and IC10 was +12 volts).

The pulse train is then passed through a simple current boost circuit employing discrete transistors (TR6, TR7) before passing to the dc motor via a pair of relay contacts and a 100Ω current limiting resistor. A relay is required to prevent any small offset voltage that may exist when the system is in its quiescent (not recentering) mode from generating power in the dc motor and so causing thermal air convection currents in the seismometer. The reed relay is driven by a single transistor (TR8) which itself is driven by the power supply that operates the multivators and which only exists when the recentering circuit is triggered.

### 1.2.2 6101 main feedback and high pass filter card

The circuit diagram of this board is shown as figure 8.

#### 1.2.2.1 Channel amplifier

IC1 and IC3 are high frequency amplifiers collectively known as the channel amplifier and have bandwidths of 100 Hz to 500 kHz to minimise any phase shift of the 50 kHz carrier signal.

#### 1.2.2.2 Phase sensitive detector

The output signal from IC3 is the amplified form of the signal picked off from the central capacitor plate and, although the amplitude of this 50 kHz carrier signal is proportional to the displacement of the transducer from its central position, only the phase of this signal relative to the phase of the original oscillator drive signal determines its polarity; if the central capacitor plate is nearer the top plate, the phase shift is zero; if it is nearer the lower plate, the phase shift is 180°. The phase sensitive detector converts the carrier signal into an analogue signal that gives a voltage and polarity corresponding to distance and direction. The circuit comprises stages IC5, IC7, IC8, IC10, IC2 and IC4.

The heart of this circuit is the operation of IC7 - the analog switches. Four FET solid state switches are contained in the AH0139CD package and these are connected to give the two-pole double-throw switch which is continuously made to operate synchronously with the positive half cycles of the drive oscillator waveform (figure 9). Suppose the capacitor plate is perfectly centralised between the two other plates, then the input signal to the phase sensitive detector will be zero and independent of the state of the relay; further the inputs to the differential amplifier will be zero thus resulting in a zero output signal. Suppose now the centre plate is offset and the input signal is in phase with the drive oscillator; on the first (positive) half cycle the relay will make and the input signal will be transferred to the non-inverting (positive) input of the differential amplifier. (The amplitude at the positive input will be $V_{in}R_4/(R_3 + R_4) = V_{in}/2$.) At the same time resistor $R_1$ will be connected to ground to give the amplifier a gain of $(R_2 + R_1)/R_1 = 2$. Therefore the output will be $V_{in}$. On the negative cycle the relay will break and the input signal will be directed to the inverting (negative) input of the amplifier, while $R_3$ is connected to ground. In this configuration the gain of the amplifier is $-R_2/R_1 = -1$ and therefore the input signal (negative going $V_{in}$) appears as a positive signal at the output of the amplifier. Thus, the sinusoidal input signal is converted to a positive full wave rectified signal. If the input signal is out of phase with the oscillator drive signal, then it can be seen that the effect of the switching is opposite to that described and this will result in a negative full wave rectified signal. If these rectified signals are then smoothed, the resulting analogue signal amplitude is proportional to the capacitance transducer displacement and the signal polarity gives the direction of the displacement. Note that for correct operation it is required to bias pin 13 at +2.5 volts.

A high-speed buffer (IC5) with ac coupling eliminates any dc offset voltages produced by the channel amplifier. The carrier signal is then fed directly into the switches. Stage IC8 is also an ac-coupled high speed buffer and links the drive oscillator to a high-speed voltage comparator IC10 whose purpose is to convert the incoming sinusoidal drive oscillator waveform into a square wave of equal mark space ratio to operate the analogue switch mechanism. Note that the non-symmetrical power supplies required for this LM710 device are +12 and -6 volts. The resulting output is a square wave whose positive amplitude is +3 volts and whose negative output is -0.4 volts relative to ground.

Stage IC2 is a high-speed operational-amplifier and is used in the differential mode of operation to sum the outputs from the analogue switches and stage IC4 is a low pass filter (single pole, fo = 100 Hz) that converts the full wave rectified signal to a steady RMS analogue signal proportional to the capacitor plate displacement.

#### 1.2.2.3 Proportional plus integrator stage (IC6)

This stage combines two desirable features for this feedback system. The capacitor in the feedback loop of the operational amplifier causes it to act as an integrator for frequencies up to ~ $2\frac{1}{2}$ Hz and enables the loop gain to be high at dc and so help counteract steady offsets of the mass due to temperature drift. The RC combination on the input of the stage reduces the loop gain and gives a phase lead at intermediate frequencies (~ 20 Hz) to satisfy the Nyquist stability criterion for the complete feedback system. The output from this stage is the acceleration output of the system (ACC) which is fed back to a velocity transducer coil on the basic spring/mass seismometer via a resistor (R) and capacitor (C) connected in parallel. Provided that the loop gain is high the ACC output is flat to ground acceleration from dc up to 20 s period and its sensitivity (volts/$\ddot{x}$) is inversely proportional to R. Over the range from 0.05 to 10 Hz (0.1 to 20 s period) the ACC output is proportional to ground velocity and the sensitivity (volts/$\dot{x}$) is inversely proportional to C.

#### 1.2.2.4 High pass filter (IC9)

The major requirement for this stage is to remove the dc offset of the input (ACC) signal before further amplification. (The dc offset is due to slight drifting of the capacitor plate transducer and is caused mainly by temperature variations in the seismic vault.) The ACC output has a response flat to ground velocity from 0.05 to 10 Hz with a single pole corner at ~ 0.05 Hz (20 s period). By making the high pass filter with a single pole also at 0.05 Hz the resulting output from this stage is equivalent to the output from a conventional long-period open-loop-seismometer with a natural frequency of 0.05 Hz, a damping factor of 1 and a magnet/coil velocity transducer. The output from this stage is therefore designated VEL.

### 1.2.3 6003 filter card

The circuit diagram of the board is shown in figure 10. The card can be regarded as consisting of three circuits: a low pass VBB filter, a low frequency bandpass LPNB filter, and an analogue to FM converter circuit. The input to both filters is the VEL output from the main feedback card. In its original form the input to the FM converter circuit was selected by a switch to be either the analogue output of the VBB filter or the analogue output of the LPNB filter, only one FM tone being then available for transmission. Subsequently a further card has been added (described in section 1.2.4) and now the selector switch has been removed so that the VBB filter output is permanently wired to the FM converter circuit.

#### 1.2.3.1 VBB filter circuit

This filter is to prevent aliasing of the data when recorded digitally at a sampling rate of 10 samples/s which gives a Nyquist frequency of 5 Hz. It is a four-pole lowpass filter with a gain of unity and a 3 db point at ~ 4 Hz. There are two stages both of which have a natural frequency of 4 Hz; the damping factor of the first stage IC1 is 1.00 whereas that of the second stage IC3 is 0.38. These stages are followed by a buffer amplifier IC5 with a gain of 2.47. The transfer function of the VBB filter circuit is given in Part 1, section 3 (AWRE Report O24/83).

For operation with a digital sampling frequency of 20 Hz the bandwidth of the filter can simply be doubled to 8 Hz by halving the values of the four resistors (390K, 430K, 330K, 330K) that is by paralleling with identical values.

#### 1.2.3.2 Analogue to FM converter circuit

The amplified signal is used to modulate a phase locked loop (IC7) set at a centre frequency of 2160 Hz to produce a frequency modulated carrier wave signal (FM tone). The centre frequency is adjusted using trimpot VR2 and the depth of modulation is adjusted using trimpot VR1 to be such that ± 10 volts of analogue signal deviate the carrier by $33\frac{1}{3}$% (±720 Hz). Note that the operation of the phase lock loop is such that a positive input voltage deviates the carrier to give a reduction in frequency and vice versa. The chosen output from the PLL (IC7) is a triangular waveform and this signal is passed through the final stage (IC10) which is a second-order lowpass filter with a corner at 2.75 kHz. This removes the higher harmonics to give a carrier waveform approaching a sine wave.

#### 1.2.3.3 LPNB filter circuit

The first stage (IC2) is a second-order lowpass filter with a gain of unity, a natural frequency of 0.033 Hz (30 s period) and a damping factor of 0.7; this stage simulates a 30 s galvanometer that is often used with conventional LP recording systems to give a "bass boost" to the signal response below the natural frequency of the conventional seismometer, that is at longer periods than 20 s. The second and third stages (IC4 and IC6) are identical; their purpose is to eliminate the 6 to 8 s oceanic microseisms. Each stage is a second-order lowpass filter with a gain of unity, a natural frequency of 0.047 Hz (21.3 s period) and a damping factor of 0.58. The fourth stage (IC8) is a first-order highpass filter to eliminate any dc offset voltage from the previous stages. The 3 db point is at 0.005 Hz (200 s). The final gain stage (IC9) has a fixed gain of 390 and is provided with a trimpot to set the final output about earth to compensate for any offsets due to the previous stage. The transfer function of the LPNB filters is given in Part 1, section 3.3 (AWRE Report O24/83).

### 1.2.4 Mixer and sender card

The circuit diagram of this board is shown as figure 11. The analogue output of the LPNB filter is converted to an FM tone by means of the phase locked loop IC1. The centre frequency of the carrier is set to 270 Hz by means of VR2 and the depth of modulation (±10 volts for 33⅓% centre frequency deviation) is set by means of VR1. The second stage (IC2) is a lowpass filter with a corner at 330 Hz, and its purpose is to remove the high frequency harmonics of the generated FM triangular waveform. The third stage is a summing amplifier and output buffer. The FM tone signal from IC2 (LPNB at 270 Hz centre frequency) is added to the FM tone signal from IC10 of card 6003 (VBB at 2160 Hz centre frequency) and the resultant sum is current limited and ac coupled to the signal transformer mounted on the electronic unit chassis. A small bias voltage is added to the input of IC3 to ensure the output has positive offset which enables the electrolytic capacitor to be used. The procedure for the initial alignment of the electronic circuits is given in section 3.6.

## 1.3 Unit No. 3: Power/tone interface box

The basic circuit diagram is shown as figure 12. This diagram shows the circuit as used in the ROC post operation (UKNET). The box was designed to hold the maximum number of separate components which is required for operation at an array station. For array station operation two mains powered power supply units connected in series, and two lightning protection cards are needed. The unit not only acts as an interface between the power supply for the system and the output FM tone which is connected to the British Telecom lines but also enables the state of both power supplies and FM tone to be monitored using three moving-coil-meters which are permanently connected.

### 1.3.1 Lightning protection cards

The element facing the external line is an AEI gas diode (black) mounted in a holder containing spark gaps. The chokes are 1 mH, 6Ω Cambion 552 2965 07 00 00. The surge suppressor diodes are Mullard BZW 70 18 (or 51). The 18 volt diodes are used for the card connected to the British Telecom lines. For the array system a second protection card is connected between the field cable and the signal transformer. The 51 volt version is used in this extra card and in the card connected between the cable and the main electronics unit in the seismic pit.

### 1.3.2 Kemo line protection unit

The unit consists of a pair of fuses and 10 volt Zener diodes and is required by British Telecom when equipment other than their own is connected to their lines.

### 1.3.3 FM tone detector

The circuit of the detector is shown in figure 13. The power supply for the circuit is self-contained (two 9 volt batteries) and is only connected by depressing a push button which also serves to connect the input of the circuit to the British Telecom lines. The circuit operates as high-input-impedance ac-voltmeter which not only gives a visual output of the amplitude of the tone but also gives an audible output from a small loudspeaker. The meter reading should be taken using the lower of the two scales (the 0 to 3 range). A value of 1 on this scale relates to the maximum signal allowed by British Telecom for continuous operation when loaded with 600 Ω. The level is referred to as the -13 dbm level referred to 1 mW and its value is 50 μW or 0.5 volts peak to peak for a single sinusoidal wave-shape. With the British Telecom line disconnected the meter reading should not exceed 2 on the lower scale. The meter readings for both normal operation and with the lines disconnected should be noted and marked on the meter for future reference as an aid to fault finding.

### 1.4 Unit No. 4: Seismic monitor box

A photograph of this unit is shown as figure 14 and its circuit diagram in figure 15. The box is intended to be connected to the main electronics can only during initial installation. For operation with the UKNET at ROC posts it has been found to be beneficial to include the box as part of the system and leave it permanently connected and available for use by ROC personnel. The box can be used in five ways.

### 1.4.1 Monitoring with the meter

The centre zero meter can be switched to monitor the following:-

(a) Positive regulated power rail of the electronics circuits (+6 ≡ 12 volts).

(b) Negative regulated power rail of the electronics circuits (-6 ≡ -12 volts).

(c) Analogue signal ACC
(d) Analogue signal VEL
(e) Analogue signal VBB
(f) Analogue signal LPNB

} ±10 = ±10 volts.

### 1.4.2 Continuous electrical signal monitoring

A row of four separate pin outlets above the meter enable any or all of the analogue signals to be monitored continuously using extra test equipment (pen recorder or oscilloscope) independent of the position of the switch. The top right-hand pin outlet marked "FM" enables the combined FM tone output to be monitored using a high impedance earphone or other equipment.

### 1.4.3 Fast recentering

The lower-right-hand push-button marked "Fast Auto" enables the recentering motor mechanism to operate at a faster rate by increasing the width of the pulse that is used to power the recentering motor (see section 1.2.1.3). The button is only operative when the seismometer mass is outside its predetermined offset limits, that is when the automatic recentering circuit has come into operation, and is only required for initial recentering after moving the seismometer.

### 1.4.4 Step calibrations

The lower left-hand button marked "Step Cal" enables a dc current to be applied to the seismometer calibration coil while the button is depressed. Thus, pressing the button and keeping it pressed is the equivalent of subjecting the seismometer to a step wave of ground acceleration. If after allowing the electronic circuits to revert to their normal level the button is released, the effect on the seismometer is equivalent to a negative step of acceleration. The magnitude of the current step that is applied to the seismometer is automatically scaled by the switch position to be appropriate for the range selected for the meter. Thus, correct operation of the system for the four analogue signals (ACC, VEL, VBB, LPNB) can be checked by calibrating using the steps on each meter position in turn and comparing the outputs with those from a similar system or previous results. The step currents to the seismometer are 60 µA for ACC, 570 nA for both VEL and VBB positions and 12 nA for LPNB.

### 1.4.5 Sine wave calibrations

The top left-hand pin enables an external signal generator to be used to calibrate and determine the frequency response of any of the outputs or of the complete system using the preselected attenuators appropriate for the analogue signal response to be calibrated. A full description of the calibration of the seismometer is given in section 4 but note that the signal generator to seismometer current conversion ratios are 5 µA/volt input for ACC, 74.6 nA/volt input for VEL and VBB, and 1 nA/volt input for LPNB.

## 1.5 Unit No. 5: Battery power supply

Where mains supply is available (EKA, the local Blacknest VBB array sites and the Charnwood Forest (CWF) site of the UKNET) the power supply is either one or two mains powered power supply units that are fitted inside the power/tone interface box (Unit No. 3). At all the ROC posts, mains power is not available so a bank of 24 batteries is used. The battery used is the EMU caustic soda battery which has a BS designation of CS2. This battery is an air depolarising system which has a capacity of 1000 Ampere hours with a 3Ω load (~ 400 mA drain). It is a primary battery and so is not rechargeable. The battery is supplied in a dry sealed state and requires only the addition of clean water to begin operation. The amount of water required is about 2.2 litres (4 pints) per battery or 12 gallons for the complete bank of 24 batteries.

From the battery characteristics supplied by the manufacturer, the open circuit potential of the batteries is ~ 1.4 volts, dropping immediately to 1.2 volts with a 400 mA drain and subsequently to 1.1 volts for the major part of the battery life. Based on these data it was forecast that with the load of our system (~ 80 mA maximum) the life of the cells would just exceed one year. In operation this battery life has been confirmed.

## 2. INSTRUCTIONS FOR DISMANTLING AND REASSEMBLING THE SEISMOMETER

General instructions for dismantling the seismometer are given below; it is assumed that at the start the seismometer is in its normal operation condition. By following selected sequences of these instructions most of the common faults that may develop in the seismometer can be corrected. The following repairs require the stated instructions:-

(a) The replacement of both coils or the cleaning of both magnet gaps: all instructions except 20 and 21.

(b) The replacement of an upper spoke: instructions 1 to 5, 15 to 19 and 25.

(c) The replacement of the upper coil: instructions 1 to 5, 15 to 19, 22 to 26, 32, 33 and 35.

(d) The replacement of a lower spoke: instructions 1 to 10 and 30.

(e) The replacement of recentering "clock" spring: instructions 1 to 5 and 15 to 21.

Reassembly is, in general, the reverse of the dismantling procedure but an asterisk (*) against an instruction for dismantling indicates that there are additional instructions for reassembly given in section 2.2.

### 2.1 Dismantling instructions

1. Disconnect the power supply.

*2. Remove the outer thermal jacket, pressure jacket, inner thermal jacket and metal dust cover.

3. Clamp the seismometer mass by using a 1/8 in. diameter screwdriver through the hole in the centre of the top capacitor plate to screw down the clamping cone located in the second plate of the seismometer frame.

4. Lift the instrument from the pressure jacket baseplate by gripping the top plate with the fingers around its circumference with one hand and separate the printed circuit edge connector to release the seismometer with the other hand.

5. Replace the metal cover and transfer the seismometer to a bench.

6. With the instrument inverted, remove the cable clamp plate after removing its three securing screws.

7. Loosen the four large screws securing the base of the instrument but remove only three of them.

8. Remove the metal cover and with the seismometer on its side on the bench remove the fourth base securing screw.

*9. Feed the cable through the baseplate to enable the baseplate to be separated from the instrument by holding the seismometer above the bench with one hand (around the circumference of the top plate) and lowering the baseplate with the other hand.

10. Put the seismometer on to the bench with the baseplate still connected to it but with it lying on its side.

*11. With one hand around the outside of the instrument use the third finger and thumb to press together the plates connecting the top ends of the main springs while the small screw fixing one of the plates to the magnet is removed.

*12. Still holding both assemblies together use the thumb and first finger of the other hand to grip the spring connecting plate and <u>slowly</u> allow it to come down and away from the seismometer mass.

*13. Repeat steps 11 and 12 for the top end of the second main spring assembly.

*14. Remove the screw and washer attaching the small spring flexure to the seismometer frame and remove both sets of main springs, bracket and flexure assemblies.

15. Label all electrical connections to the preamplifier printed circuit board.

16. Unsolder all cables and wires to the preamplifier board and motor assembly.

17. Slacken the screw securing the brass boss of the black-nylon gear-assembly on to the vertical shaft and <u>gently</u> prise the boss upwards to release it.

*18. Slacken and remove the four large screws securing the top plate to the four vertical pillars (the fourth screw will remain captive with the top plate on instruments A to F).

19. Remove the top plate assembly by lifting it vertically and at the same time unscrewing the captive screw. Great care must be taken at this point to lift the plate along the axis of the shaft of the recentering gearbox - it is easily bent.

*20. Slacken the set screw which clamps the end of the recentering "clock" spring to the block attached to one of the spokes and gently prise the spring from the block.

*21. Remove the two socket screws and washers holding the recentering gearbox to the second plate and so allow it to be lifted from the instrument. The spring can now be separated from the gearbox after removing the small screw fixing it to the spindle.

*22. See figure 16. Carefully remove the three nylon screws (A, B and C) holding the outer capacitor plates and lift off the top plate and three quartz spacers.

*23. Carefully remove the three nylon screws (D, E and F) and washers and lift off the capacitor centre plate and three quartz spacers.

24. Lift off the lower capacitor plate and three quartz spacers.

*25. Unscrew and remove the hexagon metal spacers and the aluminium pinned washers at the pillar ends.

26. Unsolder the cable from the top coil (feedback coil) and thread the cable harness assembly through the second plate.

27. Invert the seismometer using a block to safely support the attached baseplate.

28. Unsolder the leads from the cable harness to the coil connections (calibration coil).

29. The cable harness can now be threaded back through the lower plate so enabling the baseplate and harness to be detached.

*30. Remove the three U section spokes (noting whether ⊔ or ⊓). (The nut and "pinned" washer need only be removed at one end of each spoke - loosening the other end is sufficient.)

31. Reinvert the seismometer to restore its normal operating position.

32. Using two thin tommy-bars unscrew and remove the four top (short) main frame pillar sections.

*33. Gently supporting the seismometer mass and main frame with one hand, lift the second plate (with the top coil attached to it) vertically away from the mass and frame.

*34. Carefully lift the mass assembly vertically and away from the lower plate and coil assembly. Cover both top and bottom magnet gaps with masking tape <u>before</u> putting on one side.

35. The top coil can now be separated by removing four pan head brass screws. The two short screws hold the coil to the second plate directly but the two longer screws clamp the second plate between the coil and the third plate of the fixed capacitor assembly. Note the position of the feedback coil terminals on the second plate.

36. The lower plate can be released from the main pillar assembly using two tommy-bars for each pillar as in 32 above.

*37. The lower coil is fixed to the lower plate directly by four pan head screws. One screw is longer than the other three as it also accommodates a cable clamp and fixing nut. If the coil is removed, note the position of the CAL COIL terminals on the bottom plate.

## 2.2 Additional instructions for reassembly

37, 35. The coils should be fixed to the second and bottom plates to be concentric with the clamping cone attachment fixed to the plate.

34. Before repositioning the seismometer mass assembly, remove the masking tape covering the gap and inspect the gaps. Any dirt or metal filings must be removed. The easiest way is to use a narrow strip of thin plastic to which a strip of masking tape is wound "sticky side out". This can then be inserted into the gap and pressed against the pole pieces to trap the dirt or swarf.

33. Before replacing the second plate, unscrew the clamping cone by, say, one turn to ensure that the top plate seats correctly on to the main frame pillars. Clamp the mass only finger tight so that it can be rotated to symmetrically set the rods (attached to the mass) central in the large clearance holes in the second and bottom plate. Finally clamp the lower spokes.

30, 25. Only clamp the spokes loosely until both the second and top plates are connected and the seismometer mass is clamped and oriented correctly. Even then, only lightly tighten the spoke fixing nuts as excessive torque will cause the spokes to rotate and buckle despite the pinned washers which should prevent this from occurring.

23, 22. Only use very gentle finger pressure to tighten the six nylon screws fixing the capacitor plate assembly. Ensure that the central hole is in line through all the plates to enable the mass to be subsequently unclamped. Check the setting of the lower mass clamping cone by connecting a resistance meter between the lower (fixed) and central (moving) capacitor plates. With the mass clamped down there should be no contact. From below the seismometer slowly unscrew the cone until the plates just make contact (with the mass being gently depressed to follow the lower cone). Screw the cone back by, say, 1/8 turn and confirm that the plates are no longer making contact.

21. Initially, mount the gearbox to the second plate with the two socket screws only loosely inserted. Rotate the vertical spindle until the clock spring is just above the clamping block on the spoke.

20, 19, 18. Replace the top plate assembly lowering carefully on to the gearbox spindle and fix the plate in position using the four screws (one captive). Move the gearbox to centralise its spindle in the nylon bush in the top plate and then tighten the two socket screws, checking that the gearbox frame is parallel to the spoke. Check also that the spindle is not bent by rotating the spindle through $360^{\circ}$ and back again. Check that the free end of the clock spring is positioned above its receiving slot in the block and that it will enter it without creating a compressional or tensile force along it. Finally, using a pair of tweezers insert the spring end into the slot and clamp it.

14, 13, 12, 11. When reconnecting the ends of the main spring assemblies to the mass and the frame it will be found useful to use a "slotgrip" type screwdriver. The four screws securing both ends of both assemblies should initially be only fixed with light finger tightness so that the assemblies can be positioned to be symmetrical with each other. Only firm finger tightness is required for final fixing.

9. Holding both the seismometer and the baseplate above the bench feed the cable through the baseplate so that the cable is tight and with the cable duct in the baseplate in line with the axis of the cable running down the seismometer. This should ensure that when the baseplate is rotated (to align the four fixing holes with the four main frame pillars) the cable is drawn tightly away from the lower spoke and spring bracket assemblies. Check also that the cable (or pair of wires) connecting the CAL coil is also clear of the spoke and spring assemblies.

2. Reconnect power supply and check operation of mass re-centering mechanism, etc, <u>before</u> final assembly of covers and pressure jacket.

## 3. INSTRUCTIONS FOR SETTING UP AND TESTING THE SYSTEM

In this section "test box" refers to the seismic monitor box. The abbreviation "tp" (test point) refers to the location at which clips and probes may be conveniently attached or to the location of a component; there are no genuine test points. The test point locations are shown in figures 17 to 20.

### 3.1 Checking the mechanical operation of the seismometer

Before the dc power is applied to the system (but with all the other components interconnected) a check should be made on the natural period and mechanical damping of the seismometer to ensure that they are what they should be; this check can be done as follows:-

1. Disconnect the seismometer lead from the electronics can.

2. Remove the covers from the seismometer and unclamp its mass.

3. Centre the mass by applying 6 volts directly across the recentering motor.

4. Reconnect the seismometer lead.

5. Remove the can from the main electronics unit and connect an oscilloscope between pins F and G of the printed circuit board socket for the main feedback card 6101.

6. Gently displace the seismometer mass to its lower stop and then release it.

7. Use a stopwatch to time some chosen number of oscillations of the signal on the scope and from the time and number estimate the natural period; it should be between 0.6 and 0.7 s.

8. Check that the oscillations decay at a constant rate (the amplitude should halve every 7 to 10 cycles) and that the oscillations gradually merge into the background noise with no indication of sticking.

### 3.2 Checking the operation of power card 6002

1. Withdraw the power card 6002 and replace it connected with its "extender" card.

2. Apply 30 volts dc to the power/tone interface unit and check that the current drain is ~ 80 mA.

3. Switch the test box to ACC to monitor the position of the mass and continuously keep the FAST AUTO button depressed. Confirm the correct operation of the recentering mechanism by observing the meter on the test box and the rotation of the black nylon gear-wheel on the spindle of the recentering gearbox on the seismometer. (To lift the mass this gear should be rotating clockwise and vice versa.)

4. When the mass has centred clip a lead as a short across R35 (10 k Ω) on the power card 6002 at tp1 and tp2 to prevent further operation of the mechanism.

5. With a voltage meter measure the output from the voltage regulator at tp3 and tp4 with tp3 as positive and adjust the potentiometer VR1 at tp5 to give 24.0 volts.

6. Check that the voltage from tp3 to the electronic unit chassis is +12.0 volts.

7. Connect the scope to tp6 to view the oscillator output and check that it is a good sine wave shape at a frequency of ~ 50 kHz and with an amplitude of between 12 and 18 volts peak to peak.

8. Disconnect the dc power from the chassis unit. Check that when the power is reconnected the oscillator output overshoots its final amplitude by ~ 5%, thus confirming correct operation of the oscillator amplitude control circuit.

9. Check that the signal appears on both the upper and lower fixed capacitor plates of the capacitance transducer - on the top plate it will be in phase with the signal on tp6 and on the lower plate it will be antiphase.

10. Withdraw the power card 6002 and replace without its extender card.

11. Temporarily unclip the link at tp2 to allow the mass to recentre.

12. Monitor the recentering drive pulses to the motor (one pulse every ten seconds) by connecting the scope to pin F of the 6002 PCB connector beneath the chassis.

13. Set the potentiometer fixed to the chassis top plate (VR1 figure 5(b)) to the minimum anticlockwise position and check that the pulses (whose amplitude is between two and four volts) have a duration of ~ 10 ms.

14. Set the potientiometer to its maximum clockwise position and check that the pulse duration lengthens to ~ 200 ms.

15. Gently hold the seismometer at its lower stop and press and keep pressed the FAST AUTO button on the test box.

16. Check that the pulse duration is approximately two seconds and that the rotation of the black nylon gearwheel (attached to the recentering gearbox on the seismometer) is in a clockwise direction when viewed from above.

17. Repeat 15 and 16 but with the mass held up against its top stop. Check that the rotation of the black nylon gearwheel is now anticlockwise.

18. Release seismo mass and FAST AUTO button and replace seismo covers.

19. Monitor the ACC output on the scope and allow the seismometer to recentre automatically. Set the potentiometer VR1 so that the change in mass position (as indicated on the ACC output) is approximately one half of one volt every ten seconds when it is operating around the zero offset.

20. Check this operation in both directions. For methods of forcing the system to operate after recentering see section 4.3(a).

## 3.3 Checking the operation of the stages around the feedback loop

1. Withdraw the main feedback card 6101 and replace it connected to its extender card.

2. Check the output of IC8 at tp7 – the signal should be the 50 kHz sine wave of 12 to 18 volts peak to peak amplitude.

3. Check the output of IC10 at tp8 - the signal should be a 50 kHz square wave with an amplitude of +3.0 and -0.4 volts. This test point can be used to trigger the scope for the following monitoring of the carrier wave signals.

4. Check the output of the preamplifier at tp9. This signal is a 50 kHz carrier that is amplitude modulated by the displacement of the seismic mass. This signal will have a dc offset of a few volts due to the preamplifier circuit and the carrier will not be symmetrical unless the mass happens to be perfectly centred.

5. With the box switched to ACC continuously press the STEP CAL button. The carrier amplitude should increase by ~ 200 mV peak to peak before decreasing to its original background level. On releasing the button the signal pattern will repeat.

6. Check the output of IC1 at tp10; the signal should be as at tp9 but without dc offset.

7. Check the output of IC3 at tp11; the signal should be as at tp10 but with a gain of two.

8. Check the output of IC5 at tp12; the signal should be as at tp11.

On some versions (A to F) the input signal from the preamplifier is connected directly to capacitor C16 (1 µF), which is disconnected from IC3, so bypassing IC1 and IC3.

9. Check one output of IC7 at tp13 which is at both pins 3 and 5. The signal should appear as at tp12 but with alternate half cycles missing, ie, signal = 0 when the signal at tp8 is at -0.4 volts.

10. Check the second output of IC7 at tp14 which is at both pins 1 and 7. This should be the other alternate half cycles of the signal, ie, signal = 0 when the signal at tp8 = +3.0 volts.

11. Check the output of IC2 at tp15. The signal should be the difference of the two previous signals to give a "full wave rectified" carrier signal.

12. Monitor the output of IC4 at tp16 with the scope set to a low sweep rate (say, ~ 1 mm/s). The analogue trace should look "seismic". Press the STEP CAL button and only release it after, say, 20 s. The waveform shown in figure 21 should be obtained.

13. Monitor the output of IC6 at tp17 (this is also the ACC output on the test box). Press and release the STEP CAL button as above to give the waveform shown in figure 22.

3.4 Nulling the voltage offset of the feedback signal and checking the voltage offset of the VBB analogue signal

1. Disconnect the seismometer cable from the electronics unit.

2. Ensure a zero input signal by linking tp18 to the chassis earth.

3. Short across the integrating capacitor C21 (1 μF) by linking together tp17 and tp19.

4. Monitor the ACC output pin on the test box using the scope and adjust the potentiometer VR1 (10 kΩ) at tp20 to give zero volts to within 10 mV.

5. Switch the test box to VBB and confirm that the voltage offset on the test box meter does not exceed 500 mV (meter reads 10-0-10 volts). (There is no offset null potentiometer for this signal.)

6. Remove the feedback card 6101 and its extender board.

7. Disconnect the link between tp18 and earth.

8. Disconnect the link across C21 between tp17 and tp19.

9. Replace the feedback card 6101.

10. Reconnect the seismometer cable to the electronics unit.

3.5 Nulling the voltage offset of the LPNB analogue signal

1. Withdraw the filter card 6003 and replace it connected to its extender card.

2. Remove IC6 at tp22 and short its output at tp23 to earth.

3. Monitor the LPNB output on the test box with the scope.

4. Adjust the potentiometer VR3 (50 kΩ) at tp24 to give zero volts to within 50 mV.

5. Remove the filter card 6003 and remove the link from tp23 to earth.

6. Replace IC6 at tp22 and replace the card without its extender board.

3.6 Setting the centre frequencies of FM tones and the deviation sensitivities to 33.3%/volt

3.6.1 LPNB channel

1. Remove mixer and sender card and replace it connected to its extender board.

2. Remove the filter card 6003 and place to one side.

3. Connect the LPNB output pin on the test box to the earth pin on the box.

4. Monitor the FM output pin on the test box using a scope to confirm the amplitude as ~ 500 mV peak to peak.

5. Connect a frequency meter across the same pins as the scope.

6. Adjust the potentiometer VR2 (5 kΩ) at tp25 (figure 20) to set the frequency to 270 Hz.

7. Disconnect the LPNB output on the test box from earth and connect it to an external low impedance voltage source of +10 volts relative to earth.

8. Observe the FM frequency and adjust the potentiometer VR1 (20 kΩ) at tp26 to give 180 Hz.

9. Disconnect the +10 volts from the LPNB output pin.

10. Because the two adjustments (steps 6 and 8) interact it will be necessary to repeat steps 3 to 9 until both conditions are satisfied.

11. Confirm that with -10 volts connected to the LPNB output pin on the test box a frequency of 360 Hz is obtained.

12. Remove the connection from the LPNB output on the test box.

13. Replace the filter card 6003.

14. Remove the mixer and sender card and its extender board and replace the card only.

3.6.2 VBB channel

1. Withdraw the filter card 6003, remove IC5 at tp27 and replace the card.

2. Withdraw the mixer and sender card and replace it connected to its extender board.

3. Short the VBB output on the test box to the earth pin.

4. Monitor the FM signal input to the mixer and sender card at tp28 on the scope and confirm its amplitude as ~ 1.5 volts peak to peak.

5. Connect a frequency meter to the same point (between tp28 and earth).

6. Adjust the potentiometer VR2 (5 kΩ) at tp29 on the filter card 6003 to set the frequency to 2160 Hz.

7. Remove the connection from the VBB output on the test box to earth and connect it to the low impedance external voltage source of +10 volts relative to earth.

8. Observe the FM frequency and adjust the potentiometer VR1 (2 kΩ) at tp30 to give 1440 Hz.

9. Disconnect the +10 volts from the VBB output pin.

10. Because the two adjustments (steps 6 and 8) interact repeat steps 3 to 9 until both conditions are satisfied.

11. Confirm that with -10 volts connected to the VBB output pin the frequency goes to 2880 Hz.

12. Remove the connection from the VBB output on the test box.

13. Withdraw the mixer and sender card and extender board and replace the card only.

14. Withdraw the filter card 6003, replace IC5 at tp27 and replace the card.

## 3.7 Checking the amplitudes of the multiplexed FM signals

1. Disconnect the British Telecom line from the power/tone interface unit and connect a 600 Ω load in its place.

2. Monitor across this load with the FM tone detector unit and confirm the presence of the multiplexed tones.

3. Withdraw the filter card 6003, remove IC5 at tp27 and replace the card.

4. Link the VBB output pin on the test box to the earth pin.

5. Withdraw the mixer and sender card, remove IC1 at tp31 and replace the card.

6. Observe the amplitude of the single tone (2160 Hz) across the load. The amplitude can be corrected by changing R13 (47 kΩ)) at tp28.

(Note: Using the tone detector unit one volt on the lower scale (0 to 3 volts) indicates 500 mV peak to peak.)

7. Remove the filter card 6003 and put to one side.

8. Remove the link between the VBB output pin on the test box and the earth pin.

9. Link the LPNB output pin on the test box to the earth pin.

10. Withdraw the mixer and sender card, replace IC1 at tp31 and replace the card.

11. Observe the amplitude of the single tone (270 Hz) across the load. The amplitude can be corrected by changing R14 (27 kΩ) at tp32.

12. Remove the link from the VBB output pin on the test box to the earth pin.

13. Replace IC5 at tp27 and replace the filter card 6003.

14. Remove the 600 Ω load and reconnect the British Telecom line.

Note that for transmission along private wires, British Telecom stipulate that the maximum continuous power of the signal must not exceed 50 µW. (This is referred to as -13 dbm.) For a single frequency this is equivalent to the signal having a peak to peak amplitude of 500 mV across a 600 Ω load, while for two multiplexed signals it is equivalent to each component having equal amplitudes of 350 mV peak to peak.

The amplitude restriction only applies to British Telecom private wires - for operation at seismic array sites the amplitude can be increased up to, say, 8 volts peak to peak for each tone by increasing the value of R17 (22 kΩ) at tp33.

# 4. CALIBRATIONS

## 4.1 Measurement of the parameters required for the calculation of the sensitivities of the complete system

For the theoretical sensitivities (Part 1, section 3 (AWRE Report O24/83)) we require the basic parameters of the spring mass system (natural frequency $f_o$ and damping factor $n_o$), the sensitivity of the displacement transducer after amplification by the preamplifier, channel amplifier and phase sensitive detector (K) and the motor constant of the magnet/coil assembly used for the feedback signal (G).

### 4.1.1 Determining the natural frequency and damping factor

1. Switch off the system and withdraw the main electronics chassis from the can.

2. Remove the main feedback card 6101 and replace it using the extender board.

3. Make the switch on the extender board "open".

4. Switch on the system and allow to recentre. Due to the high open loop sensitivity the automatic recentering system will be too coarse and so it must be manually forced to become inoperative when the system is only approximately recentered. To do this connect a shorting link across R35 of the power card (tp1 and tp2, figure 17). Use a crocodile lead with only one clip - solder the wire end to the inner end of R35 so that the clip can be connected to the outer end of the resistor.

5. Monitor the smoothed output of the phase sensitive detector at tp16 of figure 18 preferably using a memory oscilloscope, the gain of which is selected to show the background seismic noise.

6. With the monitor box switched to ACC press and immediately release the STEP CAL button. The seismometer mass will now oscillate at its natural frequency (1 to 2 cycles/s) gradually decaying in amplitude until it resumes its former noise level. At this point check that the transition from oscillatory to background motion is smooth. If it is seen that the oscillations decay slowly at large amplitude, but decay rapidly at lower amplitude before entering the noise, then this means that there is slight friction in one of the magnet/coil transducers or perhaps even a signal wire brushing against the mass. This fault must be rectified before proceeding.

7. Use a stop watch to count the number of complete cycles of oscillation over, say, 20 s and so calculate $f_o$. Using the memory facility on the scope, repeat the oscillations and find the number of half oscillations after which the amplitude decays to one half of any former value, see figure 23.

The damping factor can now be computed as follows. Suppose the peak-to-peak amplitude decreases by a factor of two between $(a_2 + a_3)$ and $(a_9 + a_{10})$, then h, the number of half cycles, is 7. If r is the ratio of $a_1/a_2 = a_2/a_3$, then $r^h = 2$, hence r. The damping factor n is related to r by

$$r = \exp\{n\pi/(1 - n_o^2)^{\frac{1}{2}}\}$$

and hence

$$n_o = \{(\pi/\log_e r)^2 + 1\}^{-\frac{1}{2}}$$

or for small values of n

$$n_o = (\log_e r)/\pi.$$

4.1.2 <u>Determining the motor constants of the main feedback and calibration coils and the sensitivity of the amplified transducer signal</u>

The motor constant of a coil assumes its use in conjunction with a particular magnet and is the force between them that results from unit direct current passed through the coil. This constant is only a function of the number of turns on the coil and the strength of the magnet. (Its value in Newtons/Ampere is numerically equal to its "velocity sensitivity" in V/m/s, ie, its voltage output when the relative motion between the magnet and coil is of constant unit velocity.)

The motor constant (G Newtons/Ampere) can be determined using the seismometer suspension to balance two forces. A small mass of known weight is added to the inertial mass to displace it to its bottom stop. A direct current is then passed through the coil and is adjusted to restore the mass position to its original position. If the added mass is m kg, the acceleration due to gravity g $m/s^2$ and the restoring current i Amps, then Gi = mg, ie, G = (mg/i) N/A.

This method can be adopted using the seismometer alone, ie, unconnected to its normal operational electronic circuits as the mass balance position can be estimated with reasonable accuracy. However, a more precise method uses the displacement transducer and amplifier to determine this balance position.

For the feedback coil an added mass of 0.05 kg is balanced by ~ 3 mA to give G ≈ 150 N/A, whereas for the calibration coil the mass used is 0.01 kg, balanced by ~ 10 mA to give $G_{CAL} \approx 10$ N/A.

The equation relating the natural frequency ($f_o$) of a mass (M) supported by a spring of stiffness S (Newtons/metre) is given by

$$\omega_o^2 = S/M, \text{ where } \omega_o = 2\pi f_o.$$

The compliance $C = S^{-1} = (M\omega_o^2)^{-1}$ is the change in length of the spring (and hence displacement of the mass) for unit force. If a current $i_K$ is passed through the CAL coil, then the force applied is $G_{CAL} i_K$ Newtons. The displacement of the mass is $G_{CAL} i_K C = G_{CAL} i_K / M\omega_o^2$ metres. If the voltage output of the phase sensitive detector is V volts when the displacement is d and with the feedback unit disconnected from the main coil, then the sensitivity of the amplified displacement transducer signal is V/d. With M = 1.3 kg, $\omega_o = 10$ and $G_{CAL} = 10$ N/A a current $i_K$ of 50 µA would give a deflection d of $4 \times 10^{-6}$ m. With an output of say 4 volts for this deflection K = V/d is therefore $10^6$ V/m.

The detailed procedure for determining G, $G_{CAL}$ and K is given below.

1. Connect a link across resistor R9 in the monitor box unit and switch the box to ACC.

2. Remove the pressure jacket from the seismometer and lift off the thin polystyrene inner cover and then the metal dust cover.

3. Connect an external power supply of approximately 20 volts with the 0 volts to the chassis earth and the +20 volts through a 10 kΩ variable resistor, a dc 0 to 10 mA meter and a switch to the pin on the extender board (connected to pin F of the main feedback card).

4. Gently supporting the seismometer mass and with the resistor set to its maximum 10 kΩ, check that when the switch is made the mass is deflected upwards. Now break the switch circuit.

5. Monitor the output of the phase sensitive detector at tp16, as in instruction 5, section 4.1.1.

6. Temporarily remove the link inhibiting the recentering mechanism (instruction 4, section 4.1.1) and replace the link when roughly recentered.

7. Attach a thin loop of wire to a 50 g mass.

8. Noting the output at tp16, and gently supporting the mass, hook the loop attached to the mass over the fixing brackets on the side of the seismometer mass; these brackets are where the main springs are attached to the moving mass.

9. With the mass on its bottom stop remove the hand and make the switch.

10. Reduce the value of the series resistor to increase the current to raise the mass until the output at tp16 is of the same value as previously.

11. Note the reading of the dc current.

12. Repeat steps 14 to 17 to enable a consistent value of the current i to be obtained. From the value of the current the motor constant of the main feedback coil can be computed (see above).

13. Now remove the connection between the switch and the pin on the extender board (pin F of the main feedback card) and connect the switch to the EXT CAL terminal on the seismic monitor box. Reconnect the pin on the extender card to the chassis earth (this shorts out the main feedback coil to give it some damping). The current $i_{CAL}$ can now be determined by repeating steps 13 to 21 above but using a 10 g mass in place of the 50 g mass.

14. Replace the metal dustcover, the thin inner polystyrene cover and the pressure jacket over the seismometer.

15. Remove the short across the 200 kΩ resistor (R9 of seismic monitor box).

16. Change the meter or switch ranges to give 0 to 100 μA dc.

17. Temporarily disconnect the crocodile clip link across R35 of the power card (tp1 and tp2 of figure 17) to approximately recentre the mass and then refix the short.

18. Make the switch and measure the dc current $i_K$ (roughly 60 μA).

19. Monitoring the output of IC4 of the main feedback card (figure 17) at tp16 observe and record the voltage change V in signal level due to operation of the switch.

20. Repeat 19 several times to obtain a consistent estimate of $i_K$ and V and use these to determine K as described above.

21. Remove the switch, resistor and meter circuit.

22. Remove and replace the main feedback card without its extender board.

23. Disconnect the crocodile lead across R35 of the power card (figure 27) to allow the recentering mechanism to operate correctly.

4.2 Sinusoidal current calibrations to determine the frequency response of the signal outputs using the seismic monitor box

If a sinusoidal current of amplitude i sin wt is passed through the calibration coil, the force applied to the inertial mass = $G_{CAL}i$ sin wt Newtons and is equivalent to a ground motion acceleration of ($G_{CAL}i$ sin wt/M)m/s², a ground velocity of (-$G_{CAL}i$ sin wt/wM) m/s, and a ground displacement of ($G_{CAL}i$ sin wt/w²M) m. The input current will give an output voltage of amplitude $V_{OUT}$ sin (wt + α) after several cycles of input signal when the initial transients will have decayed to zero. Therefore all that is required to determine the acceleration sensitivity for each value of signal frequency ω (= 2 πf) is to measure $V_{out/i}$ and compute $V_{out}M/G_{CAL}i$ where both $G_{CAL}$ and M are known constants, the velocity sensitivity is $V_{OUT}M\omega/G_{CAL}i$ and the displacement sensitivity is $V_{OUT}M\omega^2/(G_{CAL}i)$.

To simplify the measurement of i a switched attenuator is provided in the seismic monitor box. Its purpose is not only to convert a signal voltage amplitude applied to the terminal post marked EXT CAL into a known current amplitude, but also to make the conversion applicable to the signal response being measured, allowing for the differing sensitivities of ACC, VEL (VBB) and LPNB. The conversion factors, B, are 5 µA/volt for the switch set to ACC, $47.6 \times 10^{-9}$ A/V for the switch set to VEL VBB, and $1 \times 10^{-9}$ A/V for the switch set to LPNB. Thus, i is given by $V_{IN}B$.

The responses are best plotted as V/m/s² against signal frequency for ACC, V/m/s for both VEL and VBB against signal frequency, but as magnification against signal period (1/f) for LPNB where magnification is defined as the ratio of the pen deflection to ground displacement using a pen recorder with a sensitivity of 1 cm deflection for one volt input, Thus,

$$\text{magnification} = \{V_{OUT}M\omega^2/(G_{CAL}i)\} \times 10^{-2} = V_{OUT}\, 4\pi^2 M/(G_{CAL}V_{IN}T^2B) \text{ at period } T(= 1/f).$$

In practice, for LPNB convenient values of T are chosen (eg, 20, 24 and 30 s) and the signal generator set to the required corresponding frequency.

The detailed procedure for determining $V_{OUT}/i$ with frequency is given below.

1. Connect an oscilloscope to the required signal output on the seismic monitor box (Oxley terminal pins at the top face of the box). (When using the oscilloscope to measure the input and output voltage as described below it is most convenient to measure the peak-to-peak values.)

2. Set the main switch on the monitor box to the corresponding output. When calibrating the ACC range connect a temporary short across R35 of the power card (figure 17) to prevent the system recentering at low signal frequencies.

3. Connect a signal generator to the terminal pin marked EXT CAL on the monitor box.

4. With the generator set to the required signal frequency adjust the generator output amplitude to give a convenient (say 5 volts peak-to-peak) signal on the oscilloscope monitoring the system output. (Wait for several cycles to allow the transients to die away.)

5. Observe and record this output signal ($V_{OUT}$).

6. Using the oscilloscope observe and record the output signal from the generator ($V_{IN}$).

7. Record the signal frequency (f).

8. Record the switch position on the monitor box to determine the voltage to current conversion factor.

9. Repeat steps 4 to 8 for all frequencies required to determine the response.

## 4.3 Step current calibrations using the seismic monitor box

The main purpose of these calibrations is to give a confirmation of the correct operation of all the responses in turn after installation in the field (or on any subsequent visit).

When the button marked STEP CAL is pressed and kept pressed the input of the internal switchable attenuator is connected to the +12 volt power supply rail. This passes a steady current through the CAL coil depending on the position of the main selector switch and is equivalent to a step of ground acceleration ($= iG_{CAL}/M$). For switch position ACC i = 60 µA, VEL and VBB i = 571 nA and for LPNB i = 12 nA.

Due to the long time constants in the circuits the button must be kept depressed for, say, 120 s. For the VEL, VBB and LPNB responses the output should reach a peak value (after, say, 3 s for VEL, VBB and 20 s for LPNB) before slowly returning to zero (after approximately 30 s for VEL, VBB and 100 s for LPNB). When the button is released VEL, VBB and LPNB are deflected in the opposite direction and give a mirror image to the waveform displayed previously. Thus, the single button gives a positive step of acceleration when pressed and a further negative step of acceleration when released. The waveforms for the system installed at the ROC Post, Lampeter, South-West Wales are shown as figure 24. They were obtained using a portable battery operated pen recorder and show the background seismic noise.

The STEP CALs on the ACC range have two useful functions:-

(a) With the system operating with its mass centered, the re-centering mechanism can be made to operate by depressing the STEP CAL button for several seconds until the current as measured on the meter in the power/tone interface unit is seen to increase from 60 to 70 mA. This is useful for checking the correct operation of the mechanism for the ACC output going from negative, through zero to + 1 volt. To check the operation the other way, ie, with the output going from positive through zero to -1 volt it is first necessary to press the button until the recentering mechanism operates and then depress the FAST AUTO button. This will cause the mechanism to overshoot the stop position (+ 1 volt) when this button can be released. Provided that the ACC output is greater than +3 volts the mechanism will then operate to bring the output through zero to -1 volt.

(b) If the recentering mechanism is prevented from operating (by connecting a short circuit across R35 of the power card (tp1, tp2 of figure 17)), the output can be used to calculate the dc acceleration sensitivity of the closed feedback loop. When the STEP CAL button is pressed and kept pressed the ACC output on the meter will be seen to move to the left and exponentially reach a new rest position. If the voltage change as read on the meter is $V_{ACC}$, then the acceleration sensitivity is $V_{OUT}M/(60 \times 10^{-6}\ G_{CAL})$ V/m/s$^2$. This signal (ACC) is the output of the closed loop seismometer whose output we predicted (Part 1, section 2.1 (AWRE Report O24/83)) as $MR/G = (1.3 \times 1.62 \times 10^6)/158 = 1.33 \times 10^4$ V/m/s$^2$ where R is the feedback resistor (R18 + R20 of the main feedback card, figure 8) and G is the motor constant of the feedback coil.

## REFERENCES


1. P L Willmore: Patent Specification 1442297, Application No. 39775/72

2. Sensonics Ltd: Willmore Mk IIIA Operating and Servicing Instructions

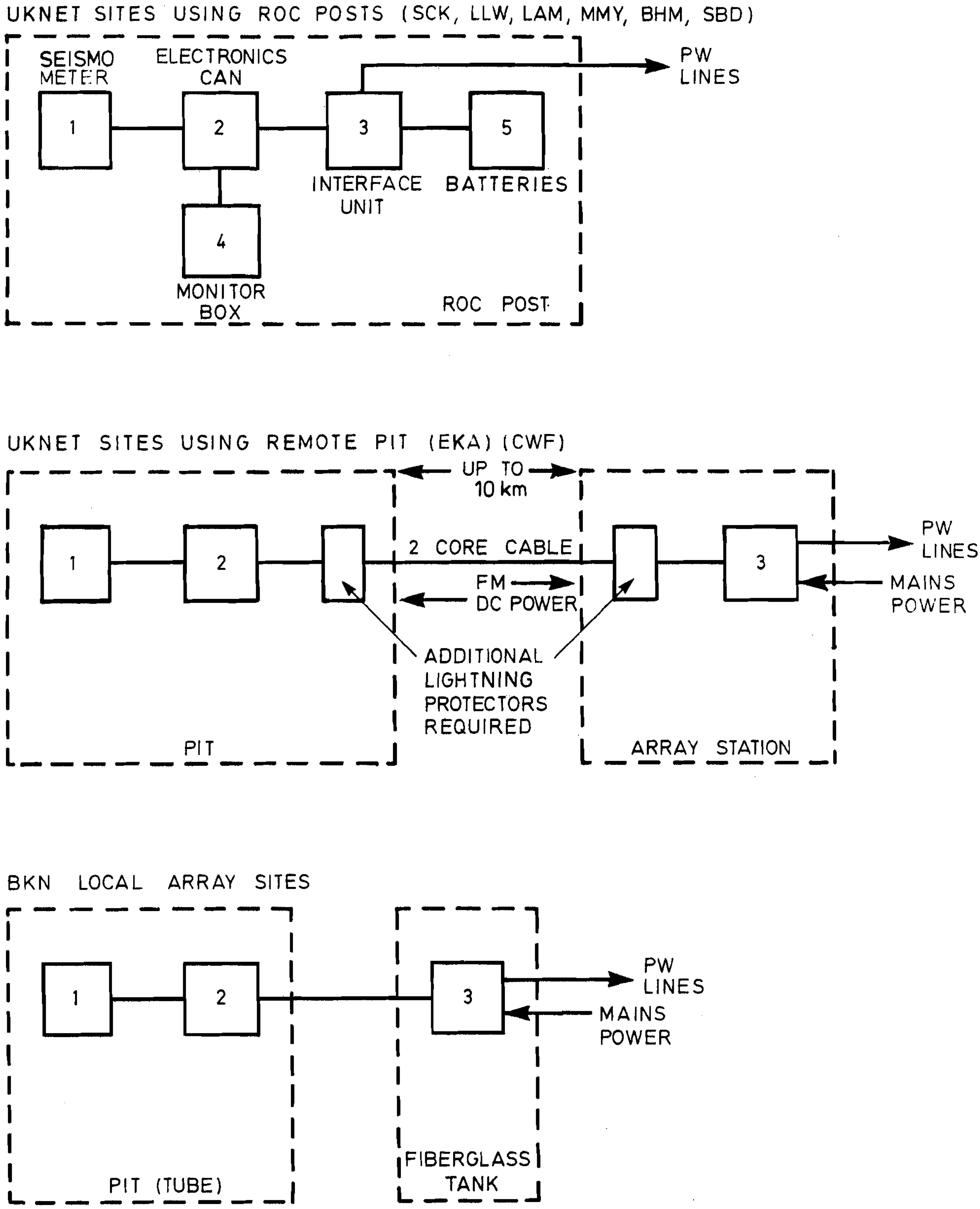



Figure 1. Unit Requirements for MKIIIC Installations

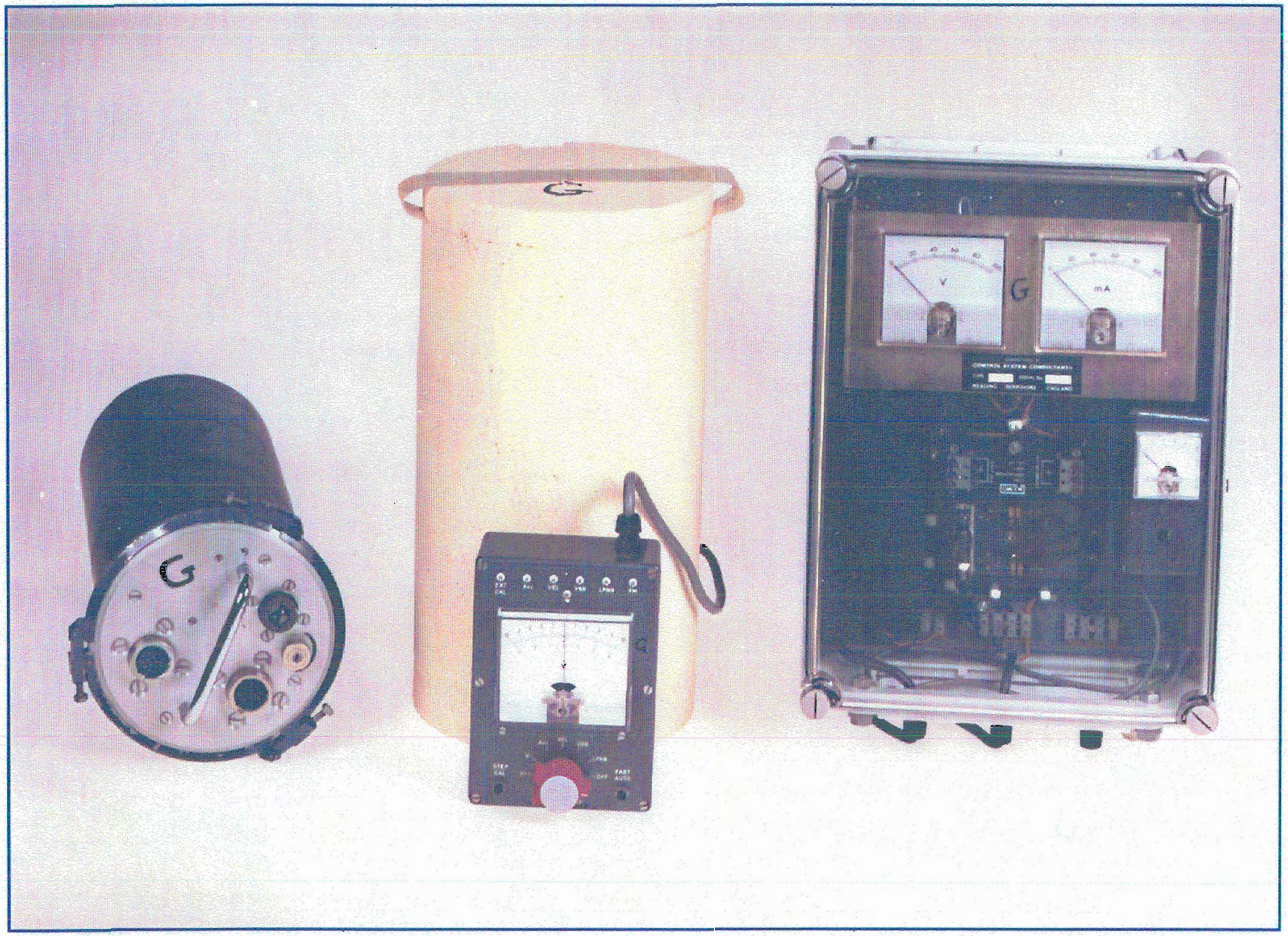


FIGURE 2

Complete System

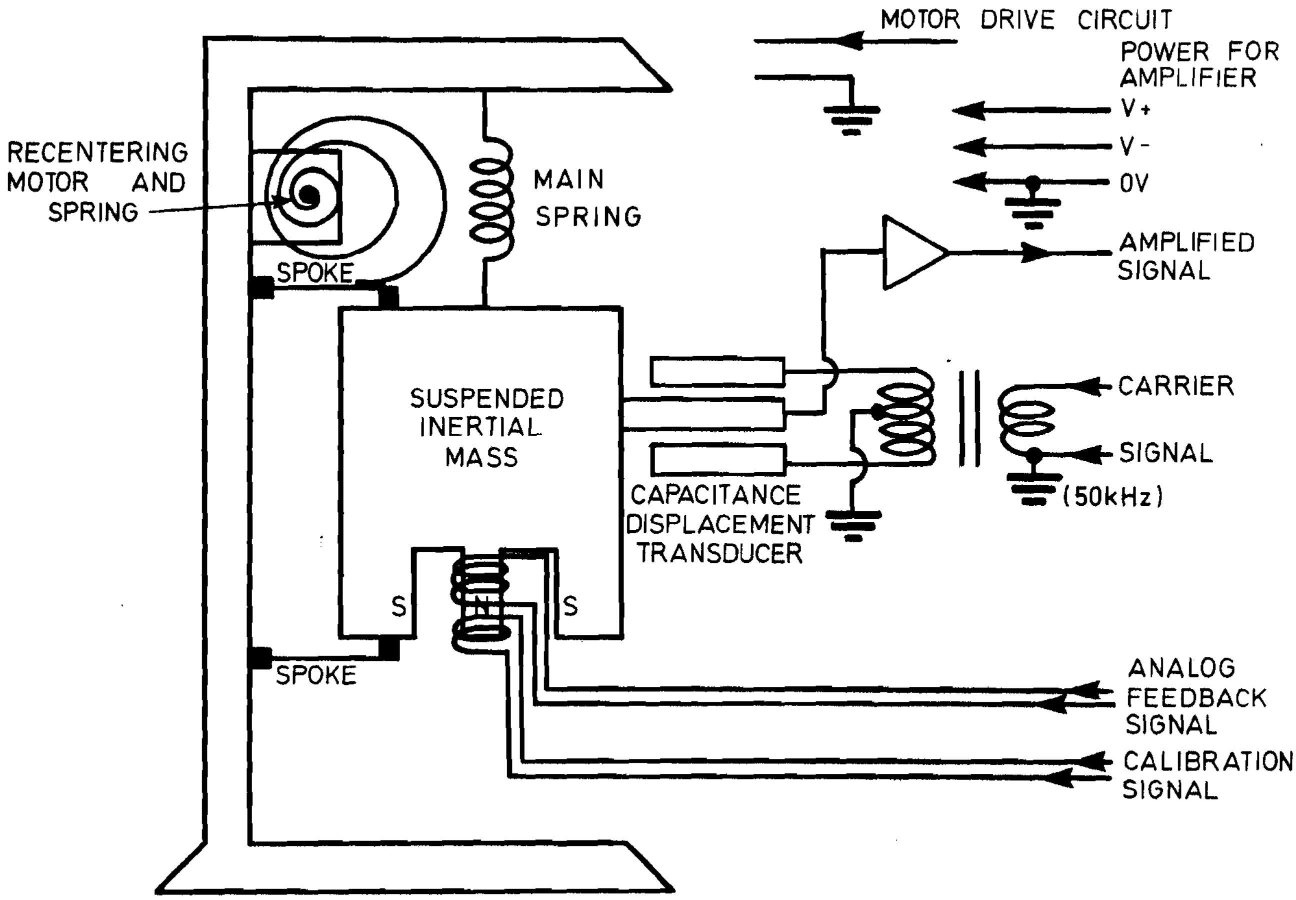



Figure 3(a) Representation of Unit Number 1
(Seismometer and Preamplifier)

FIGURE 3(b)

Seismometer with Thermal and Pressure Jackets Removed

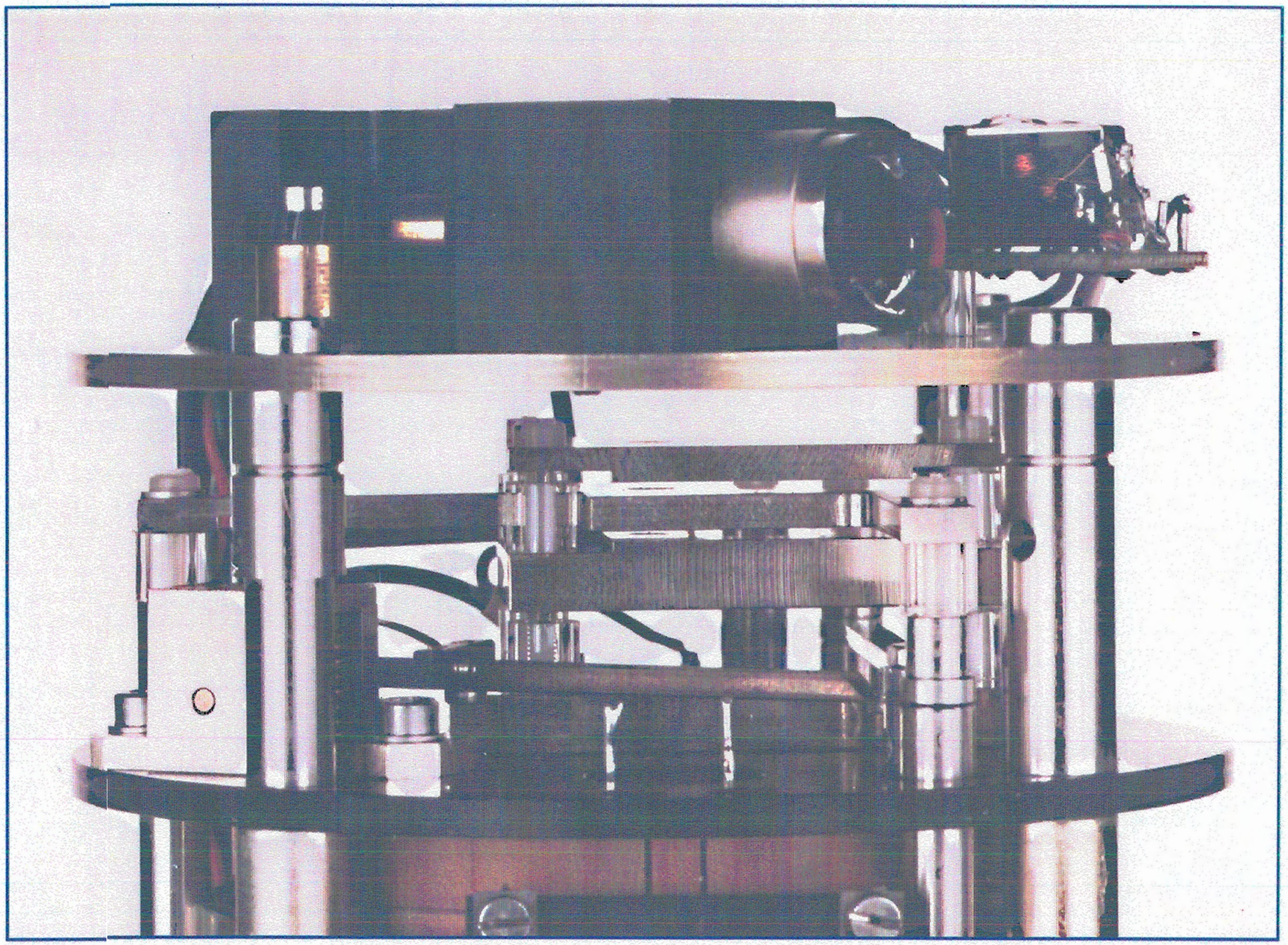


FIGURE 3(c)

Displacement Transducer on Seismometer

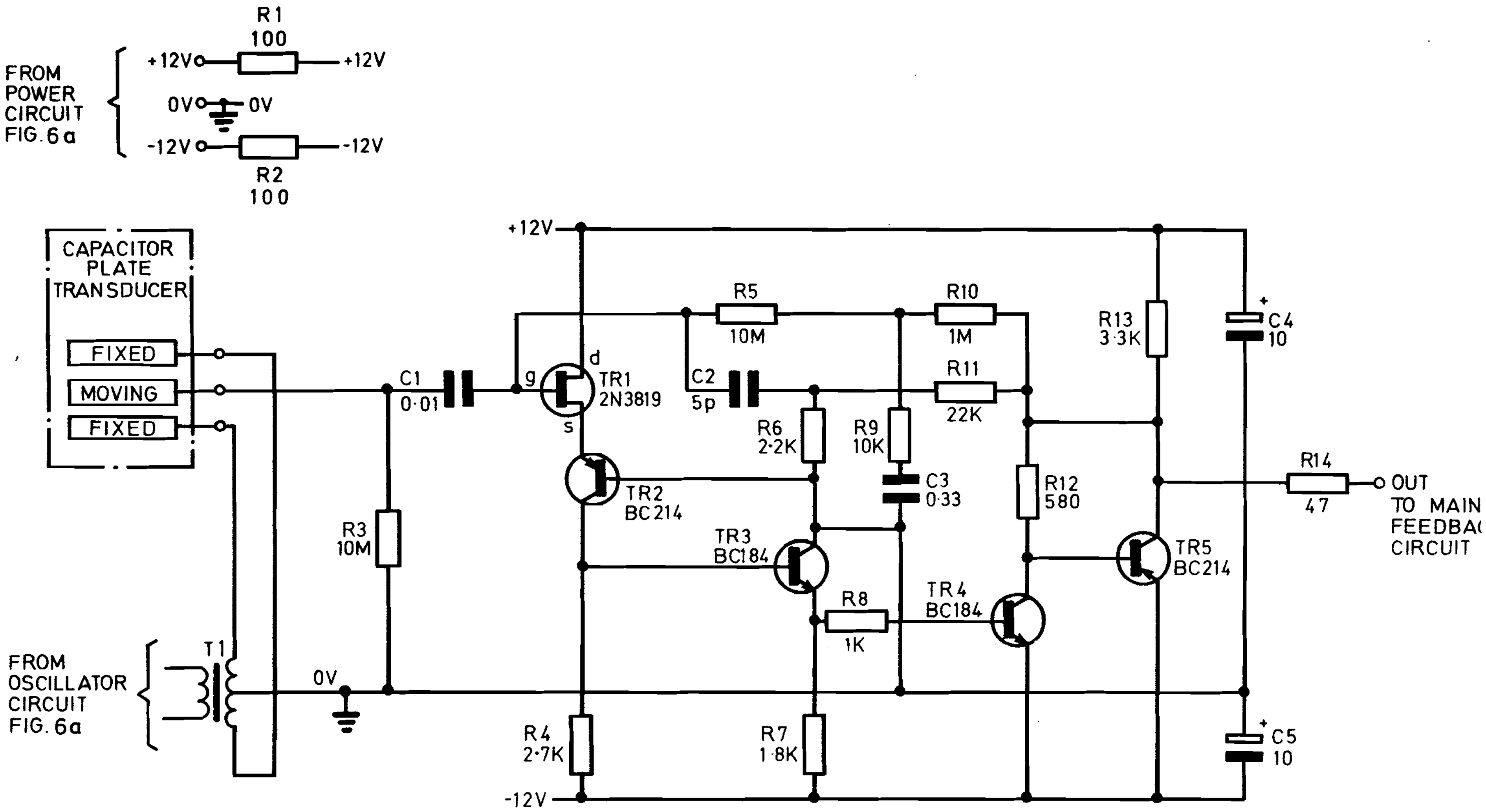



Figure 4. Signal Source and Pre-Amplifier

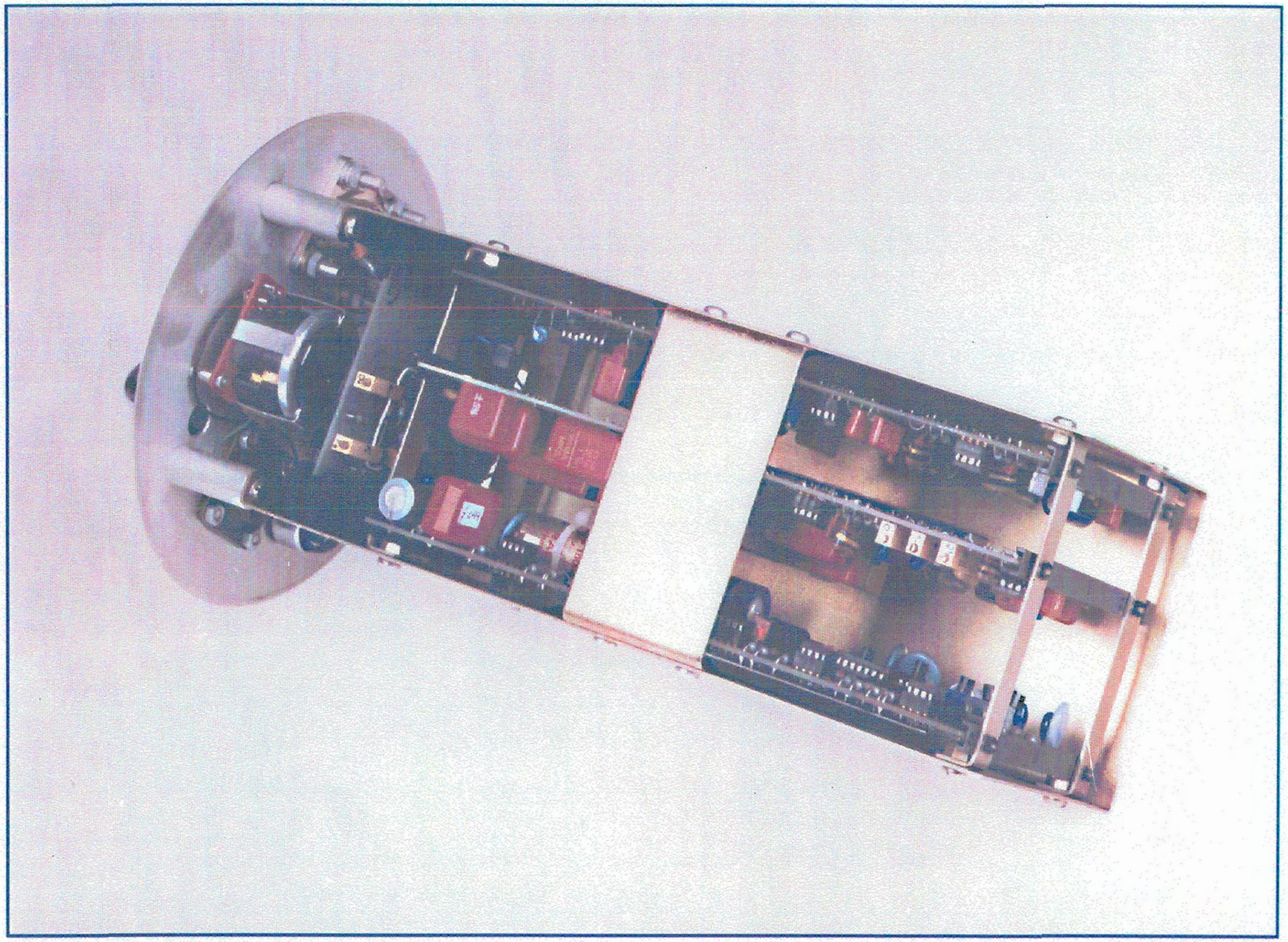


FIGURE 5(a)

Chassis and Printed Circuit Boards for Main Electronics Unit

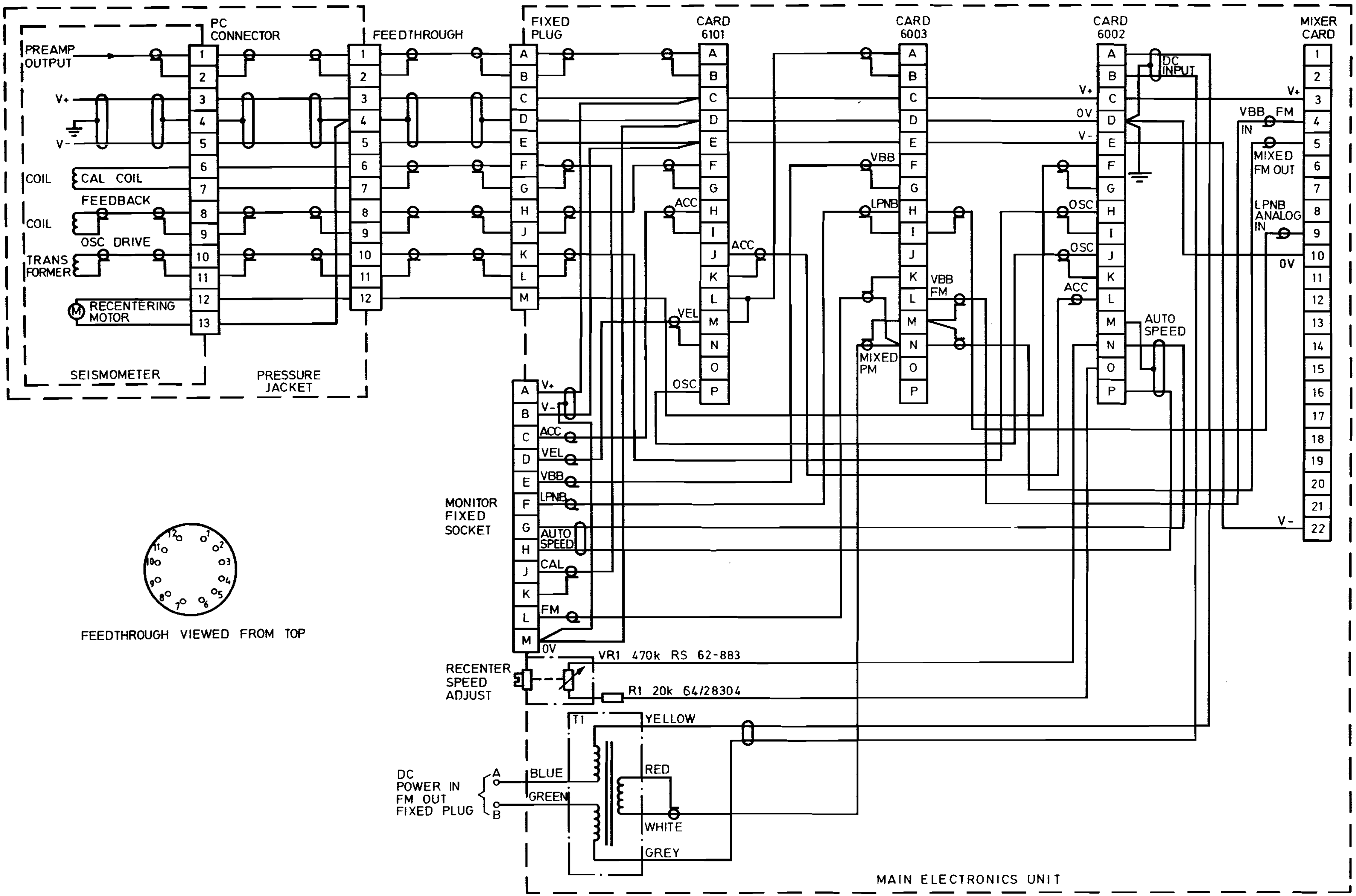
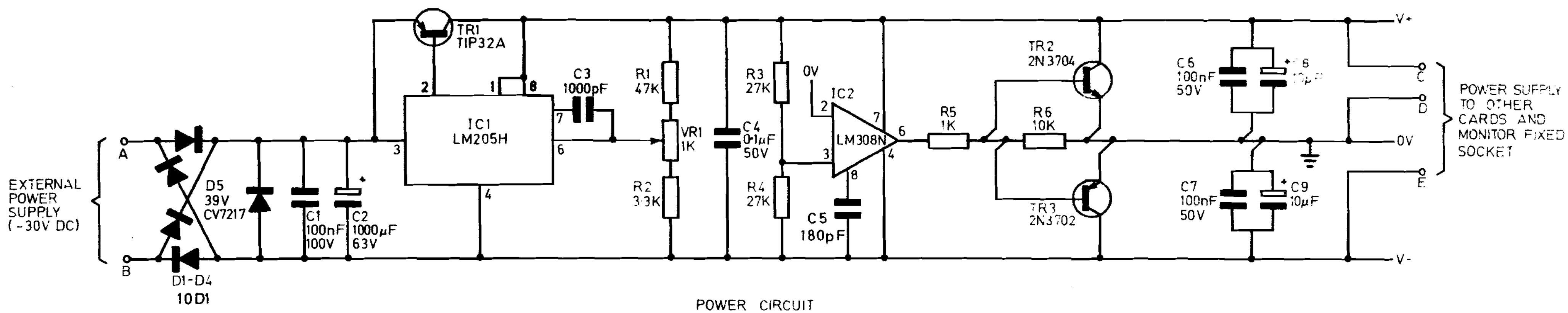
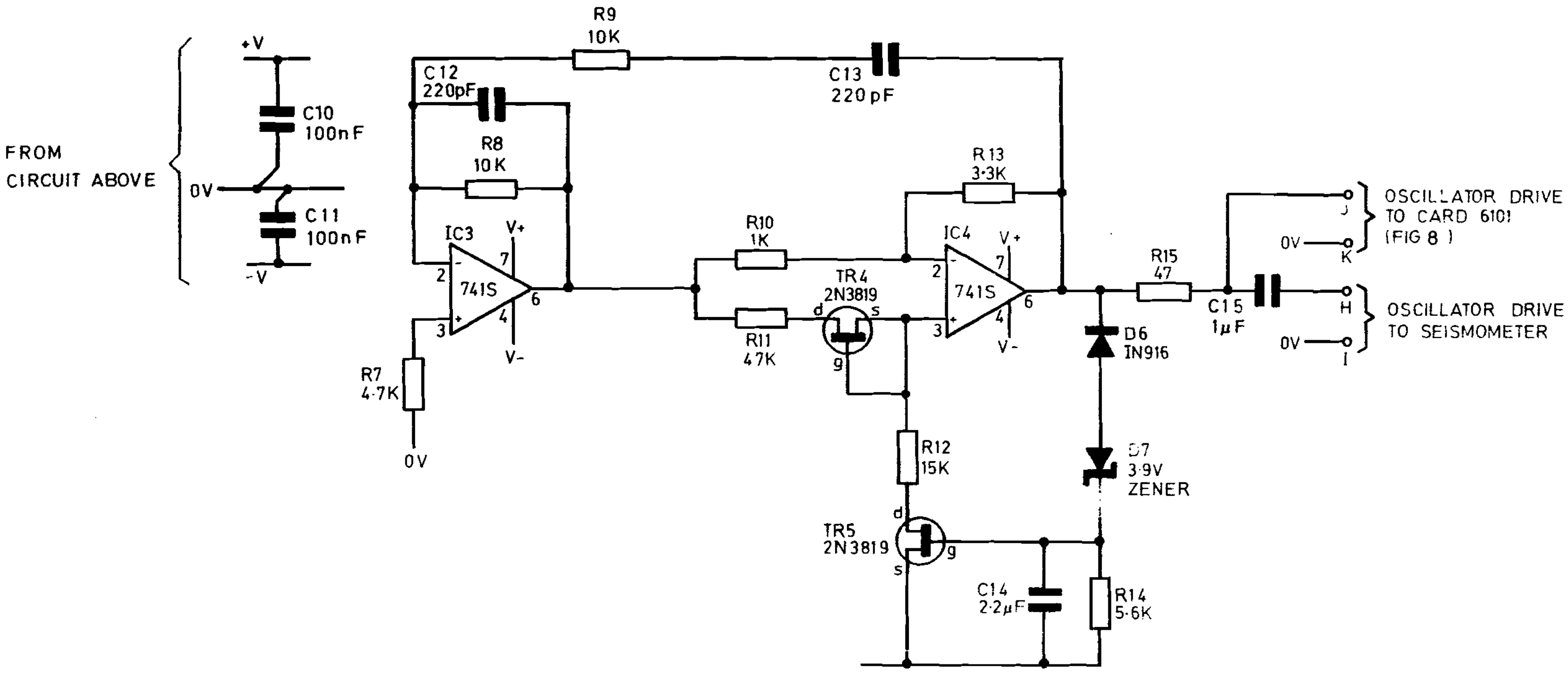



Figure 5(b) Main Electronics Unit Chassis Wiring




POWER CIRCUIT




DRIVE OSCILLATOR

Figure 6(a) Card 6002 Power and Oscillator Circuits

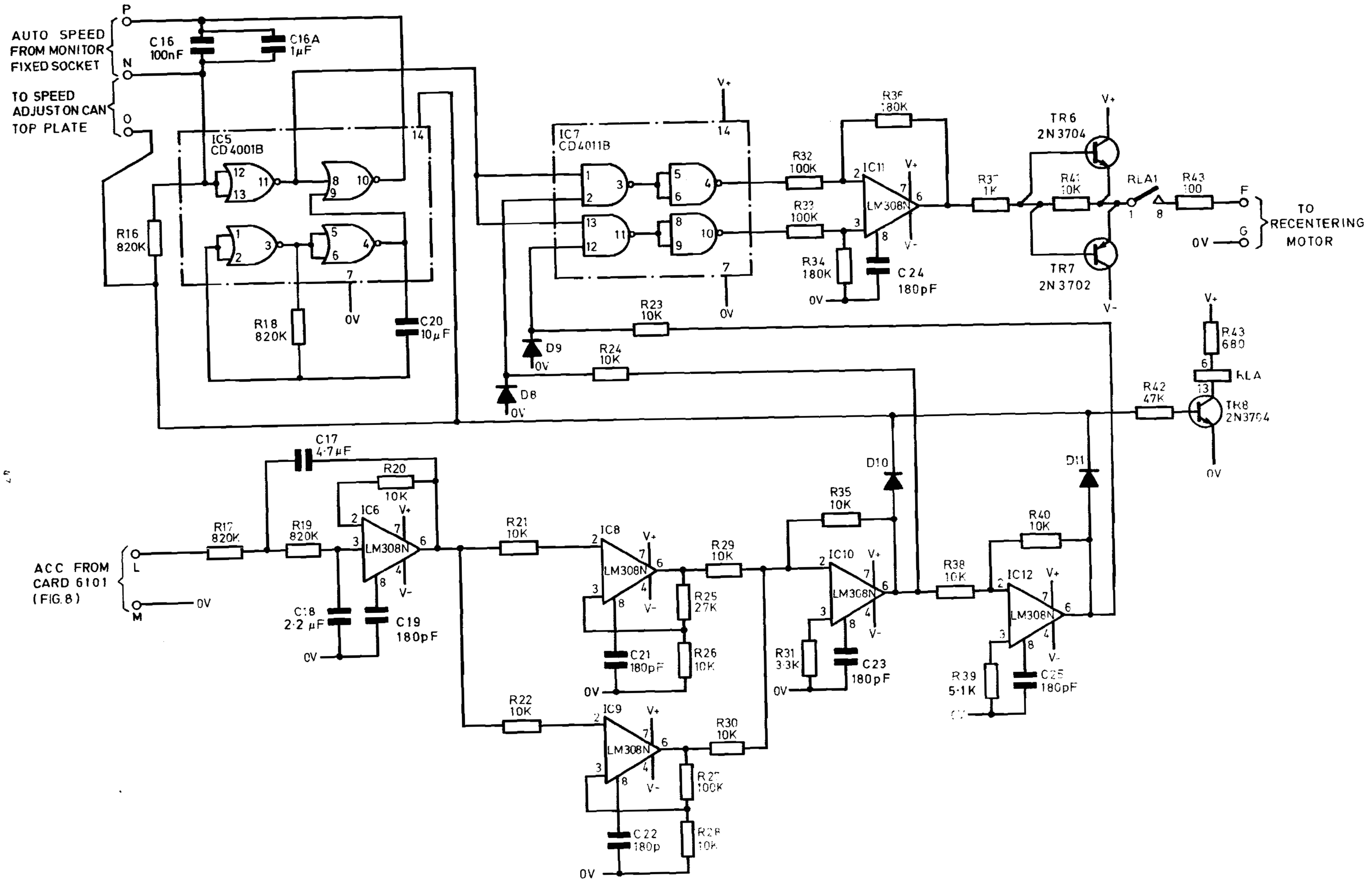



Figure 6(b) Card 6002 Recentering Circuit

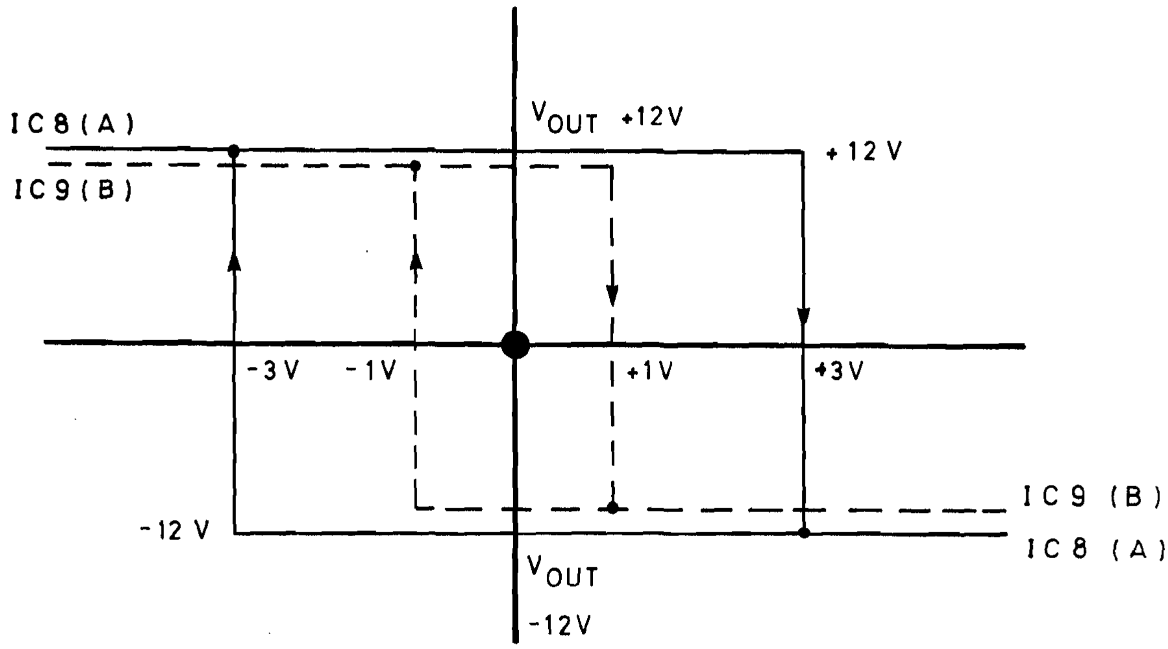



Figure 7. Range of Hysteresis Loops used in Recentering Detection Circuit

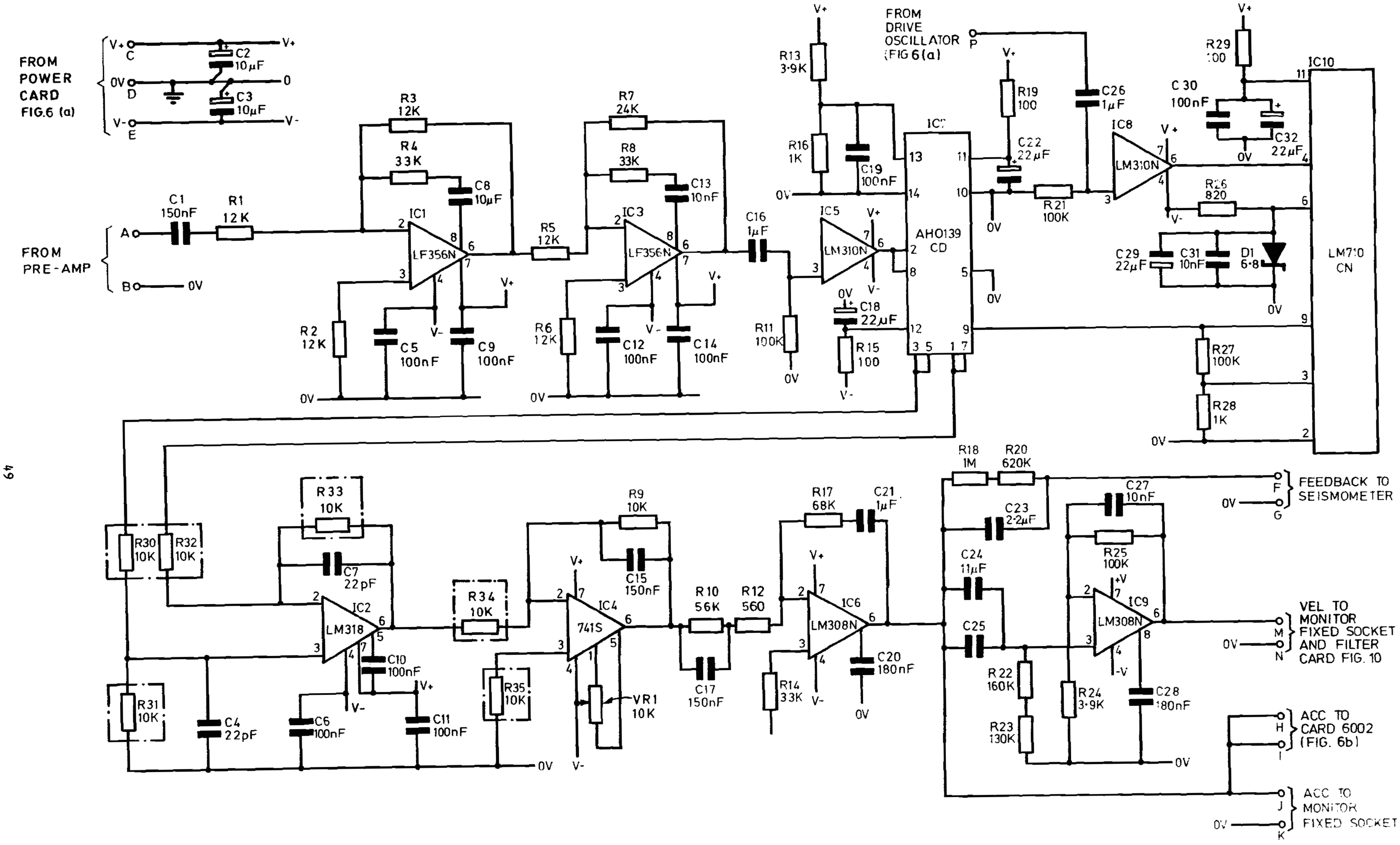



Figure 8 Card 6101 Feedback and High Pass Filter Circuits

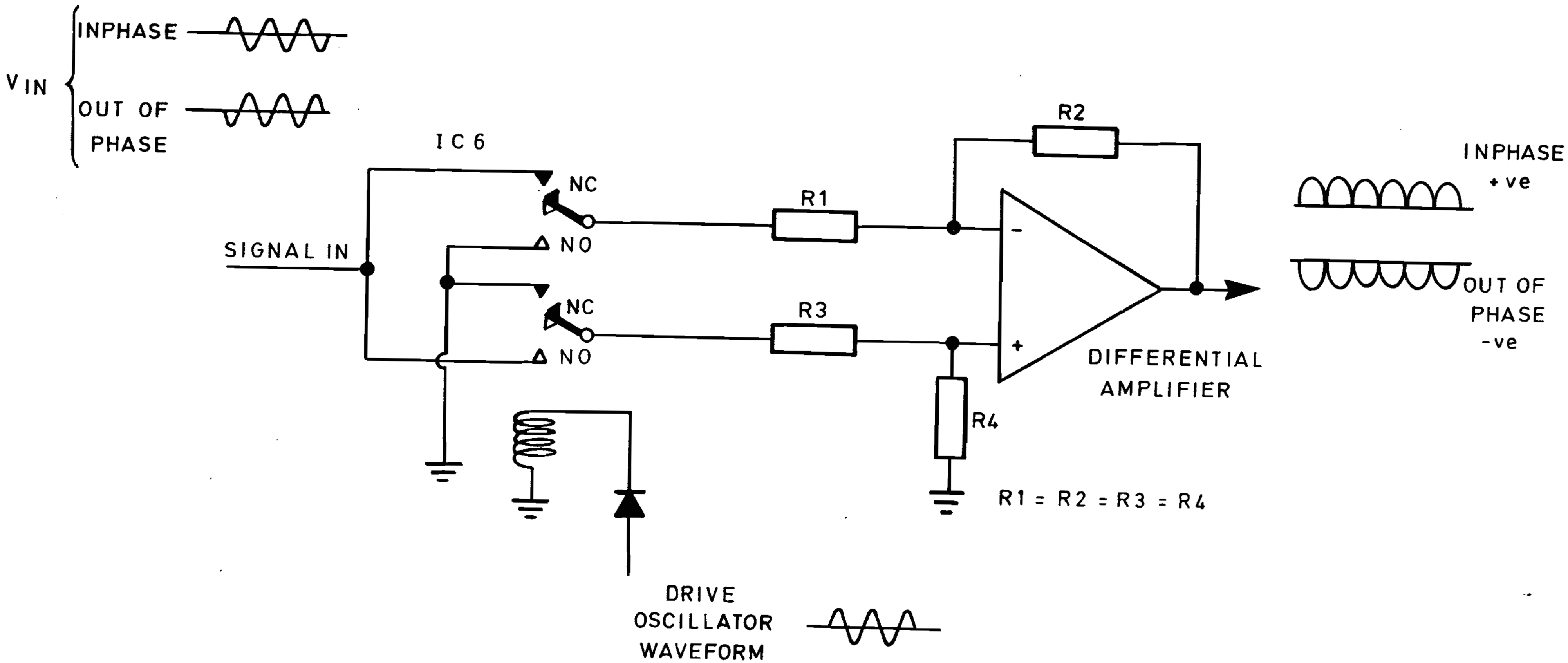



Figure 9. Basic Principles of Phase Sensitive Detector ( P S D )

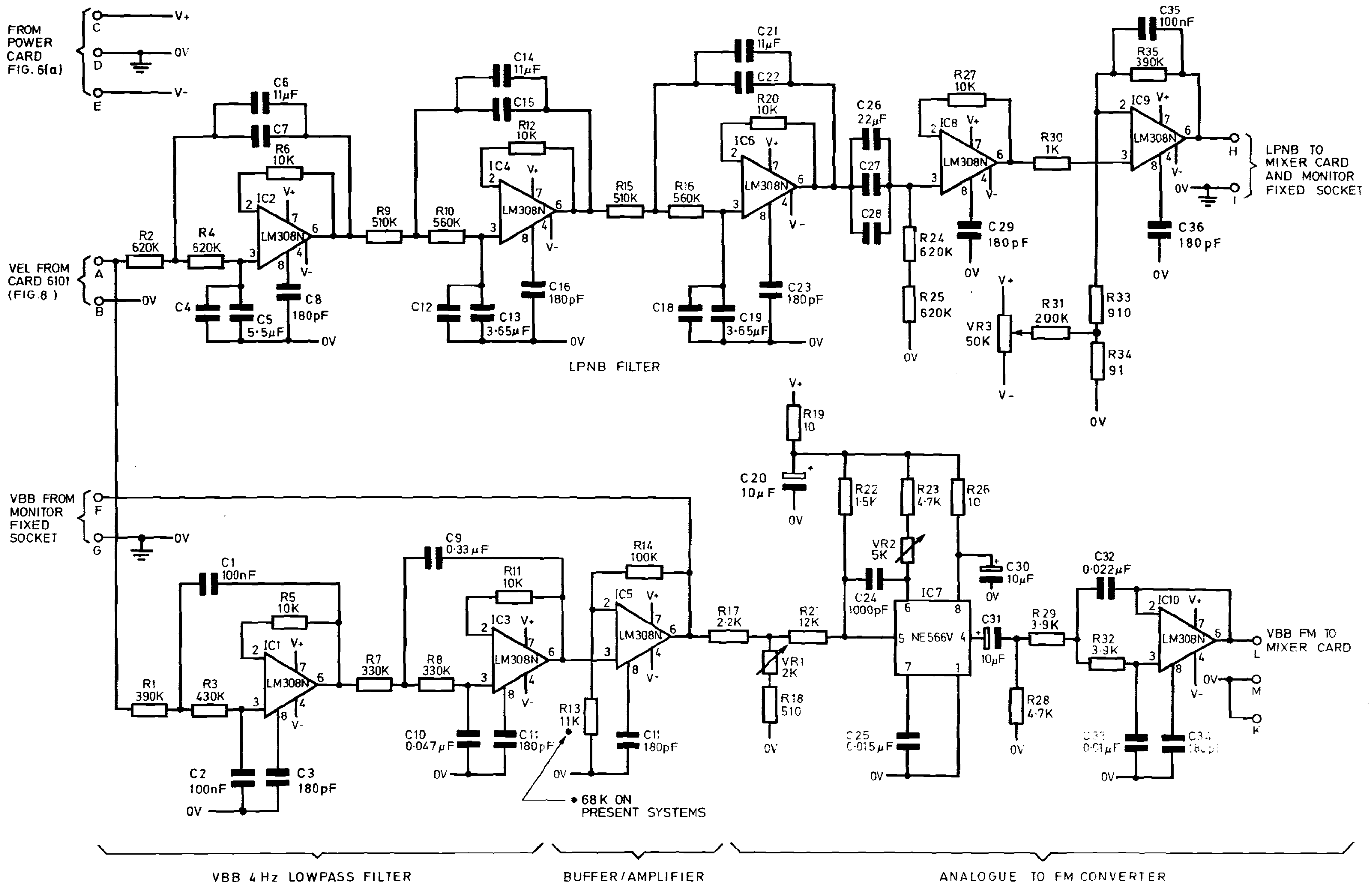



Figure 10 Card 6003 Filter Circuits

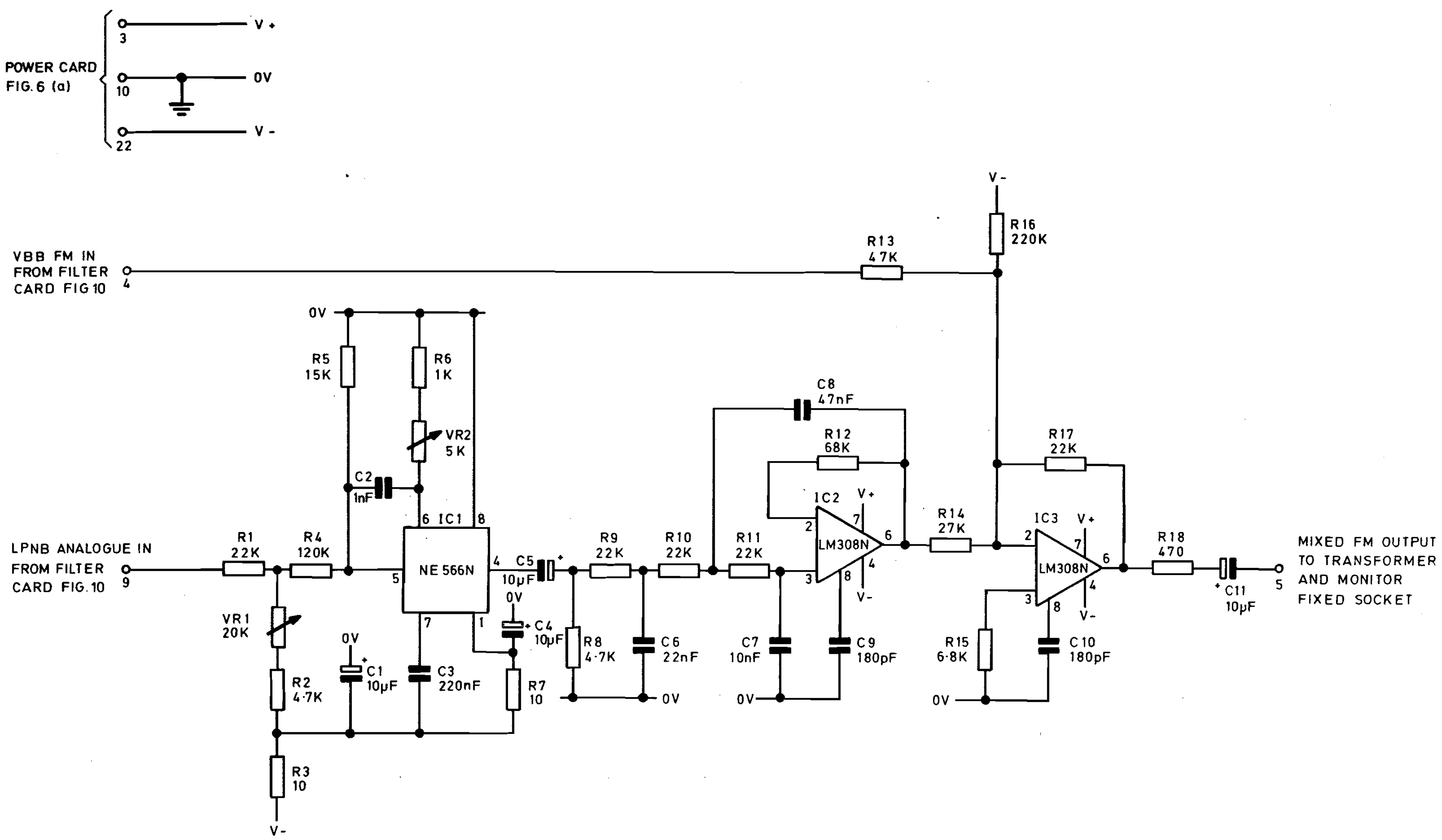



Figure 11. Mixer and Sender Circuit

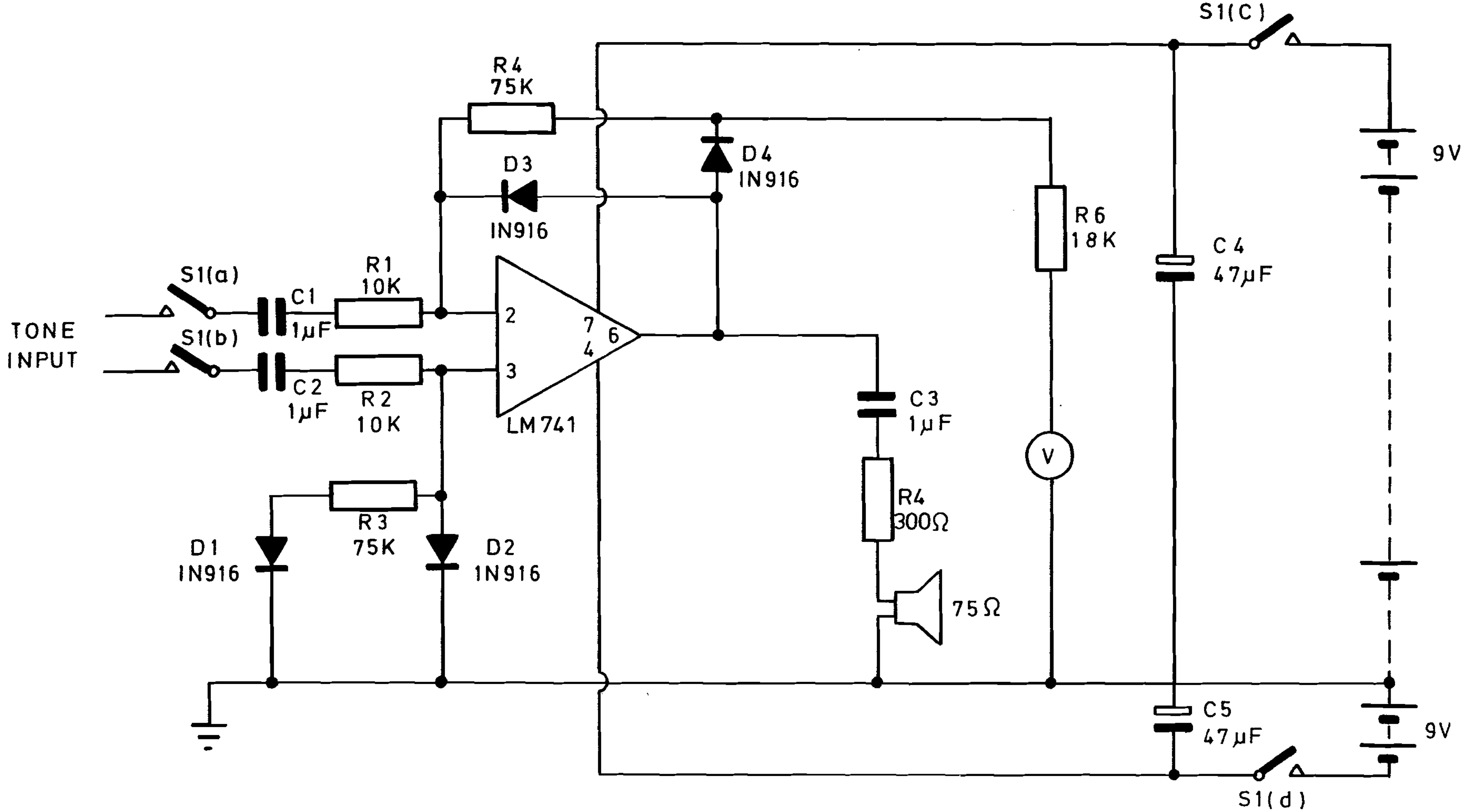



Figure 13. Circuit Diagram of F M Tone Detector


FIGURE 14

Seismic Monitor Box

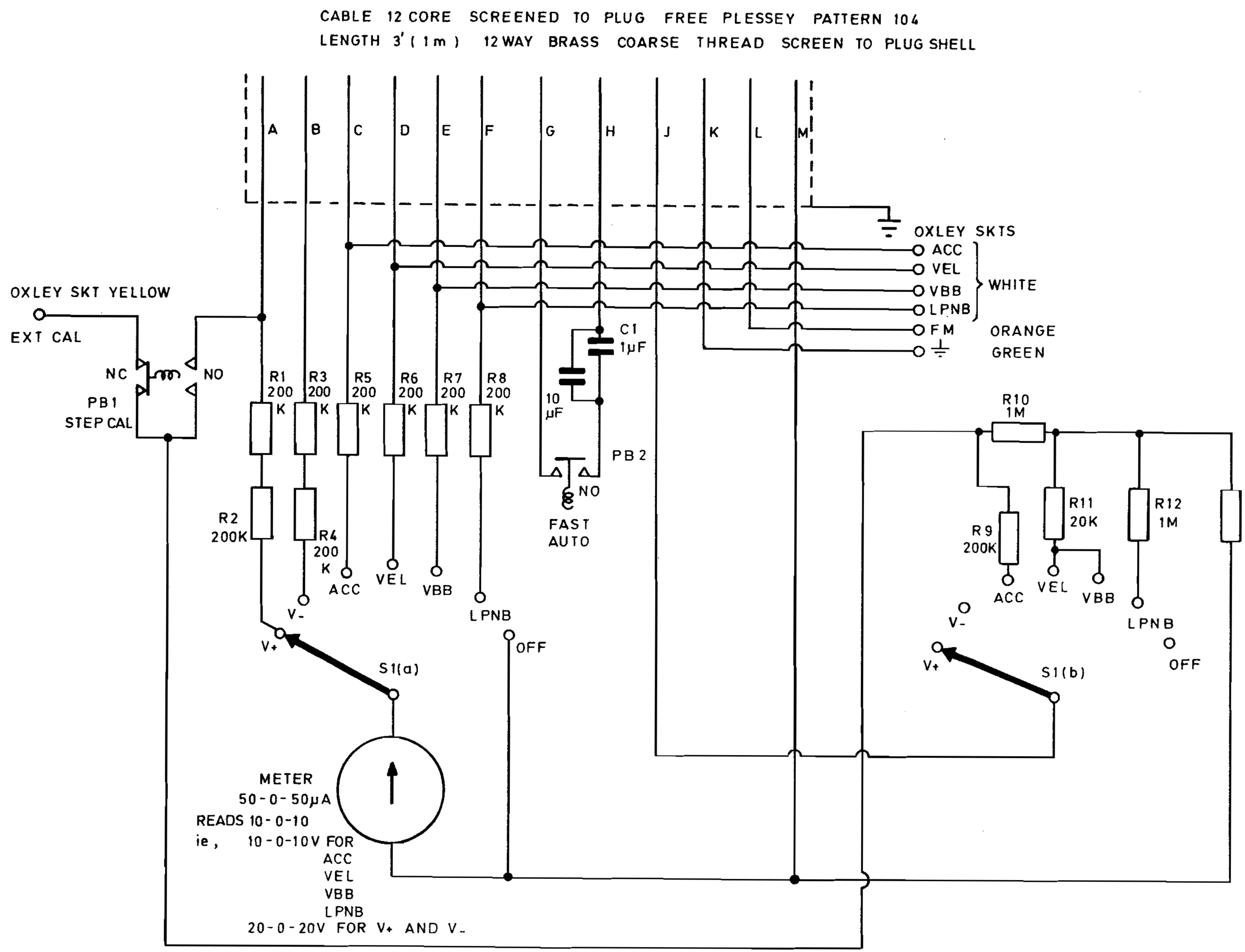



Figure 15. Circuit Diagram of Monitor Box

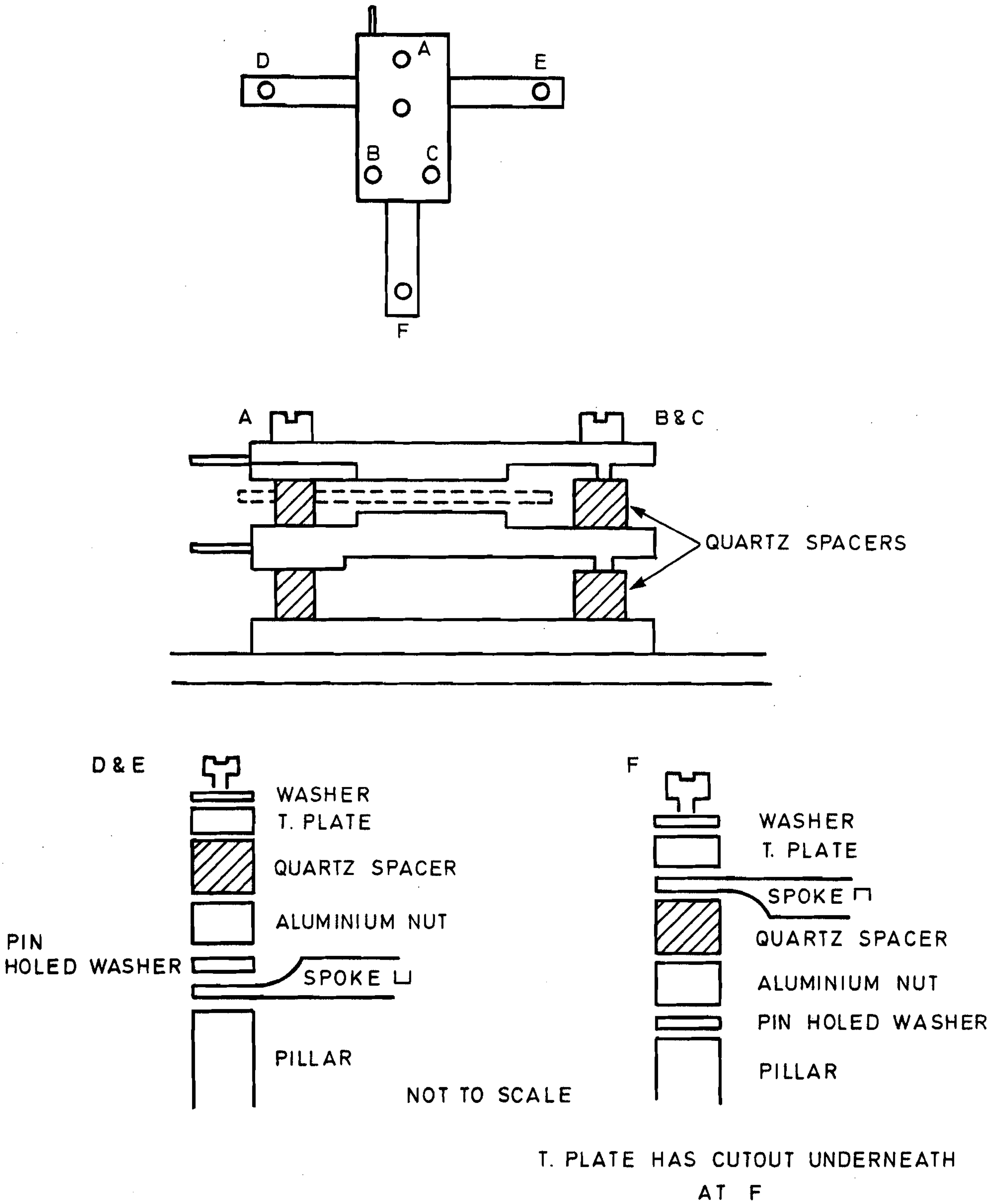



Figure 16. Capacitor Plate Assembly

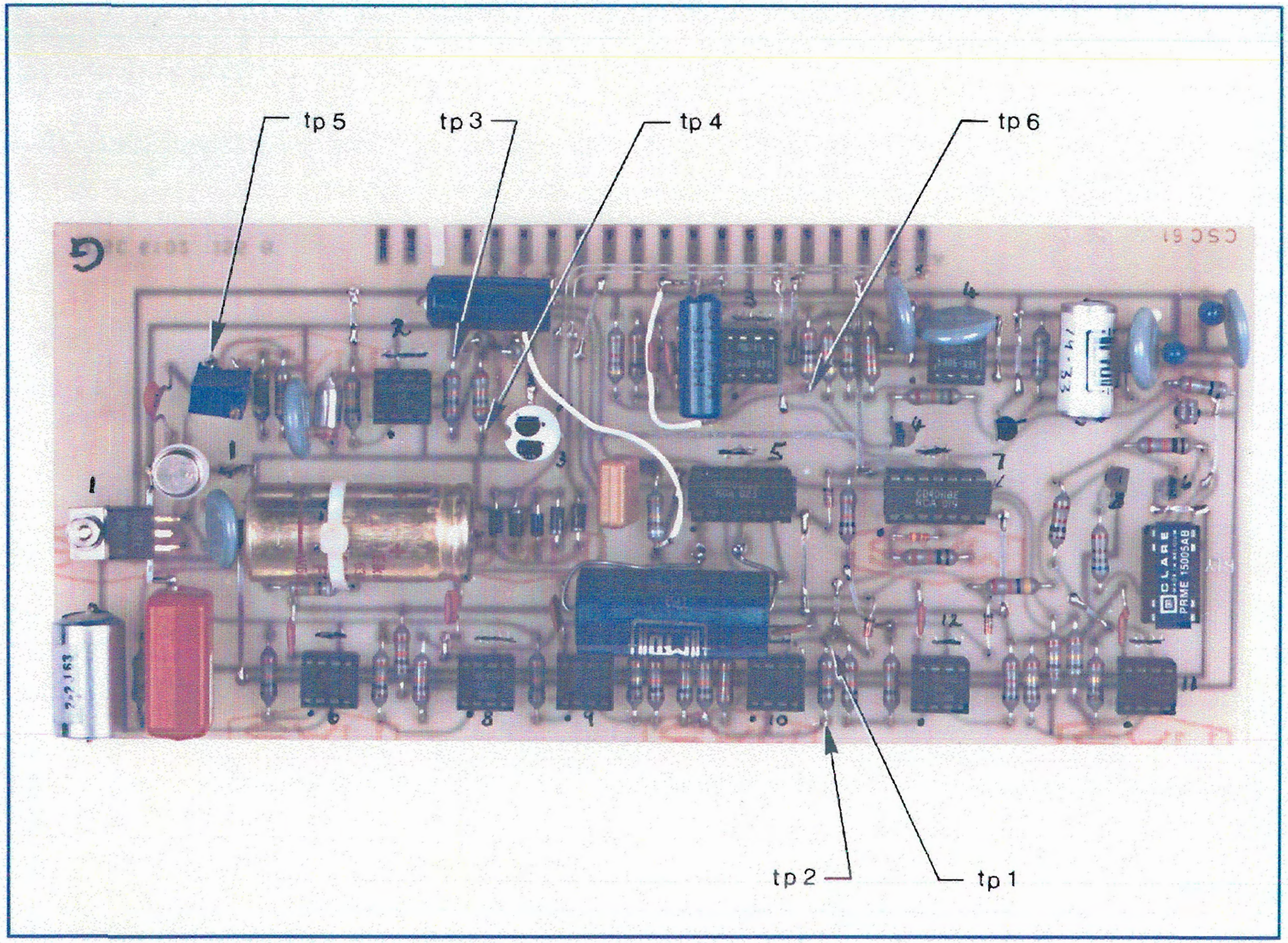



FIGURE 17

Location of Test Points on Power Card 6002

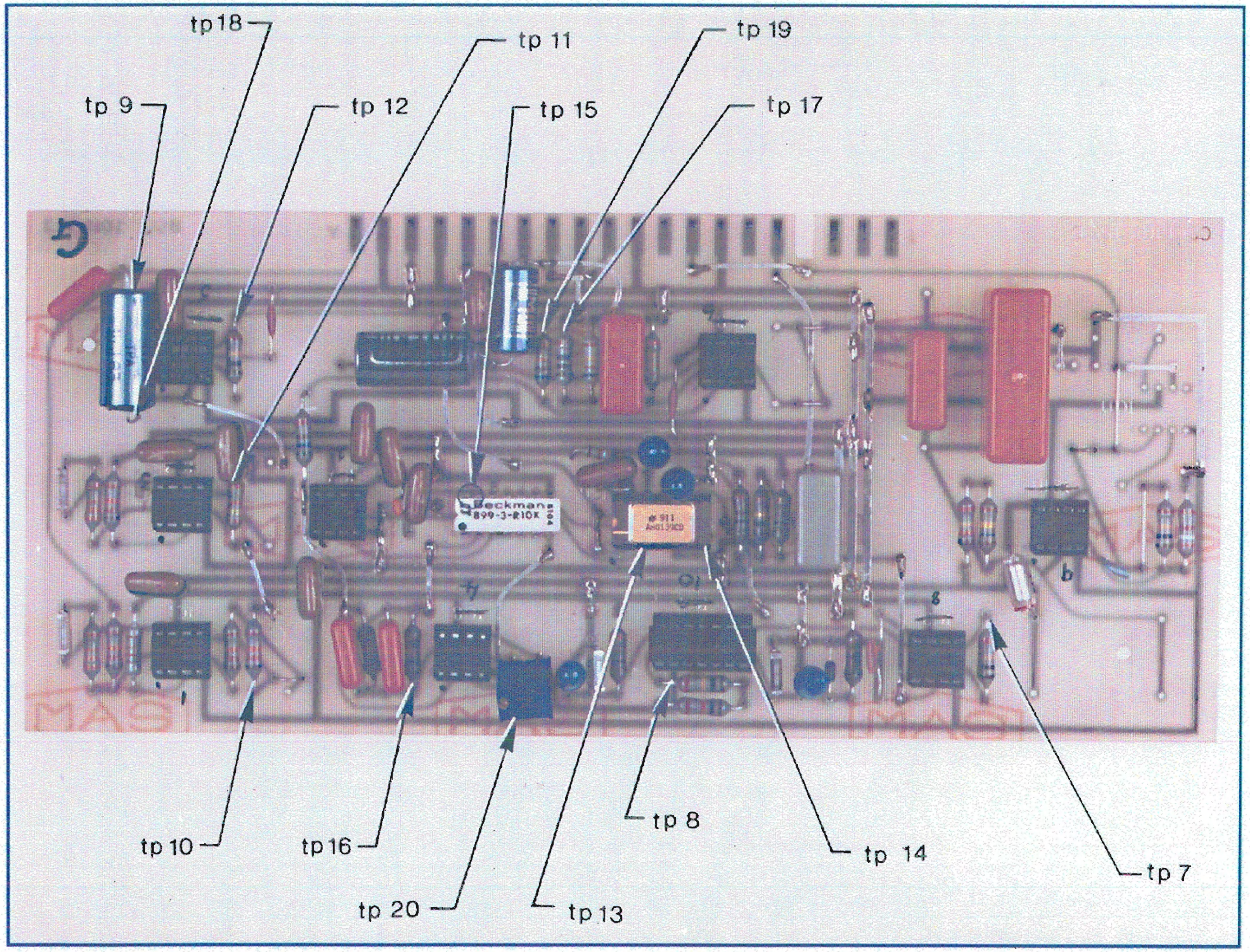



FIGURE 18

Location of Test Points on Feedback Card 6101

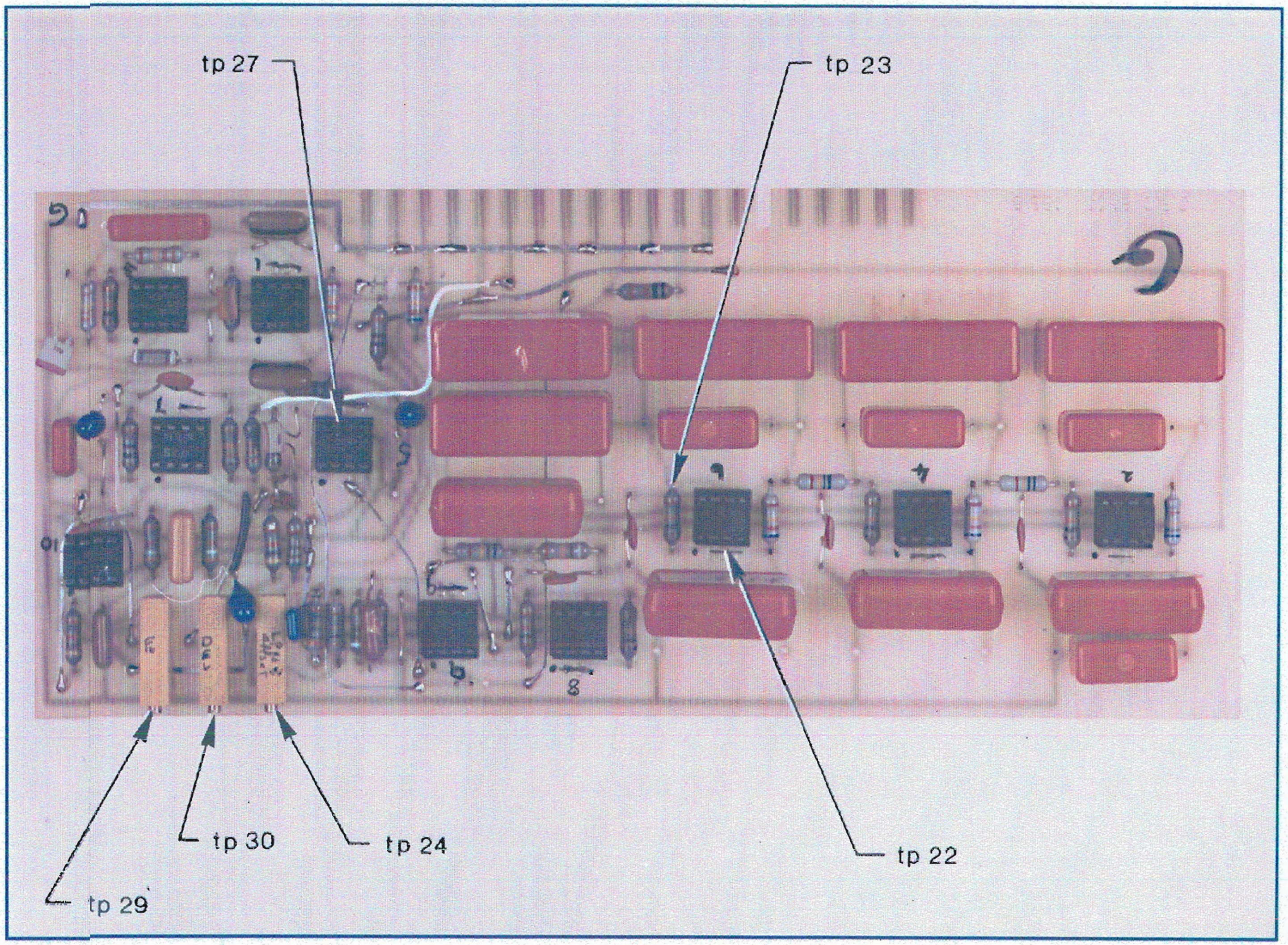



FIGURE 19

Location of Test Points on Filter Card 60

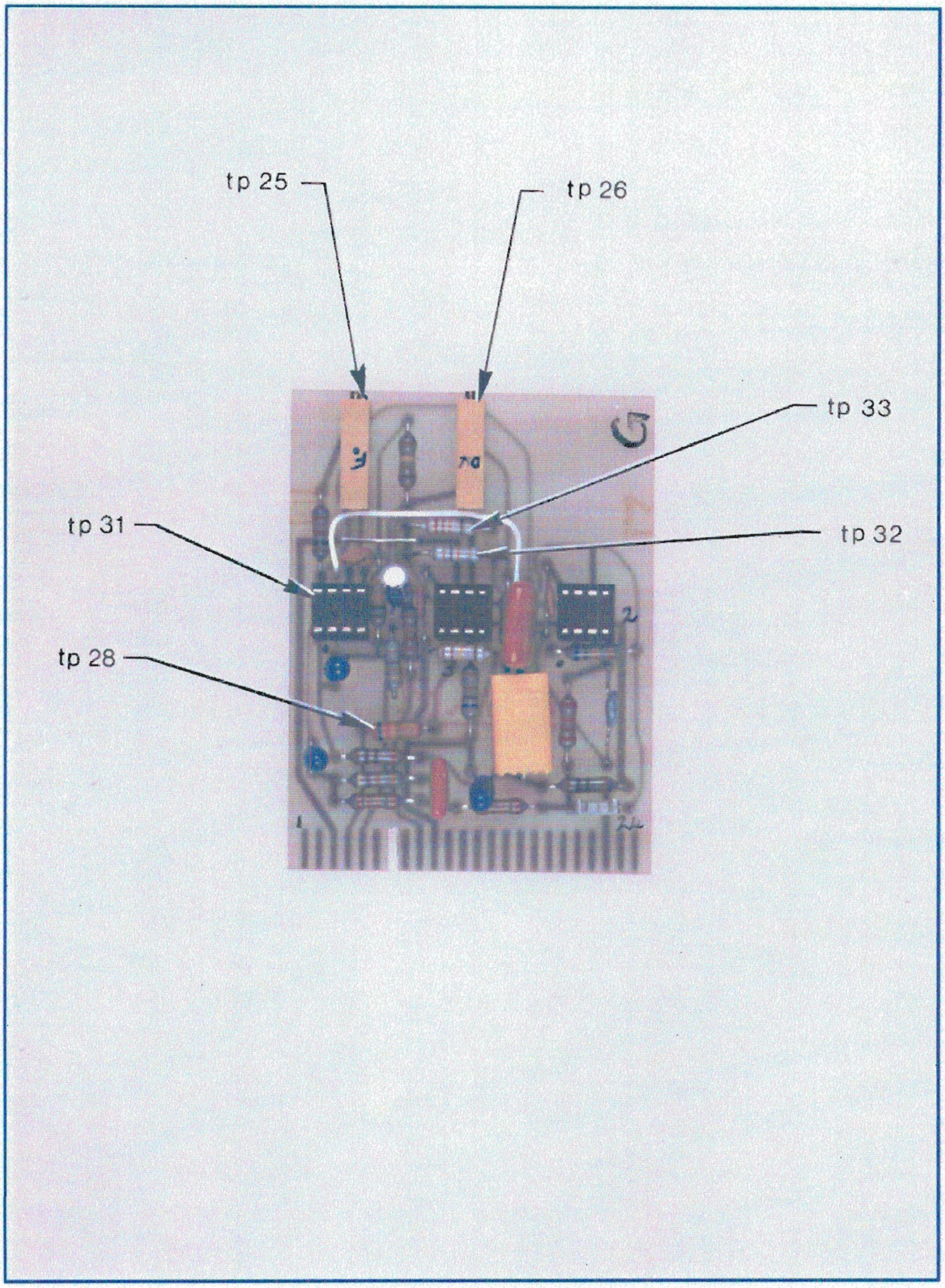



FIGURE 20

Location of Test Points on Mixer and Sender Card

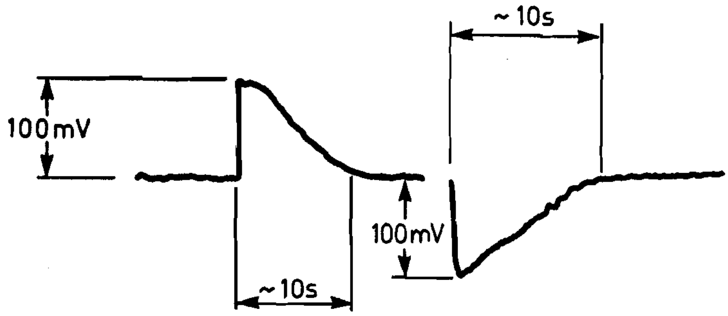



Figure 21. Signal Output from IC4 (Figure 8) in Response to a Current Step through the Calibration Coil

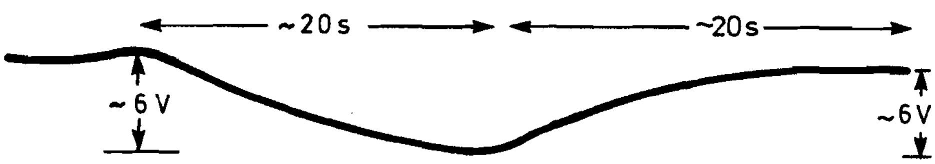
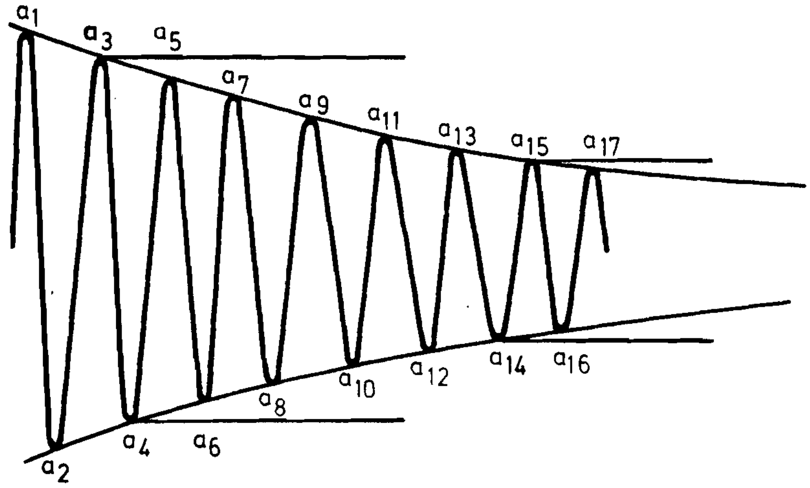



Figure 22. ACC Signal Output in Response to a Current Step through the Calibration Coil




IF AMPLITUDE OF $a_3 + a_4 = 2 \times (a_{15} + a_{14})$

NUMBER OF HALF CYCLES = $a_{14} - a_3 = a_{15} - a_4 = 11$

Figure 23. Example of Decay to Half Amplitude of Lightly Damped Oscillations

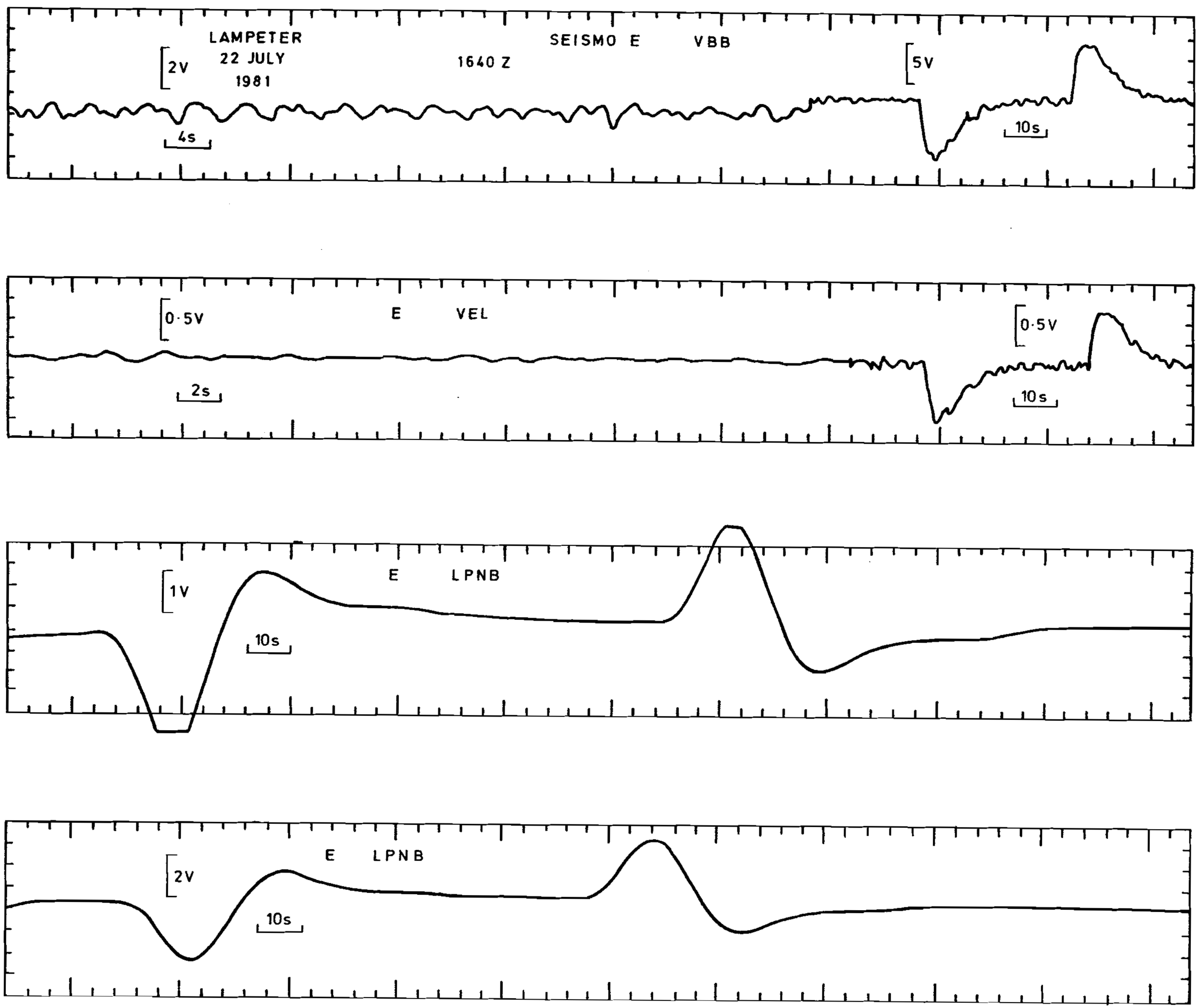



Figure 24. Examples of Current Step Calibrations using Monitor Box

DOCUMENT CONTROL SHEET

Overall security classification of sheet ..........UNCLASSIFIED..........

(As far as possible this sheet should contain only unclassified information. If it is necessary to enter classified information, the box concerned must be marked to indicate the classification eg (R), (C) or (S)).

| 1. DRIC Reference (if known) | 2. Originator's Reference | 3. Agency Reference | 4. Report Security Classification |
|---|---|---|---|
| - | AWRE Report No. 025/83 | - | UNLIMITED |

| 5. Originator's Code (if known) | 6. Originator (Corporate Author) Name and Location |
|---|---|
| - | Atomic Weapons Research Establishment, Aldermaston, Berkshire |
| **5a. Sponsoring Agency's Code (if known)** | **6a. Sponsoring Agency (Contract Authority) Name and Location** |
| - | - |

7. Title

The Mk IIIC Vertical Component Force Balance System. Part 2: Detailed Description, Calibration, Maintenance and Repair

7a. Title in Foreign Language (in the case of Translation)

-

7b. Presented at (for Conference Papers). Title, Place and Date of Conference

-

| 8. Author 1.Surname, Initials | 9a. Author 2 | 9b. Authors 3, 4 .... | 10. Date | pp | ref |
|---|---|---|---|---|---|
| Burch R F | - | - | February 1984 | 65 | 2 |
| **11. Contract Number** | **12. Period** | **13. Project** | **14. Other References** | | |
| - | - | - | - | | |

15. Distribution Statement

No Restriction

16. Descriptors (or Keywords) (TEST)

Seismometers

Abstract

A detailed description of the Mk IIIC vertical component force balance seismometer system is given and its repair, maintenance and calibration are discussed.

# Some Metric and SI Unit Conversion Factors

(Based on DEF STAN 00-11/2 "Metric Units for Use by the Ministry of Defence", DS Met 5501 "AWRE Metric Guide" and other British Standards)

| Quantity | Unit | Symbol | Conversion |
|---|---|---|---|
| **Basic Units** | | | |
| Length | metre | m | 1 m = 3.2808 ft<br>1 ft = 0.3048 m |
| Mass | kilogram | kg | 1 kg = 2.2046 lb<br>1 lb = 0.45359237 kg<br>1 ton = 1016.05 kg |
| **Derived Units** | | | |
| Force | newton | $N = kg\ m/s^2$ | 1 N = 0.2248 lbf<br>1 lbf = 4.44822 N |
| Work, Energy, Quantity of Heat | joule | J = N m | 1 J = 0.737562 ft lbf<br>1 J = $9.47817 \times 10^{-4}$ Btu<br>1 J = $2.38846 \times 10^{-4}$ kcal<br>1 ft lbf = 1.35582 J<br>1 Btu = 1055.06 J<br>1 kcal = 4186.8 J |
| Power | watt | W = J/s | 1 W = 0.238846 cal/s<br>1 cal/s = 4.1868 W |
| Electric Charge | coulomb | C = A s | - |
| Electric Potential | volt | V = W/A = J/C | - |
| Electrical Capacitance | farad | F = A s/V = C/V | - |
| Electric Resistance | ohm | $\Omega$ = V/A | - |
| Conductance | siemen | $S = 1\ \Omega^{-1}$ | - |
| Magnetic Flux | weber | Wb = V s | - |
| Magnetic Flux Density | tesla | $T = Wb/m^2$ | - |
| Inductance | henry | H = V s/A = Wb/A | - |
| **Complex Derived Units** | | | |
| Angular Velocity | radian per second | rad/s | 1 rad/s = 0.159155 rev/s<br>1 rev/s = 6.28319 rad/s |
| Acceleration | metre per square second | $m/s^2$ | 1 $m/s^2$ = 3.28084 $ft/s^2$<br>1 $ft/s^2$ = 0.3048 $m/s^2$ |
| Angular Acceleration | radian per square second | $rad/s^2$ | - |
| Pressure | newton per square metre | $N/m^2$ = Pa | 1 $N/m^2$ = $145.038 \times 10^{-6}$ $lbf/in^2$<br>1 $lbf/in^2$ = $6.89476 \times 10^3$ $N/m^2$ |
| | bar | bar = $10^5$ $N/m^2$ | -<br>1 in. Hg = 3386.39 $N/m^2$ |
| Torque | newton metre | N m | 1 N m = 0.737562 lbf ft<br>1 lbf ft = 1.35582 N m |
| Surface Tension | newton per metre | N/m | 1 N/m = 0.0685 lbf/ft<br>1 lbf/ft = 14.5939 N/m |
| Dynamic Viscosity | newton second per square metre | N $s/m^2$ | 1 N $s/m^2$ = 0.0208854 lbf $s/ft^2$<br>1 lbf $s/ft^2$ = 47.8803 N $s/m^2$ |
| Kinematic Viscosity | square metre per second | $m^2/s$ | 1 $m^2/s$ = 10.7639 $ft^2/s$<br>1 $ft^2/s$ = 0.0929 $m^2/s$ |
| Thermal Conductivity | watt per metre kelvin | W/m K | - |
| **Odd Units*** | | | |
| Radioactivity | becquerel | Bq | 1 Bq = $2.7027 \times 10^{-11}$ Ci<br>1 Ci = $3.700 \times 10^{10}$ Bq |
| Absorbed Dose | gray | Gy | 1 Gy = 100 rad<br>1 rad = 0.01 Gy |
| Dose Equivalent | sievert | Sv | 1 Sv = 100 rem<br>1 rem = 0.01 Sv |
| Exposure | coulomb per kilogram | C/kg | 1 C/kg = 3876 R<br>1 R = $2.58 \times 10^{-4}$ C/kg |
| Rate of Leak (Vacuum Systems) | millibar litre per second | mb l/s | 1 mb = 0.750062 torr<br>1 torr = 1.33322 mb |

*These terms are recognised terms within the metric system.