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DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1971/48

THREE COMPONENT FLUXGATE MAGNETIC VARIOGRAPH TYPE MFR 1

by

K.J. Seers

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This equipment was designed by staff of the Geophysical Laboratories of the Bureau of Mineral Resources, Geology and Geophysics.

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K.J. Seers

Mechanical Design : W. Olbrich

Project Engineer : K.J. Seers

The detector assembly was constructed by staff of the Geophysical Workshops.

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FOREWORD

In 1962 a proposal was put to the Design and Development Group (now Instrument Development Group) of the Geophysical Branch to produce a three-component fluxgate variograph for use in regional magnetic surveys by the Bureau of Mineral Resources (BMR). Instruments used for this work up to that time were of the suspended magnet type and consequently could not provide the resolution, repeatability, ruggedness and ease of operation inherent in the electronic fluxgate magnetometer. The then leader of the Design and Development Group, Mr J.K. Newman, had had extensive experience in designing fluxgates for airborne application and he, together with Dr W.D. Parkinson from the Observatory Group, laid down the fundamental specifications required. The only possible problems foreseen were the attainment of a low baseline drift, and the possible interaction of the three detectors in close proximity.

Because of other work, the project did not progress far until late in 1963, by which time Mr Newman had resigned from BMR. The author completed the project in 1965. Since then the variograph has been in almost constant use by the Regional Magnetic Group. Minor modifications have been necessary, but up to the time of submitting this Record (August 1969) satisfactory results have been obtained.

The main part of this Record was written in 1965 for use as a handbook. Modifications incorporated since then are described in an addendum, reference being made to this in the text where necessary.

Although all circuit development and testing was performed in the BMR laboratories, construction of the electronics chassis was contracted out to Zephyr Products Pty Ltd.

It is of interest to note that the development involved in this project contributed to the improvement of ground station storm-warning fluxgates (Type MFD4) and to the development of an improved airborne fluxgate (Type MFS6). The development of these instruments has in turn laid the basis for an improved three-component fluxgate, the design of which is a current project in the Instrument Development Group.

Note on Units: Geophysics traditionally use the unit "gamma" for measurements of magnetic induction. In the cgs emu system 1 gamma = 10^{-5} gauss. However, to workers in other fields this unit is virtually unknown. With the recent widespread acceptance of the SI system of units, wherein the "use of the unit gamma is deprecated", the text of this record was altered to conform with SI requirements. The fundamental unit of magnetic induction in the SI system is the tesla, which corresponds to 10^{4} gauss. Hence the gamma is equivalent to the nanotesla (abbreviated nT).

To summarize, 1 gamma = 10^{-5} gauss = 10^{-9} tesla = 1 nT.

As it is not convenient to alter circuit diagrams at this time, the term gamma or its symbol does still appear on a few diagrams.

SECTION 1 : SPECIFICATIONS

The MFR1 was designed as a three-component instrument but is constructed, with the exception of the detector, as three physically independent units which can each be used as a single-component instrument.

1.1 Specifications per Channel

Sensitivity:	Four switched ranges, viz., 50, 100, 250 and 1000 nT full scale with independent calibration for each range.
Noise:	Less than 1/4 nT.
Output:	-0.5 to +0.5 milliamp into 100-ohm centre zero recorder.
Baseline:	Zero or variable from ±5.5 to ±61,000 nT.
Fiducial marking:	By remote non-magnetic foot switch. Fiducial deflection may be switched positive or negative and has amplitude approximately one-tenth full scale for each range. See Addendum.
Temperature effects:	
(a) Detector.	
Zero drift:	Approximately 1 part in 10^4 per degree C uncompensated. See Addendum for details of compensation.
(b) Electronics excluding baseline supply:	
Zero drift:	Better than 0.01% of full scale per °C.
Sensitivity:	Better than 0.1% per °C.
(c) Baseline supply:	
Zero drift:	Approximately - 1 part in 10^5 per °C.
Power supply:	11-16 volts d.c. internally regulated to 9.0 volts. Current drain at 12 volts is 325 milliamps, excluding recorder motor. Internal regulator is equipped with reverse polarity, overvoltage, and short circuit protection.

Operating temperature range: 0 to 50°C.

Total weight of three-component station including transit cases, but excluding power supply and test instruments: 166 lbs.

SECTION 2 : PRINCIPLES OF OPERATION

2.1 The Fluxgate Detector

The detector is a balanced saturating transformer type as described by Vacquier (1), and utilizes secondary tuning as proposed by Serson and Hannaford (2).

Two hollow cylindrical "PERMALLOY C" cores are placed in glass or ceramic tubes. Around each tube is wound a primary or drive coil. The two primaries are placed together side by side and the windings connected, in series opposition, to a 5-kHz voltage source which causes each core to saturate for part of each half-cycle.

If the two cores are identical and there is no external magnetic field, the astatic configuration of the drive coils will ensure that no emf is induced across a secondary or detector coil wound round the entire primary assembly.

If, however, a component of an external magnetic field exists along the cores' axes, it will aid the saturation of one core and oppose that of the other, i.e. the cores will not saturate simultaneously. It can be shown that under these conditions a signal will be induced in the secondary at frequencies which are even harmonics of the drive frequency. Moreover, the amplitudes of the harmonics are proportional to field strength, for small fields. A reversal of field produces a reversal of phase of the induced signal.

The signal is richest in second harmonic (10 kHz) and it is this frequency which is filtered, amplified, and measured for amplitude and phase to give a measurement of strength and direction of the component of external field along the detector axis.

Detection sensitivity is considerably increased by tuning the detector coil to 10 kHz. In fact, unless a damping network is used, tuning can produce infinite sensitivity, with resultant instability. There exists an optimum combination of drive frequency, drive amplitude, tuning capacitance, and damping resistance for maximum stable sensitivity.

(1) Vacquier, V.V., and Gulf Research Development Company 1946 - U.S. Patent No. 2406870.

(2) Serson, P.H., and Hannaford, W.L.W., 1956 - "Portable Electrical Magnetometer", Canadian Journal of Technology. Vol. 34, p. 232.

Tuning also removes a large proportion of unwanted harmonics which may otherwise overload the amplifier and so produce zero error and reduced sensitivity.

If the cores are not matched exactly and the drive signal contains a small second-harmonic component, this component will be detected as though it were part of the desired signal and will produce a small zero error. Provision is made for removing this error. (Section 5).

2.2 Backing-off

Variations of a few nanoteslas are to be detected in a field of many thousands of nanoteslas. This is achieved by neutralizing or backing-off most of the field by the baseline controls. These cause a stable direct current to flow through the detector coil in the direction required to produce a field opposing the measured field. Hence the detector sees only the difference between the two fields.

2.3 Feedback coil

To stabilize the instrument against sensitivity changes caused by component drift, temperature variation, etc., the standard technique of applying negative feedback is used. Feedback current is passed through a third coil wound round the detector coil.

The feedback coil can be used for calibration purposes if its coil constant is known. Also, fiducial marking is achieved by passing a current through this coil.

2.4 Scale values by variable feedback

The forward signal path with no feedback applied is drawn in Figure 2.1.

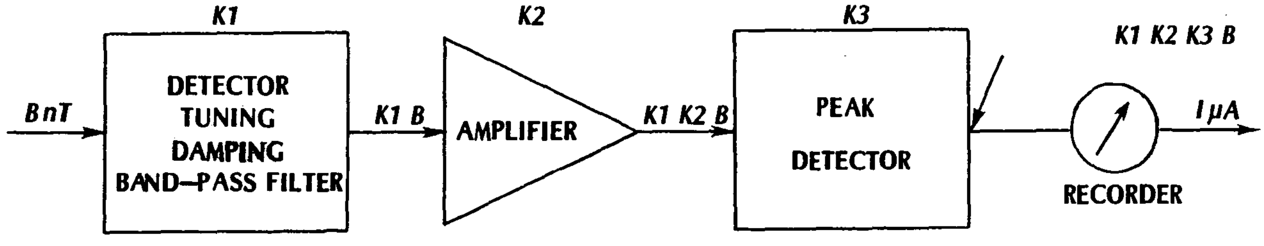


Fig. 2.1 Forward Signal Path

Let K_1 volts/nT be the transfer function of the tuned and damped detector followed by the bandpass filter. Let K_2 be the amplifier voltage gain.

Let K_3 microamps/volt be the transfer function of the peak detector. Then for a field B nT,

$$I = K_1 K_2 K_3 B$$
$$= Ao\ B \text{ microamps}$$

where $Ao = K_1 K_2 K_3$ is the open loop system gain.

Now consider the application of negative feedback, as in Figure 2.2.

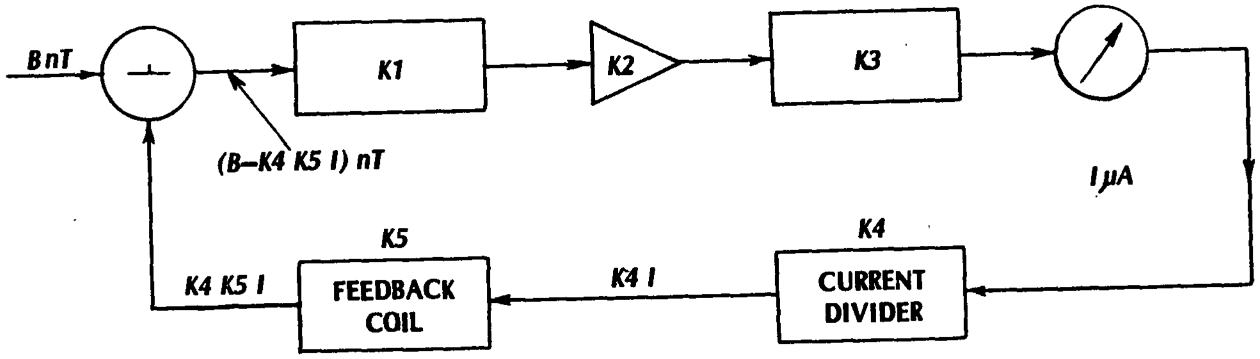


Fig. 2.2 Application of Negative Feedback

Let K_4 be the transfer function of the current divider, i.e. K_4 is the fraction of the recorder current I passed through the feedback coil. (K_4 1). Let K_5 nT/microamp be the coil constant of the feedback coil. The field produced by the feedback current subtracts from the external field and this is indicated by the negative sign in the summing node in Figure 2.2. Current through the recorder is now given by:

$$I = Ao\ (B - K_4 K_5 I)$$

i.e.

$$I/B = Ac = Ao/(1 + \beta\ Ao)$$

where $\beta = K_4 K_5$ is known as the feedback factor and Ac is the closed loop gain in microamps per nanotesla.

If Ao is very large and β Ao is much greater than unity,

$$Ac \approx \frac{1}{\beta}$$

i.e. the closed loop gain is essentially independent of open loop gain and is determined mainly by a resistor ratio K_4 and a coil constant K_5, both of which are stable.

In the MFR1 the value of K_4 required for each scale value is obtained with the circuit arrangement of Figure 2.3.

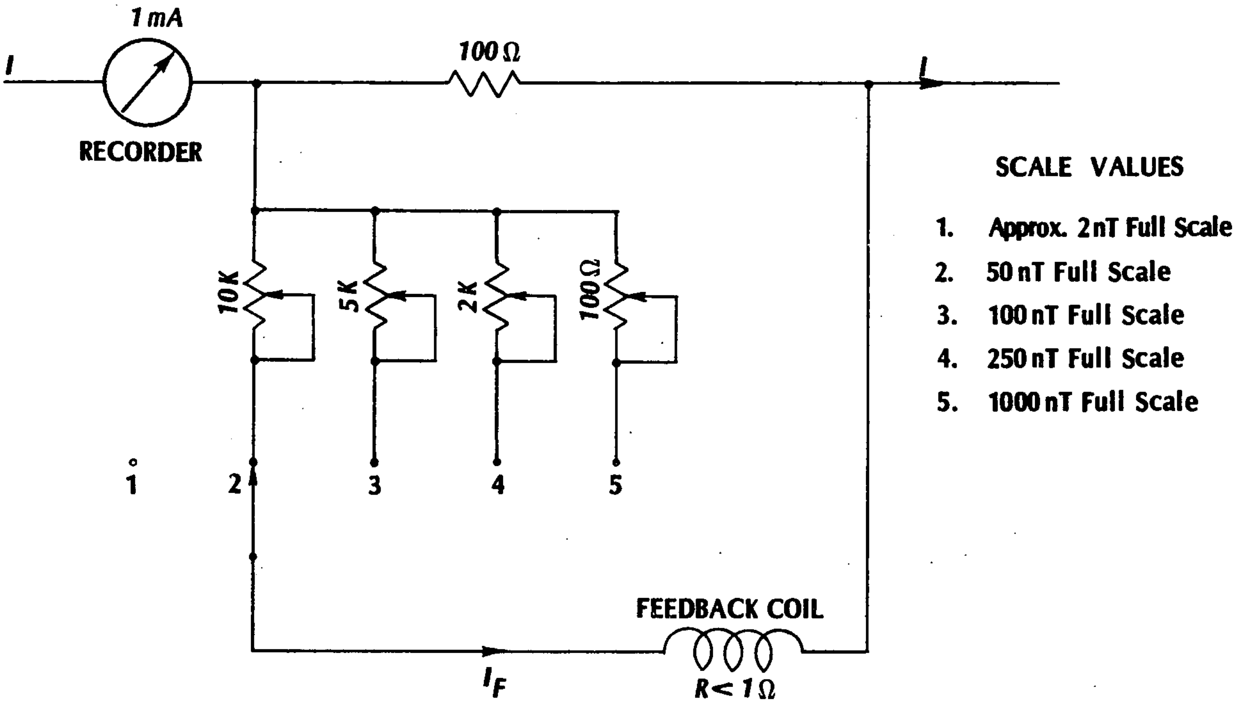


Fig. 2.3 Scale Value Selection

On scale value 1, no feedback is applied. This position is used only in setting up the instrument, as described in Section 5.

As an example of the calculation of K_4 consider scale value 2, (50 nT full scale). The required value of Ac for a 1mA recorder is evidently 20 microamps per nT.

For the MFR1, $Ao \approx 500$ microamp/nT

and $K_5 \approx 2.4$ nT/microamp

Substituting in the equation

$$Ac = Ao/(1 + K_4 K_5 Ac)$$

gives $K_4 \approx 0.02$

With scale value 2 potentiometer in its centre position (5K), the current flowing through the feedback coil is

$$I_F \approx \frac{100}{5000} I$$

$$= 0.02 \ I$$

Hence the required value of K_4 is obtained.

For accurate scale value adjustment the scale value potentiometers are 25-turn pre-set types and are accessible from the front panel.

It is inadvisable to try to extend the range of the instrument outside the limit of 50 to 1000 nT full scale, as too little feedback renders the system sensitive to component drift, etc., and too much feedback may cause instability.

2.5 Frequency response

Non-linearities in the fluxgate detector and peak detector prohibit an exact calculation of frequency and phase response. To a first approximation, however, the peak detector time constant alone determines the frequency response. On scale value 2 the response is 3 dB down at about 2 Hertz. At higher frequencies the response falls by 6dB octave and the phase shift approaches $-\pi/2$ radians.

Increased feedback (i.e. higher scale values) increases the 3 dB frequency but the roll-off and ultimate phase shift remain unchanged.

The foregoing takes no account of recorder response.

SECTION 3 : BLOCK DIAGRAM DESCRIPTION (See Sheet 17)

3.1 Drive current supply

A 5-kHz oscillator supplies current to the drive coils in the detector head via a monitor jack, reversing switch, and on-off switch. Drive current amplitude is adjusted by a 25-turn pre-set potentiometer accessible on the front panel. A check on drive level may be performed by connecting an a.c. milliammeter to the drive monitor jack. With drive coils connected, the current waveform will not be sinusoidal, the amount of distortion depending on the degree of core saturation. As saturation is a function of the field strength at the cores, it cannot readily be duplicated. Thus, to remove possible measurement errors a 100-ohm resistor is used to load the oscillator in the "off" position of the on-off switch.

Operation of the drive reverse switch checks zero errors caused by core unbalance and second harmonic in the drive signal.

A variable-phase network, fed by the drive oscillator, provides the phase reference for the balance peak detector.

Both the oscillator and variable phase network are assembled on module D1.

3.2 Backing-off supply

Backing-off current is derived from a stable 9-volt supply whose output is floating, enabling either side to be earthed by the reversing switch. This allows for reversal of backing-off field when the detector is rotated through 180°. The reversing switch also has a central "off" position.

Low values of backing-off field are provided by the baseline multiplier switch, which simply taps down a decade voltage divider formed by precision low-temperature-coefficient resistors.

The voltage tapped off by the baseline multiplier switch is then applied to a further network of low-temperature-coefficient resistors, which may be connected in parallel in any desired combination by the two eleven-position baseline switches. The resistor values are chosen such that with the baseline multiplier set to "X1" the baseline switches can be set to any field between zero and 55,000 nT in steps of 500 nT. A ten-turn helical potentiometer provides an additional field continuously variable from 5450 to 6000 nT.

Taking all baseline controls into account, the following backing-off ranges are possible:

a) -61,000 to -5.45 nT

b) Zero gammas

c) +5.45 to +61,000 nT

The values of a) and c) are not absolute and will vary slightly from one unit to another, but for any unit the ratios between steps are accurate to 2%. Backing-off current is applied to the detector coil via the detector reversing switch.

The floating 9-volt supply requires three floating input voltages:

+ 15, - 15, and - 25 volts.

These are supplied from a d.c. converter assembled on module PP 3.

Backing-off step resistors and floating 9-volt supply are assembled on module PP 1.

Note that the voltages measured with respect to earth at the front panel monitor jacks will be + 15, - 15, - 25 when the backing-off switch is set to "normal" and + 24, - 6, -16 when the backing-off switch is set to "reverse".

3.3 Signal circuits

The detector coil output containing the desired second harmonic signal as well as unwanted fundamental and other harmonics is applied to the amplifier detector module AM 1 via the detector reversing switch. Detailed description of the various blocks in AM 1 will be found in Section 4.1.

An explanation of the feedback circuit was given in Section 2.4.

The detector reversing switch is provided in case the relative phasing of detector and feedback coils is reversed either in the detector itself or in the interconnecting cables. Note that if the position of this switch has to be altered, that of the backing-off switch will also have to be altered for the same detector orientation.

A known current may be passed through the feedback coil for calibration purposes by means of the calibrate jack. Fiducial marking is performed by the same means. A remote non-magnetic foot switch actuates the fiducial relay, which connects a mercury cell and series resistor across the feedback coil. The scale-value switch also switches this series resistor to give a fiducial deflection approximately one-tenth of full scale. Fiducial deflection to either left or right is selected by the fiducial polarity switch. (See Addendum).

3.4 Power supply

Nominal negative 12-volt input is connected to the 9-volt regulator (module PP2) via a fuse and power switch. PP2 provides the power supply for modules AM1, D1, and PP3. A reset button on the front panel allows the operation of the regulator to be resumed after cut-out caused by overload or excessive input voltage.

Front panel monitor jacks are provided for both the input voltage and regulated 9 volts. The positive side of the supply is earthed at the chassis ground terminal.

Unregulated input voltage is applied directly to the recorder motor and foot switch.

SECTION 4 : CIRCUIT DESCRIPTIONS

4.1 Detector amplifier AM1

The AM1 comprises: the tuning and damping networks; the bandpass filter; 10 kHz amplifier; peak detector; and portion of the feedback network.

C1 and L1 decouple the circuit from the 9-volt supply.

R14 is the variable damping potentiometer and is in series with the detector coil. Tuning of the detector is performed by C2.

The tuned detector output is capacitively coupled to emitter follower Q1 whose high input impedance ensures no additional damping of the detector circuit. The coupling capacitor C3 must show no signs of leakage, which could produce a small zero error by passing current through the detector coil.

Q1 feeds directly into a T-section constant-K bandpass filter centred on 10 kHz and having a passband of about 900 Hz. This serves to remove any remaining fundamental or harmonics other than the second. One disadvantage with a filter of this type is that a slight change in frequency or in one of the filter component values can produce a significant phase shift at the filter output. If such a phase shift occurs, sensitivity will be reduced. For this reason the passband cannot be made too narrow as this would aggravate the effect.

The terminating impedance for the filter is 1.5 k provided by R2 and R17 which are effectively in parallel for a.c..

Q2 and Q3 form a voltage feedback pair amplifier whose gain is almost independent of transistor gain and is given by the ratio of R19 to R18, i.e. 47.

A similar amplifying stage is formed by Q4 and Q5, the output of Q5 being fed to one input of the phase-sensitive peak detector, Q6 to Q9. Q6 and Q7 have their outputs added algebraically in the primary of T1. Thus a composite signal is formed from the 10-kHz detector amplifier output applied to Q6 and the 5-kHz phase reference signal applied to Q7.

For correct adjustment of the phase reference, the waveform across T1 primary is as shown in Figure 4.1, (a) or (b).

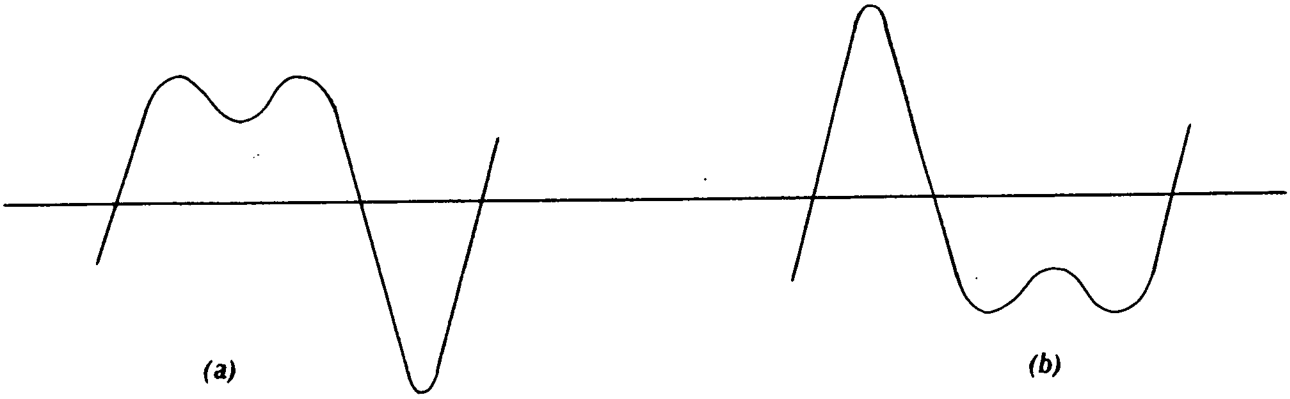


Fig. 4.1 T1 Waveforms

The waveform of Figure 4.1 (a) may be represented by the expression:

$E = M (\sin\omega t + A \cos 2\omega t)$, with A positive, and the waveform of Figure 4.1 (b) by the same expression with A negative. In this expression E is the amplitude of the waveform at time t, ω is the angular frequency of the drive signal, M is the peak amplitude of the reference signal, and $M|A|$ is the peak amplitude of the second harmonic signal and is thus proportional to the field. The direction of the field along the detector axis determines the sign of A.

Analysis of the composite waveform of Figure 4.1 shows that with respect to the average value of the waveform, the amplitude of the "double-humped" peak is always less than or equal to the amplitude of the peak in the opposite direction. Moreover, the difference in amplitude of the two peaks depends on the value of A, i.e. the strength of the field to be measured. The difference is a linear function of A for the range $- 0.6 \leq A \leq 0.6$.

(Note that the double hump will be apparent only for $|A| > 0.25$. As the value of A is reduced, the humps move closer together until they coalesce when $|A| = 0.25$. Considering the cycle commencing at $\omega t = 0$ radians, the positions of the humps are given by solutions of the expression arsin (1/4A) for $|A| > 0.25$. These positions are symmetrical about $\pi/2$ radians or $3\pi/2$ radians depending whether A is positive or negative. For $|A| \leq 0.25$ the humps coalesce at $\pi/2$ or $3\pi/2$ radians. The position of the opposite peak is at $3\pi/2$ radians for A positive and $\pi/2$ radians for A negative).

T1 has two secondary windings, phased so that C13 charges to the positive peak via CR1, and C12 charges to the negative peak via CR2. Thus a voltage proportional to the value of the positive peak is produced at the base of Q8, and a voltage proportional to the value of the negative peak is produced at the base of Q9. R11 and R30 which are required for transistor operating point stability also, with C13 and C12, provide the time constant referred to in Section 2.5.

Q8 and Q9 are complementary transistors with equal emitter resistors. The circuit of Figure 2.3 connects between their common collectors and the power supply centre tap at the junction of R32 and R13.

With equal voltages developed across C13 and C12, equal collector currents will therefore flow in each transistor; i.e. all of the current flowing out of Q9 will flow into Q8 and none will flow through the recorder. If, however, the capacitor voltages are not equal, i.e. $|A| > 0$, more current will flow in one collector than the other and the difference will flow through the recorder, the direction depending on the sign of A.

Thus a recorder deflection is obtained whose magnitude is linearly related to field strength (if $|A| \leqslant 0.6$) and whose direction depends on the direction of the field.

To ensure zero deflection for zero field <u>either</u> R34 <u>or</u> R35 is selected to obtain accurate balance of the peak detector.

A diode network CR3, CR4 is provided to protect the recorder from excess currents. The diode types and circuit configuration will depend on the recorder resistance.

The foregoing discussion of the peak detector circuit is valid only for small signals; i.e. the output from Q5 must not be clipped. Such a signal may not only be shifted in phase but, if the clipping is uneven, will not contain the required amplitude information. Generally, clipped signals give rise to a reduction in sensitivity and a zero shift. If the detector is situated in a region where there are large a.c. fields produced by mains currents, the amplifier could easily be overloaded and the output clipped. There is nothing that can be done about this with the present system. It is therefore extremely important to avoid noisy locations.

4.2 Driver oscillator D1

This circuit and the following description are due mainly to Newman (3).

The oscillator is basically a feedback voltage amplifier with a tuned bridged-T network in the feedback path as illustrated in Figure 4.2.

(3) Newman, J.K., "MFD3 Fluxgate Magnetometer Handbook" p. 6. (Unpublished BMR instrument handbook).

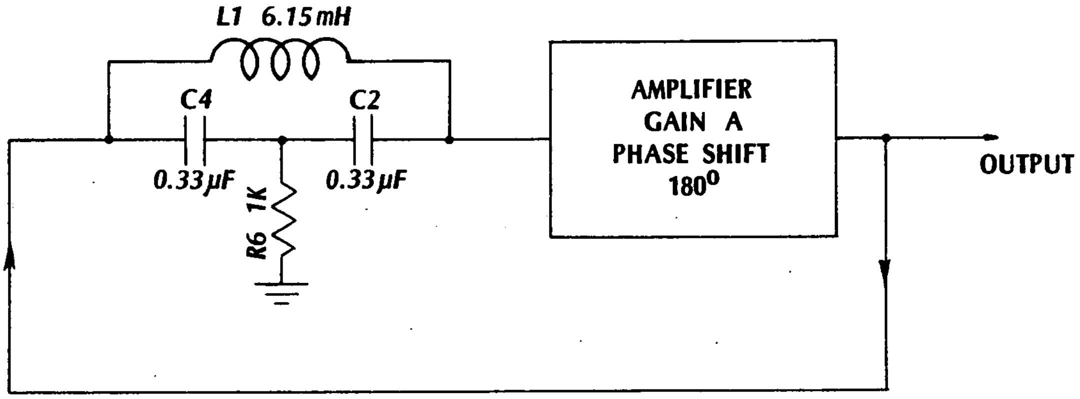


Fig. 4.2

The relevant properties of the bridged-T network may be summarized as follows:

a) The network will pass all frequencies except ω_0 with little attenuation or phase shift, where ω_0 is given by $\sqrt{2/LC}$, with L the bridging inductance and C the capacitance in each arm.

b) If the a.c. resistance of the tuned circuit (mainly resistance of L) is r, and R6 is set equal to $\omega_0^2 L^2/4r$, then frequency ω_0 is completely blocked. If, however, R6 is set slightly below this value, a small amount of ω_0 is passed with phase shift of 180°.

The feedback is therefore negative for all frequencies except ω_0 for which it is positive. If the product of the network attenuation, set by R6, and the amplifier gain is greater than unity the system will oscillate at ω_0. L and C are chosen so that ω_0 equals 2π x 5000.

Note that r increases with temperature; hence R6 is made small enough to ensure that oscillation will start at the maximum operating temperature.

Inductance L1 is actually the primary of a transformer whose secondary connects, via diode CR1, to a pre-set d.c. voltage provided by potentiometer R1 mounted on the front panel. If the negative peak of the secondary voltage exceeds the potentiometer voltage, CR1 conducts, drawing energy from the circuit; i.e. the Q of L1 is lowered. This reduces the amount of positive feedback and therefore acts as a regulator for the drive level. R1 thus functions as a drive level control.

C3 is a coupling capacitor which isolates the d.c. level of the feedback network from the bias voltage for Q1 provided by R2 and R8.

C5 and R9 together with collector load R3 provide an a.c. voltage gain across Q1 of about 45 with a phase shift at 180°.

Cascaded emitter followers Q2 and Q3 supply no additional voltage gain but provide low output impedance for the amplifier. Q3 is mounted on the heat sink module to allow the necessary power dissipation.

Transformer T1 in the emitter load of Q3 couples the oscillator output to the drive coils. Bypassed resistor R12 limits d.c. current through Q3 to a safe value. The feedback line is taken from this emitter load as is the connexion to the variable phase network L2, C7, R13. The range of R13 provides roughly 0 to 145 degrees of phase shift.

Because of negative feedback at all frequencies other than 5000 Hz the unloaded output waveform at Q3 emitter contains less than 0.1% distortion. Distortion is produced, however, when the drive coils are connected, because of non-linear loading on the output impedance, which is essentially the winding resistance of T1.

A useful check on circuit operation is to measure the ratio of voltages at Q3 emitter and Q1 base. This should be about 45.

Heavy power-supply bypassing is obtained with capacitor C1. This reduces the possibility of spurious 5-kHz signals being picked up from power-supply wiring and also reduces the chance of modulation of the drive current by other signals which may be present on power supply leads.

An innovation in this instrument is the series network R7, R15, CR2 across the output of T1. The purpose of the network is to introduce deliberately a small adjustable amount of unbalance in the drive signal to compensate for core unbalance. The polarity of CR2 must be selected for the particular detector head in use.

4.3 Constant-current supply PP1

Negative 25 volts is regulated to -18 volts by R1, CR1, CR2. CR1 and CR2 are 9-volt temperature-compensated zener diodes with guaranteed maximum temperature coefficients of 0.01% per °C at O° and 75° when operating at a current of 7.5 mA.

Further regulation to -9 volts is accomplished with R2 and CR3 which is also a 9-volt temperature-compensated zener diode with guaranteed maximum temperature coefficient of 0.0005% per °C at 0° and 75°when operating at 7.5 mA. The purpose of the first stage of regulation is to provide constant current for CR3.

Backing-off current required varies in the range 0 to 10 mA. This could not be taken from CR3 directly without degrading its temperature specifications. Hence a d.c. isolating amplifier with unity feedback separates the load from CR3. Q1, a silicon transistor emitter follower, provides the required output current capability and is included in the feedback loop so that temperature and current variations of base to emitter voltage are not passed on to the load.

The d.c. amplifier is an encapsulated differential type having a minimum d.c. open loop voltage gain of 80,000, and an offset voltage temperature coefficient of ± 12 microvolts per °C maximum over the range -25° to +85°. Offset is adjusted with R3.

Thus, to a high degree of accuracy, the voltage developed across R4 is the same as that across CR3 for all required load currents.

R5 to R13 are wirewound resistors with temperature coefficients of less than ± 0.0005% per °C, thermal emfs less than 3 microvolts per °C and long-term stabilities better than ± 0.005% for the first 2000 hours' use. These resistors are switched in desired combination to the emitter load of Q1 to give a stable backing-off current.

Actual measurements of backing-off current temperature coefficient for the four PP1 modules so far constructed show an average value of -0.00075% per °C for each of three modules and -0.0014% per °C for the fourth taken over the range 10° to 50°. The latter module will be used as a spare. Appendix A gives details of the measuring technique together with curves obtained. The excellent general agreement between the four modules is an indication that long-term temperature coefficient stability will be good. (See Addendum for modifications to compensate for detector drift).

4.4 9-Volt Regulated power supply PP2.

This is a conventional feedback regulator with the addition of protection circuits. The regulator operation may best be described by reference to the block diagram of Figure 4.3.

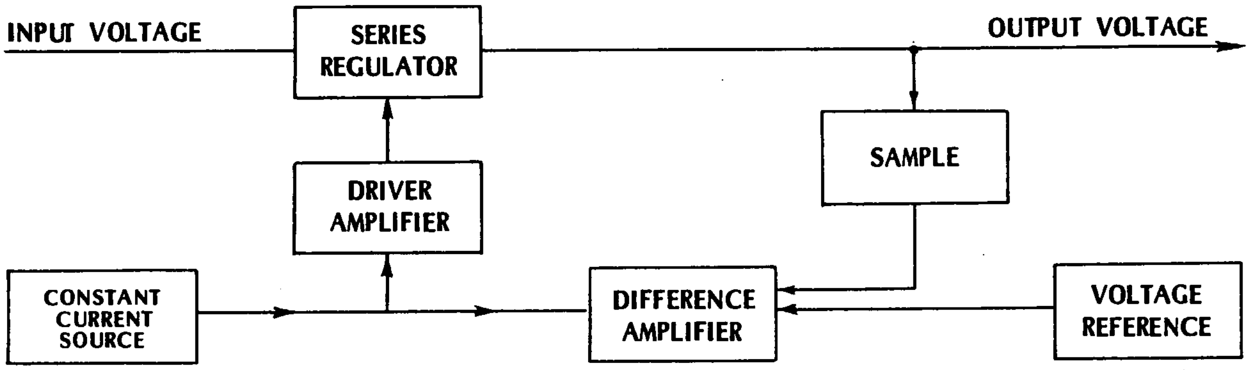


Fig. 4.3

The series regulator acts like a variable resistance whose value is automatically adjusted to give a constant output voltage irrespective of input voltage and load current. The series regulator is controlled by the driver amplifier, which in turn is controlled by current from a constant-current source. If the difference amplifier were disconnected, the constant-current source would turn the series regulator fully on. However, with the difference amplifier connected, some current is bled from the constant-current source, the amount depending on the difference between a reference voltage and a fraction of the output voltage obtained by the sampling circuit. The reduced current thus available for the driver amplifier increases the voltage dropped across the series regulator.

Consider now what happens if the output voltage suddenly increases either because of increased input voltage or decreased load current. The sampled voltage increases and the current bled off by the difference amplifier also increases. Less current is available for the driver amplifier and the series regulator tends to turn off, thus increasing the voltage dropped across it; i.e. the series regulator is controlled in such a way as to reduce the effect of the initial disturbance. Regulation of a typical PP2 is 800 and output resistance 7 milliohms.

Input current is applied via CR1 which only permits operation with correct polarity. R3 is a current sensing resistor used in the protection circuit. The series regulator Q2 is mounted on the heat sink module.

The sample voltage is obtained from the slider of R10 and applied to the base of difference amplifier Q6, the emitter of which is held at the reference voltage by 6.2-volt zener diode CR5. R6 assists in keeping the zener current constant. Temperature coefficients of CR5 and Q6 roughly cancel. Q6 collector current is a function of the difference between the reference voltage and the sample voltage.

The constant-current source is the collector of Q4. The current is set by emitter resistor R4 which has about one volt across it maintained by CR3 and CR4 forward biased by R5. The constant current is therefore about 2mA.

The driver amplifier Q3 is an emitter follower with the series regulato as load.

Capacitor C3 increases the a.c. gain of the feedback path in order to regulate against load currents at 1 kHz and above produced by the d.c. converter and driver oscillator. C2 prevents high-frequency oscillation which may result because of phase shifts in the feedback path.

The protection circuit is designed to turn the series regulator off if the load current exceeds about 600 mA or the input voltage exceeds about 19 volts. Operation of the circuit relies on the fact that if the base to emitter voltage of Q1 exceeds about half a volt, Q1 will turn on and cause Q5, which was previously off, to saturate. The base of Q3 is then clamped almost at ground level, effectively turning Q2 off, and thus causing the output line to fall to ground potential. CR2, a 6.2-volt zener diode connected to the output line via R2 and the reset button, is then able to conduct via R1, so producing a voltage at Q1 base which keeps it on. Operation cannot be restored until this circuit is broken by pressing the reset button.

During cut-out no current flows through R3, hence CR6 is reverse biased and so prevents R12 from shunting R1 and thus reduces the drive to Q1.

For normal operation, CR6 is always forward biased, allowing the voltage at Q2 collector to be applied to Q1 base. For load currents greater than about 600 mA, the voltage across R3 and thus Q1 base to emitter would be 0.6 volt or greater. However, this is sufficient to turn Q1 on, thus tripping the cut-out.

If the input voltage is increased to a point at which the potential at Q1 emitter is equal to the sum of the output voltage and CR2 breakdown voltage, still further will cause sufficient current to flow to raise Q1 base to the potential required to turn Q1 on. Because of variations in transistor parameter, R1 must be selected for each Q1 so that the cut-out operates at about -19 volts input. R1 turns out to be the order of 1000 ohms.

Capacitor C1 provides a time-constant for the operation of the protection circuit. This prevents the circuit from operating when power is first applied, and also prevents transients from tripping the circuit.

By changing the sample voltage slightly, the output voltage can be adjusted. R10 is used for this purpose.

4.5 D.C. Converter PP3

This is a conventional two-transistor saturating-core converter operating at about 1kHz and capable of delivering about 2 watts of power, although in this instrument the load requires only about one-half watt.

Two transformer secondaries are employed to provide outputs both positive and negative with respect to the return line. Each secondary feeds a full-wave bridge rectifier CR1-CR4, CR5-CR8, and R C filtering provides ±25 volts with only a small amount of ripple. Further zener diode regulation is used to obtain ±15 volts.

SECTION 5 : CIRCUIT ADJUSTMENTS

The adjustments detailed below should be checked regularly for optimum performance. The main source of adjustment drift will probably be vibration of trimming potentiometers during transport.

It is essential that adjustments concerning the driver oscillator and detector amplifier be made with the detector head and cable intended for use with the particular amplifier and driver.

Any module which has been adjusted for one channel is not necessarily adjusted for another channel. When two or more adjustments are to be performed, the order in which they are set out below should be adhered to.

5.1 Regulated 9-volt supply

With all modules plugged in and an input voltage of about 12 volts adjust R10, PP2 for -9.0 volts measured between the -9 volt monitor jack and ground with a multimeter such as the AVO Model 8.

5.2 Constant-current supply zero offset

a) Disconnect the POS input of the encapsulated amplifier on PP1, having first turned the power off.

b) Connect the POS amplifier input to the return line.

c) With a d.c. coupled CRO observe the voltage at the emitter of Q1 with respect to the return line when the power is turned on.

d) Allow ½ hour for the internal temperature to stabilize, then adjust R3, PP1 for zero output volts.

e) Re-connect the amplifier.

5.3 Drive level and detector damping

a) Rotate R14, AM1 and R1, D1 (front panel drive adjust) fully anti-clockwise. This produces maximum damping and minimum drive.

b) Observe the waveform at the base of Q1, AM1, with a CRO sensitivity of 1 volt/cm. Very little signal will be seen. Set the scale value switch to position 1 (no feedback).

c) With the detector in a large field, obtained either by orienting or backing-off, increase the drive level by rotating R1, D1 clockwise. A 5-kHz signal will appear and increase as the drive level is increased. After passing through a maximum the 10-kHz second harmonic will appear as the drive level is further increased. Adjust the drive level for a 10-kHz maximum.

d) Decrease the detector damping by rotating R14, AM1 clockwise. The 10-kHz signal will increase in amplitude slowly at first, then very quickly as instability is reached. In this condition reducing the field does not reduce the signal amplitude. Only the phase can be changed by reversing the field. Having determined the point at which the detector is about to become unstable, back-off the damping control three full turns.

e) Record the drive level for future reference in Appendix E.

5.4 Phase reference

a) With the detector in almost a null field and the scale value switch on position 1, observe the waveform at the collector of Q7, AM1 with a CRO sensitivity of 2 volts/cm.

b) Adjust R13, D1 to obtain the waveform of Figure 4.1; i.e. adjust for symmetry of the double-humped peak.

c) Switch to scale value 2, 3, 4, and 5. Recorder deflection should successively reduce. If recorder deflection increases with application of feedback, the feedback is positive. To overcome this reverse the detector switch and re-commence adjustments at Section 5.3.

5.5 Drive balance

Orient the detector to null field on scale value 2. Operate the drive reverse switch. If recorder deflection occurs, the drive is unbalanced and the apparent null was not a true null.

Adjust R7, D1 until operation of the drive reverse switch does not alter recorder deflection. (It may be necessary to re-orient the detector to bring the recorder on scale during this adjustment).

If a different detector is ever used with any given driver it could be necessary to reverse diode CR2, D1 for this adjustment to be effected.

5.6 Scale value calibration

In Appendix B a method is given for determining the coil constant of the feedback coil, i.e. the field produced per unit current passed through the coil. Its value is approximately 2.4 nT per microamp but varies slightly from one detector to another. Once this value is known, the current for a given recorder deflection can be calculated and fed into the calibrate jack for each of scale values 2, 3, 4, and 5, the nominal scale values of which are 50, 100, 250, and 1000 nT full scale respectively.

The calibrating current should be supplied from a source with resistance at least 10,000 ohms to avoid loading effects. A 6-volt battery and series resistance will ensure that this condition is met. The calibrating source should be floating with respect to the magnetometer power supply.

A Magnetometer Calibrate Source, designated MCR1 has been designed specifically for this purpose.

Front panel potentiometers R7, R6, R5, R4 adjust scale values 2, 3, 4, 5 respectively. Clockwise rotation increases sensitivity.

Appendix D provides a calibration record for the feedback coil constant.

SECTION 6 : OPERATION

It is assumed that the adjustments described in the previous section have been carried out.

6.1 Siting the detector

The detector should be located clear of magnetic materials that are subject to movement by wind or other causes. For normal observations, locations close to fixed magnetic materials should be avoided because of their effect on magnitude and direction of the Earth's field.

Where possible, the detector site should be at least 3 metres from the electronic chassis and 6 metres from the recorders. (Rotation of a Rustrak recorder at 6 metres produces a field variation of 5 nT.)

Proximity to power lines, transformers, and electrical machinery is likely to saturate the amplifier from the 50-Hz field and reduce sensitivity.

A stable support, such as a cement block 60 cm square or a metal plate sitting firmly on three pegs, is desirable to avoid spurious changes in orientation.

6.2 Recording declination, D

Set backing-off switch to 'off', set scale-value switch to position 5, and orient the detector to approximately the required direction. Switch on and slowly rotate the detector until the recorder indicates a null. Switch to the required sensitivity and make fine adjustments to the detector orientation to null the reading.

6.3 Recording horizontal component, H

If the H detector is known to be at right angles to the D detector, orientation of H is achieved by orienting D as in the previous paragraph. Backing-off current is then adjusted to bring the recorder on scale.

When using the instrument without a D detector, firstly find the null in the horizontal plane, then by successive adjustments of backing-off current and orientation, hunt for the maximum field.

6.4 Recording vertical component, Z

With the Z detector vertical, simply adjust the backing-off current to bring the recorder on scale. Adjustment is easier if it is initially performed on the least sensitive range.

6.5 Three-component recording

There is a degree of interaction between the H and Z backing-off fields, so final backing-off adjustments are performed with all channels operating.

The effect of H and Z operating together on D is small. An experiment in Canberra indicated the error to be about two minutes of arc. A similar error was found when the mount was rotated 90° and H used for D. This indicates that the instrument can be set up with all detectors operating.

6.6 Drift in backing-off supply

Apart from temperature drift already mentioned, there will be some drift immediately after switching on until component temperatures become stabilized.

The time taken for this drift to settle will depend on ambient temperature, but a minimum of half an hour should always be allowed.

6.7 Field increase and recorder deflection

Each detector is marked with an arrow which points to the direction of field increase for recorder deflection to the right.

SECTION 7 : THE THREE-COMPONENT DETECTOR ASSEMBLY

7.1 Description

The three detectors, labelled D, H, and Z, are mounted at right angles in a cast aluminium housing. Fine adjustments in each of two directions at right angles to each detector axis are provided for accurate orthogonality. Slots have been machined in the housing to prevent inductive loading of the detectors.

The housing is mounted on a Carnegie Institution (C.I.W.) magnetometer circle fastened to a two-screw levelling system which, in turn, is mounted on a cast base.

Three points on an aluminium tripod plate engage slots in the cast base, and the tripod plate rests on three nickel-silver pegs which are driven into the ground at the apices of a rough equilateral triangle. Slots in the tripod plate allow a considerable degree of freedom in locating the pegs. A level bubble is fitted to the tripod plate for rough preliminary levelling.

Electrical connexions to each detector are made via miniature plugs and sockets, the combined cables running down through the centre of the assembly to the main connector under the cast base. To avoid excessive twisting of the cables, a stop has been fitted to the circle which permits rotation only a little greater than 360°.

A cylindrical aluminium cover fits over the detector assembly and is secur fastened to the cast base. A handle on the cover permits the assembly to be carried easily.

With the exceptions of the detectors and circle, the entire assembly was designed by W. Olbrich.

SECTION 8 : MAINTENANCE AND TROUBLE-SHOOTING

8.1 Preventive maintenance

a) All connectors have been fitted with dust caps. These should always be screwed on tightly when the connector is not in use. To avoid dust getting into the dust cap when the connector is in use, screw the dust cap into the dust cap of the mating connector.

b) Keep the equipment generally free from dust and moisture. Regular inspection and cleaning should be carried out. Wafer switch contacts are especially prone to trouble from dust. In extremely dusty conditions, a useful technique is to tie a plastic cover over the switch. When cleaning contacts with a solvent, Freon TF is recommended. Do not use lubricating solvents, which tend to leave an oily film and so attract dust.

c) Avoid straining the cables, particularly at the connectors.

d) Never insert or remove module cards with the power turned on. Transistor damage could result. Similarly the power should always be off before attempting any soldering job on the unit.

e) Pack well before transit. Shocks and vibration not only alter adjustments but may affect soldered joints adversely.

f) Keep detector away from strong permanent magnets which could produce remanent magnetism.

8.2 Trouble-shooting

The best aid to trouble-shooting is a thorough understanding of equipment operation, at least to block diagram level. Possible causes can then be logically diagnosed from the observed symptoms, and the appropriate spare module cards can be substituted and adjusted if necessary to suit the particular unit affected.

When this idealized method does not work, it will be necessary to observe waveforms and voltages throughout the instrument, or at least the suspected sections. To this end, d.c. voltages, as indicated on an AVO Model 8 multimeter, have been included at key points on the circuit diagram. Also accompanying drawings show waveforms at various points. Voltages and waveforms are measured with respect to ground unless indicated otherwise.

A module extension card enables necessary points on the modules to be monitored easily.

The following table lists a few of the more likely symptoms, their possible causes, and means of verification. It is assumed that all circuit adjustments have been carried out where possible.

When the table suggests substituting a spare module, firstly make sure the suspected module has the correct supply voltages and input signal applied.

Symptom	Possible Causes	Verification
1. System completely dead when turned on. No voltage at 12V monitor jack.	(i) Blown fuse	(i) Test and/or replace fuse
	(ii) Broken power supply connection	(ii) Check all leads to power supply
	(iii) Break in connection of positive line to chassis ground.	(iii) Ground the positive supply line with a length of wire. If operation commences look for broken lead in chassis wiring.
	(iv) Faulty power switch.	(iv) Connect AVO on 1 amp range across switch. Deflection indicates fault.
2. System completely dead except recorder motor.	(i) Input voltage too high or too low	(i) Check voltage at -12 volt jack
	(ii) PP2 cut-out tripped	(ii) Press reset button
	(a) Overload caused by fault on a module or short circuit in chassis wiring.	(a) Remove all modules. If fault still present, check chassis wiring for shorts. If fault absent insert modules one by one to locate faulty one
	(b) Internal fault.	(b) Substitutes spare and/or heat sink.
3. -9 and -12 monitor jack voltages OK, but recorder will not deflect	(i) Faulty recorder or cable	(i) Substitute AVO on 1 MA range for recorder
	(ii) No drive signal	(ii) Listen for detector singing at 5kHz. Check that drive switch is on
	(a) Faulty D1 (b) Drive monitor jack open (c) Faulty drive switches (d) Fault in cable	(a) to (d) Trace drive signal from D1 to detector connector with CRO, after disconnecting detector. If necessary substitute spare D1 and/or heat sink
	(e) Faulty detector	(e) Observe drive waveform when detector is connected. No distortion indicates open circuit. No signal indicates short circuit. Or, substitute another detector
	(iii) No detector signal	(iii) Substitute another detector
	(a) Faulty cable	(a) Substitute cable from another channel
	(b) Faulty detector switch	(b) Place temporary short across switch
	(c) Faulty AM1	(c) Substitute spare AM1
	(d) Signal loaded in chassis	(d) Remove AM1, PP1, Resistance between J1/A and J1/B should be infinite when detector cable disconnected. Replace PP1 with equipment turned off. Resistance should not be less than 1.5K for any position of backing off controls. Check for short circuit across calibrate jack
	(e) Signal loaded at detector	(e) Check for conducting objects close to detector which could form closed conducting paths around detector
	(iv) No phase reference	(iv) Check phase reference input to AMI with CRO. If signal absent check phase reference output from D1. If signal present fault is in wiring, if absent substitute spare D1.
4. Recorder deflecting normally on scale value 1 but off scale on other positions	Positive feedback	Reverse detector switch.
5. Recorder cannot be nulled on scale value 1 but swings violently across the scale as detector orientation is changed. Hysteresis present in orientation required to restore recorder to other side of scale	Insufficient detector damping	Check damping adjustment.

6. Recorder very sluggish and only deflects to one side of zero	Amplifier saturated (i) Field too large (ii) Interference from ac mains	(i) Re-adjust orientation and/or baseline (ii) Check amplifier AM1 Q5 collector for saturation at 50 Hz.
7. Orientation through 180° does not produce consistent readings	Zero error due to drive unbalance	Check drive balance adjustments
8. Baseline adjustments all not functioning	(i) Faulty PP3 (ii) Faulty PP1 (iii) Faulty baseline multiplier switch, backing off resistors or interwiring	(i) Measure -25, -15, +15 voltages with B/O switch on normal. If absent, or incorrect, substitute spare PP3. Also listen for 1kHz whistle in PP3 transformer to verify converter is operating (ii) Check for 9 volts across B/O switch. If absent substitute spare PP1. If still absent check wiring between PP1 and B/O switch. (iii) Set both baseline switches to 0 with multiplier at X1 and B/O switch at normal. 9 volts should be present at each of the four inputs to each baseline switch. This is best measured with a dc coupled CRO to avoid meter loading effects. If voltage is absent, check back through the circuit until voltage appears, thus isolating the faulty area.
9. Baseline adjustments functioning on some switch positions only	(i) Faulty switches or wiring (ii) Faulty multiplier resistors	(i) Check switches and wiring (ii) Check resistance values
10. Fine baseline control not operating	(i) Faulty helipot or wiring (ii) Faulty 16K resistor in PP1	(i) Check helipot with AVO (ii) Check 16K resistor and substitute spare PP1 if necessary.
11. Instrument operating with correct drive level and normal signals from detector and phase reference but low sensitivity on all scale values	(i) Faulty AM1 (ii) Faulty recorder	(i) Substitute spare AM1 (ii) Substitute recorder from another channel.
12. As above but normal sensitivity on at least one scale value	Corresponding calibrate potentiometers or wiring faulty	Check with AVO.
13. Fiducial marking inoperative on all ranges	(i) Faulty foot-switch or cable (ii) Faulty relay (iii) Faulty polarity switch or wiring	(i) Bridge contacts of foot-switch connector. Normal operation indicates fault in cable or foot-switch (ii) Substitute spare relay (iii) Check with AVO.
14. Fiducial marking normal on some but not all ranges	Faulty switch, series resistor or wiring	Check with AVO.
15. Fiducial deflection very small on all ranges	Flat battery	Replace battery.

SECTION 9 : EQUIPMENT LIST

The equipment is housed in two wooden boxes containing the following items:

3	MFR1 Chassis	
1	Three-component detector assembly and cover	
1	Tripod plate	
3	Nickel-silver pegs	
*3	Rustraknrecorders	s/c T10195
*1	Non-magnetic foot-switch	Vocab BSM3
1	Detector cable	
1	Power cable	
1	Foot-switch cable	
1	Recorder cable	
1	Phone plug and cable	
1n	Extension cord	
*1	Handbook	Vocab ZMA7
1	Spare kit comprising :	
	AM1 Module	
	D1 "	
	PP1 "	
	PP2 "	
	PP3 "	
	Heat sink module	
	10 1-amp fuses	Vocjb BFM 102
	1 Fiducial relay	Vocab BSY 1/2
	3 Mercury D cells	Vocab BBM 142

* With the exception of these items all above equipment, including wooden boxes, is listed on BMR stock card M 11795.

ADDENDUM

Since the completion of the MFR1, certain modifications have been made, the more important of which are listed below.

Monitor points

Monitor points used in tuning the amplifier have been brought out to the front panel, and holes drilled in the top covers above associated trimming potentiometers, so that adjustments may be performed without dismantling.

Extended backing-off range

The backing-off range provided was found to be marginal in some instances, so a front panel switch was added, switching in an additional 1.92 k resistor to give a nominal 50,000 nT increase. The total range is thus extended to more than 100,000 nT.

Fiducial system

The non-magnetic foot-switch was discarded in favour of a Bulova clock and relay fiducial marking system. Contacts on the clock provide regular timing marks.

Mounting

The original wooden transit cases have been replaced by an aluminium rack, also containing the MCR1 calibrator, which can be mounted in a trailer, thus permitting the instrument to be easily transported and well protected when left unattended.

Detector drift compensation

A baseline drift, originating in the detector presumably because of dimensional change with temperature, was found to be about -1 part in 10^4 per degree C. This drift is well outside the original specifications, and a large insulating cover has had to be used over the detectors.

An attempt has been made to compensate by altering the backing-off reference voltage with temperature to cancel the effect. This is done by changing the current through the reference diode CR3 PP1 and making use of the resistance of the diode (about 20 ohms) to change the voltage. The current is changed by replacing resistor R2 PP1 with a series-connected string of silicon diodes mounted within the detector housing so that they share the same thermal environment as the detectors themselves. A series resistor is also required (back on the PP1 card) to set the correct current level for CR3. Silicon diodes exhibit a temperature change, when forward biased, of about -2 mV/°C over a wide temperature range. Calculations, verified by experiment, showed that the current changes required by CR3 necessitated a string of 10 diodes in series with 390 ohms. Fortunately diode type BA148 was found to be non-magnetic, and 10 for each component are mounted in the housing in such a way that the magnetic fields produced by the diode currents tend to cancel.

No evaluation of the compensation has yet been carried out, but it is expected that the drift will be decreased by at least an order of magnitude.

APPENDIX A

MEASUREMENT OF BASELINE TEMPERATURE COEFFICIENT

Variations of baseline level with temperature may arise from three effects:

(a) Backing-off current variations produced in the floating 9-volt supply and associated resistors. This effect will be termed "supply coefficient".

(b) Backing-off field variations produced in the detector, e.g. by expansion of windings or resistance variations. This effect will be termed "detector coefficient".

(c) Detector alignment variations caused by expansion in the mounting assembly.

The effect of (c) is thought to be small compared with those of (a) and (b), although this has not been verified.

A.1 Determination of supply coefficient

The measuring circuit is shown in Figure A.1.

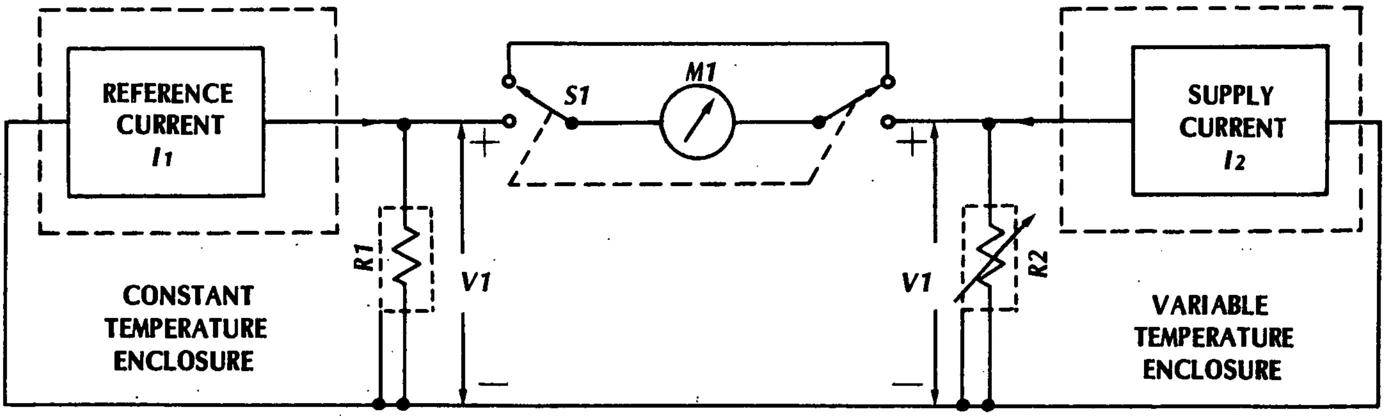


Fig. A.1

Reference current I1 develops voltage V1 across resistor R1. R2 is adjusted to give an identical voltage from supply current I2. Thus meter M1 is used as a null indicator, and the measurement is independent of meter calibration. The variations in R2 required to maintain the null are a measure of the supply current variations.

At some temperature T1, let $I2 = V1/R2$

At another temperature T2, $I2 + \Delta I2 = V1/(R2+\Delta R2)$

Therefore $\Delta I2/I2 = R2/(R2+\Delta R2)-1$
$= -\Delta R2/(R2+\Delta R2)$

To obtain the required resolution, R2 is a decade resistance box of nominal resistance 500 ohms variable in steps of 0.001 ohm. By using the same type of resistance box for R1, and by setting it also to 500 ohms, temperature coefficients of R1 and R2 cancel if they share the same thermal environment. This obviously requires I1 to be virtually identical with I2, and in fact an identical system is used.

Each current source consists of an MFR1 chassis with all modules operating and the lid bolted down. This ensures that internal thermal conditions are the same as for normal operation. The coarse baseline controls are set to 50,000 nT and the fine control to minimum. Output connexions are made to pins A and B of the detector connector. Each chassis is fed from a separate, floating 12-volt supply to avoid errors caused by earth currents. Note that R1 and R2 reduce the current to a value which would give a nominal 43,000 nT.

Before measurement commences, the decade resistance contacts should be thoroughly cleaned with Freon TF, and contact pressures checked. The system should then be set up, roughly balanced and allowed to operate for 24 hours to allow I1, R1 and R2 to become stabilized.

Measurements are taken at intervals of 10°C from 0° to 50°. At least one hour should be allowed at each temperature, for I2 to become stabilized. Switch S1 enables meter zero to be checked before and after each reading. M1 should be a d.c. millivoltmeter with a full-scale sensitivity of 1 millivolt. If one meter terminal connects to case, ensure that the meter does not touch R1 or R2.

Temperature variations in the constant temperature enclosure should be less than 1°C.

The accompanying curves were obtained with a slightly different setup, as no constant temperature enclosure was available. I1 was obtained from PP1 module number four in an MFR1 chassis at ambient temperature. The relative temperature drifts for PP1 modules 1, 2, and 3 were then determined. Module 4 was then checked with module 1 as reference. A first-order correction for ambient temperature was applied to this result from the uncorrected results for module 1. Similar first-order corrections were then applied to the results from modules 1, 2, and 3. Because of the small change in ambient temperature during the measurements, these corrections were all small and did not affect the results significantly.

Note that for repeatable results, a given PP1 module should always be used in conjunction with the same PP3 module.

Although the result for module 4 is not as good as those for the other modules, it is still within worst case tolerance for the components used. It is suggested that this module be used as a spare.

A.2 Determination of detector coefficient

The detector to be checked is clamped horizontally in a non-magnetic box specially made for this purpose. Hot air can be blown through the box by means of a hair dryer or similar apparatus, situated far enough away so as not to interfere with detector operation. An electronic thermometer (thermistor type) is used to measure the temperature of the detector exterior. The detector is oriented to record H in the normal way.

A second detector also recording H, but at ambient temperature, is situated nearby. This checks natural field variations, which can then be eliminated from the results.

Initial measurements indicated a temperature drift of about -1 part in 10^4 per degree C. In the Addendum, modifications are detailed which should reduce this by an order of magnitude.

APPENDIX B

DETERMINATION OF FEEDBACK COIL CONSTANTS

A single-layer solenoid has been constructed in which a detector can be centrally positioned. Relevant details of the solenoid are:

Winding length	:	16 3/16 inches
Winding diameter	:	1 7/8 inches
Number of turns	:	643

Allowing for end affects, the central field is calculated as 1.95 nT per microamp. Because of the detector's finite length and offset of cores from the centre, the average field along the detector will be slightly less than this, but the above value is sufficiently accurate.

The detector is set up in the solenoid and nulled in the normal manner. The solenoid field is then applied and a current source fed to the 'calibrate' jack and adjusted to back-off the solenoid field.

Designating the coil constant by K, the solenoid current by I_s, and the calibrate current by I_c, we have

$$K = 1.95\ I_s/I_c$$

Both I_s and I_c should be supplied from a source impedance greater than 10,000 ohms to avoid loading the detector.

If a common source voltage is used and the currents are derived from decade resistance boxes R_s and R_c, then the ratio I_s/I_c is simply given by R_c/R_s, neglecting the very small error introduced by ignoring the solenoid and feedback coil resistances (6.8 ohm and 0.8 ohm plus lead resistances respectively). If desired, R_c and R_s can be accurately determined with a Wheatstone bridge, or, preferably, their ratio measured with a potentiometer.

As one end of the feedback coil connects to a potential above ground, the voltage source should always be floating with respect to ground.

The circuit is shown in Figure B.1.

Values of K for each detector have been measured at 2.4 nT per microamp to an accuracy of 95%. The above method will give an accuracy better than 99%.

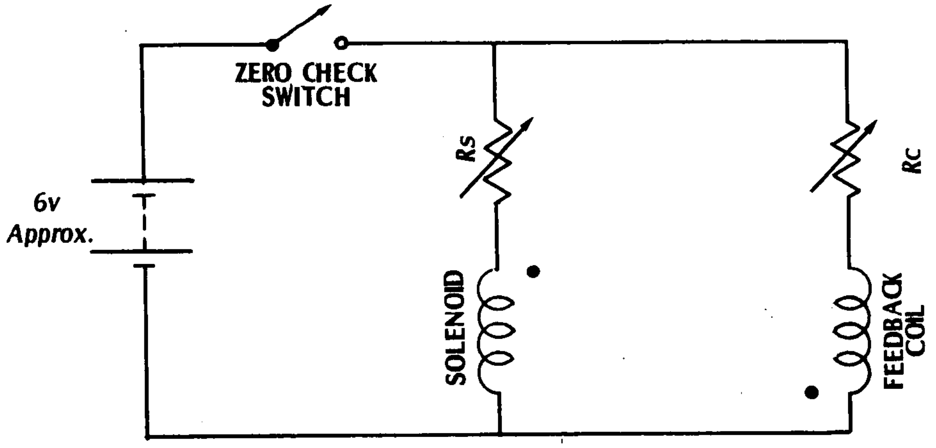


Fig. B.1

APPENDIX C

NOTES ON CORE MATCHING

The Permalloy C fluxgate cores are normally supplied in annealed matched pairs, and further matching is usually unnecessary. The following paragraph describes a procedure for matching cores in the event of matched cores being unavailable or of unequal ageing of initially matched cores.

Disconnect the balancing network across the secondary of T1, D1. Observe the null signal at the base of Q1, AM1. If the cores are not well matched there will still be an appreciable signal at null. Select a pair of cores which gives a null sugnal of 0.1 volt peak to peak or less. Re-connect the balancing network and seal the detector.

APPENDIX D

RECORD OF FEEDBACK COIL CALIBRATION

Date	D	H	Z	Date	D	H	Z
20/4/66	2.43	2.37	2.45				
31/1/68	2.41	2.40	2.37				

In this measurement, at least two of the detectors had been interchanged. It is known for certain that the 'new' H detector was the 'old' Z detector.

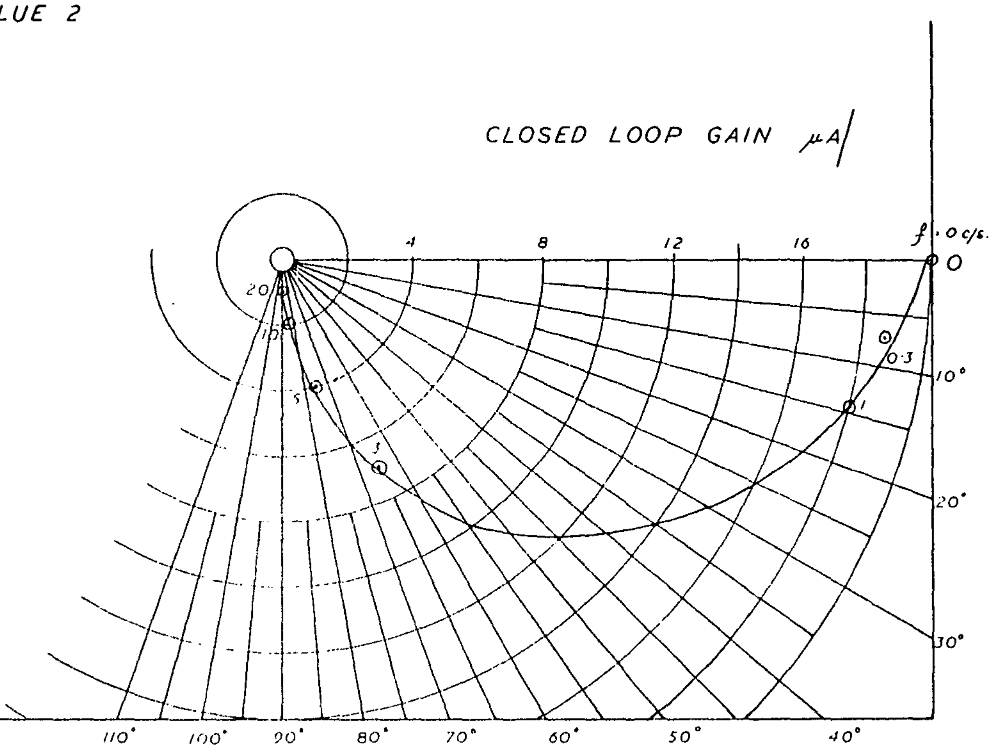
APPENDIX E

RECORD OF DRIVE CURRENT LEVELS

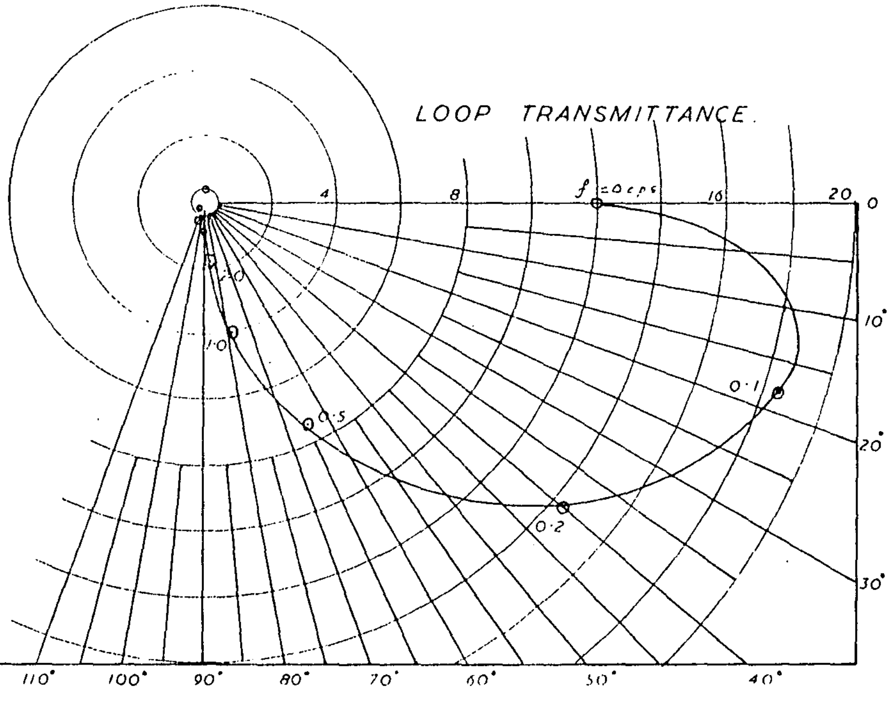
Date	D	H	Z	Date	D	H	Z
21/4/66	26 mA	27 mA	30 mA				

PLATE I

CLOSED LOOP RESPONSE FOR SCALE VALUE 2



LOOP TRANSMITTANCE FOR SCALE VALUE 2



BUREAU OF MINERAL RESOURCES
GEOLOGY AND GEOPHYSICS

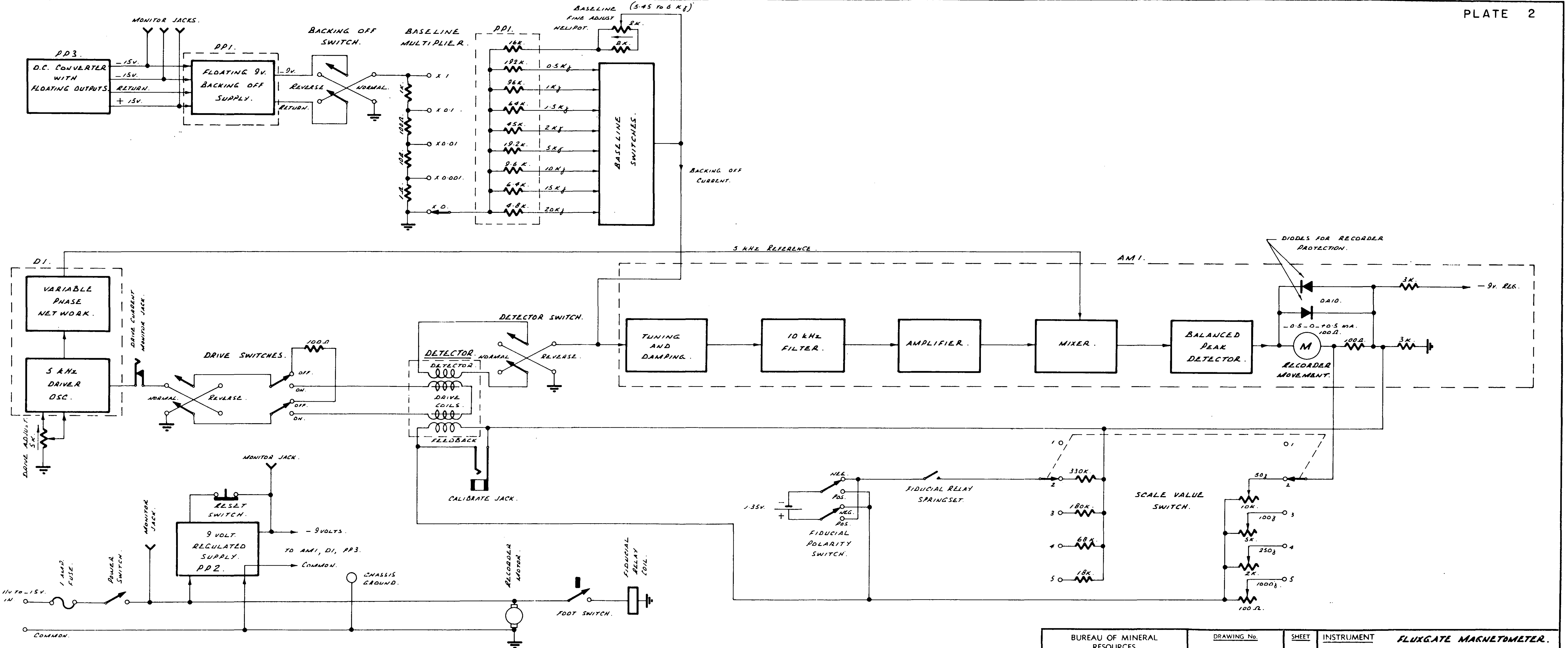
DRAWING No.
MFR I

SHEET
16

INSTRUMENT
RESPONSE CURVES
MFRI. FLUXGATE MAGNETOMETER.

TO ACCOMPANY RECORD NO 1971/48

PLATE 2

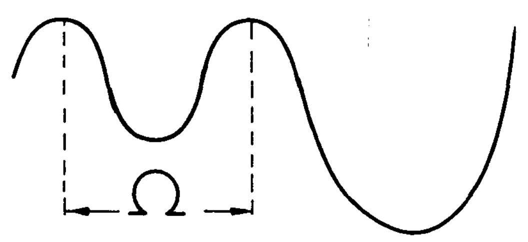


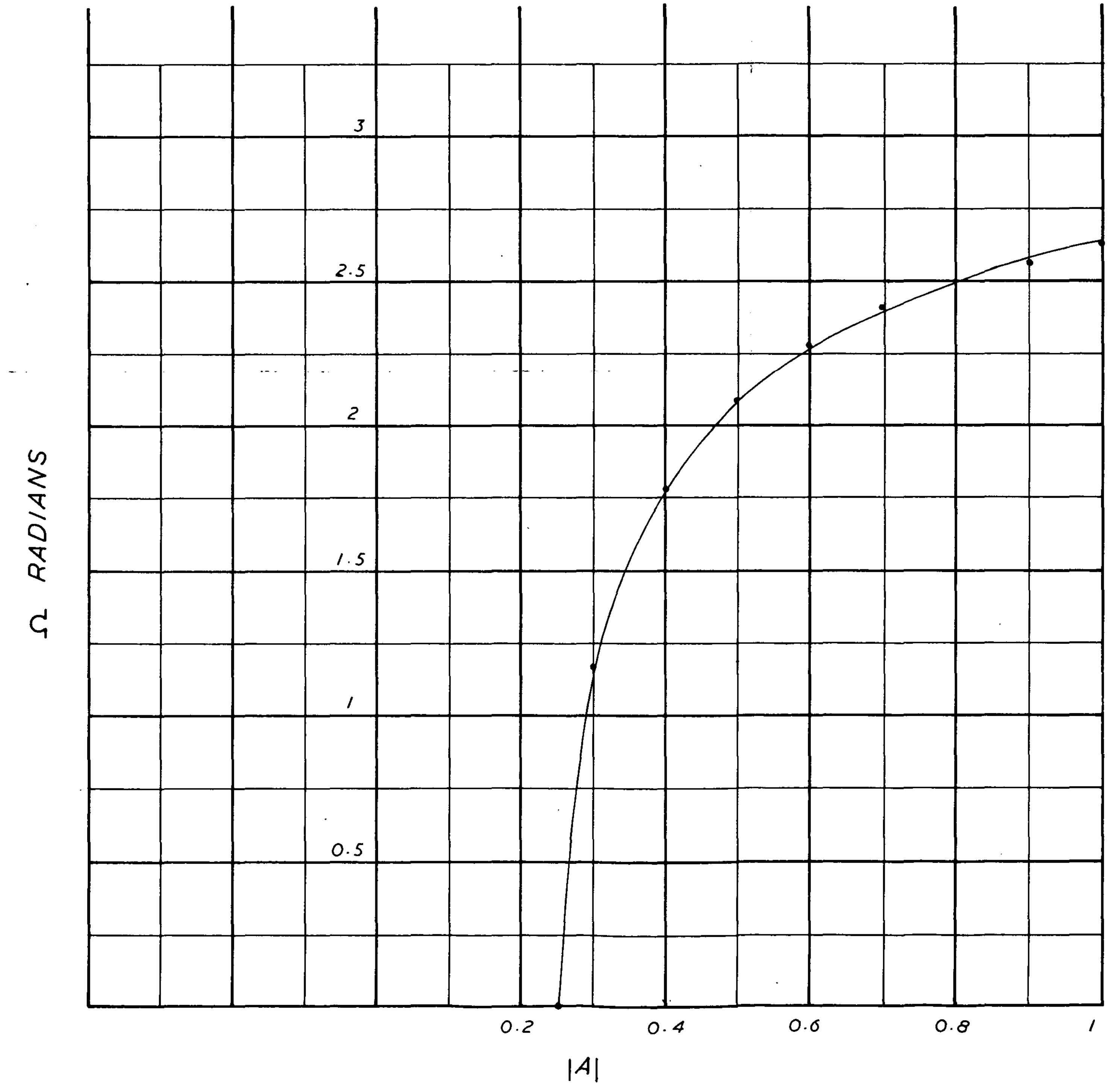
To ACCOMPANY RECORD NO 1971/48

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS	DRAWING No. MFR1.	SHEET 17.	INSTRUMENT FLUXGATE MAGNETOMETER. (SINGLE CHANNEL) BLOCK DIAGRAM.

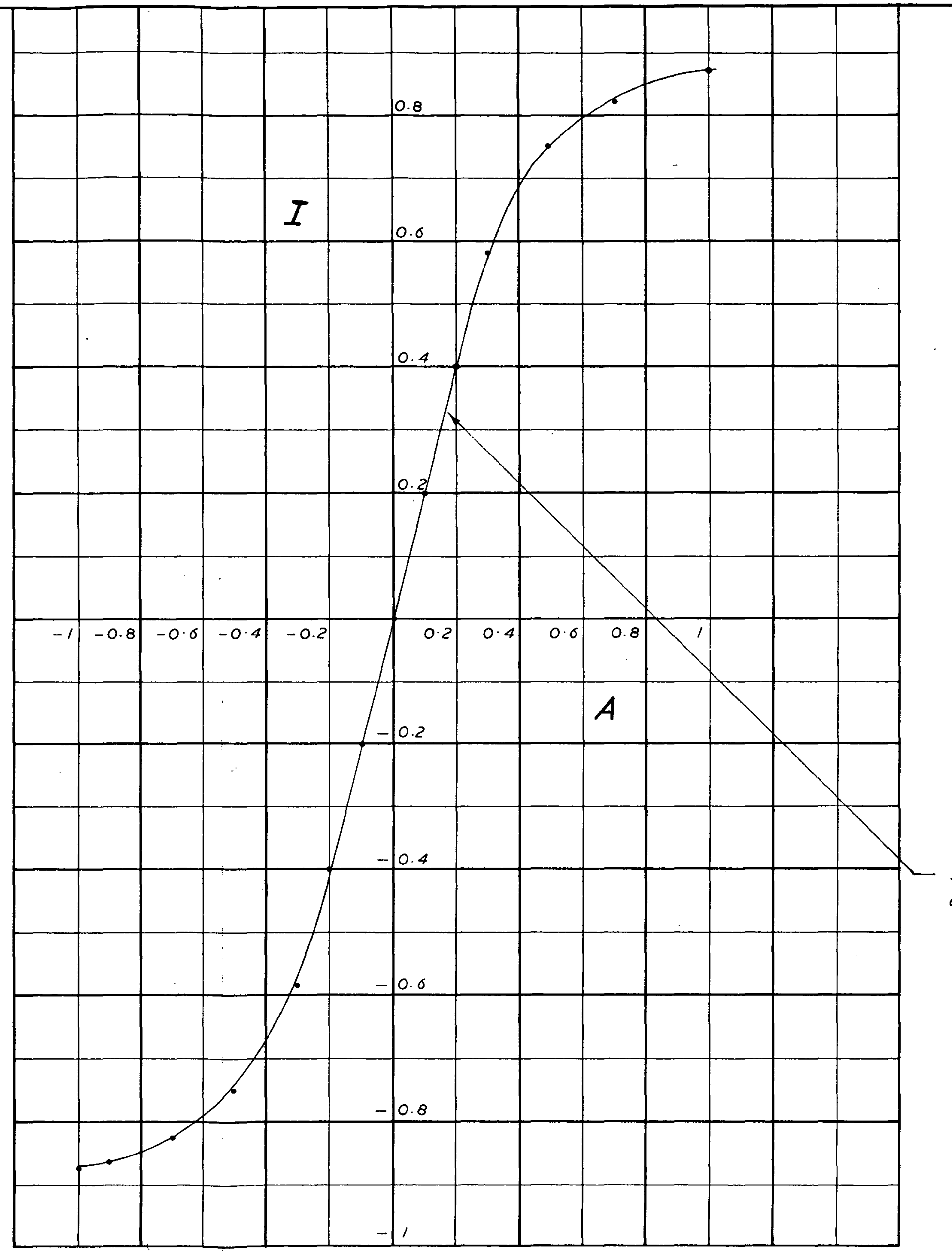
PLATE 3

SEPARATION Ω RADIANS OF DOUBLE HUMPS
IN EXPRESSION $\sin \omega t + A \cos 2\omega t$



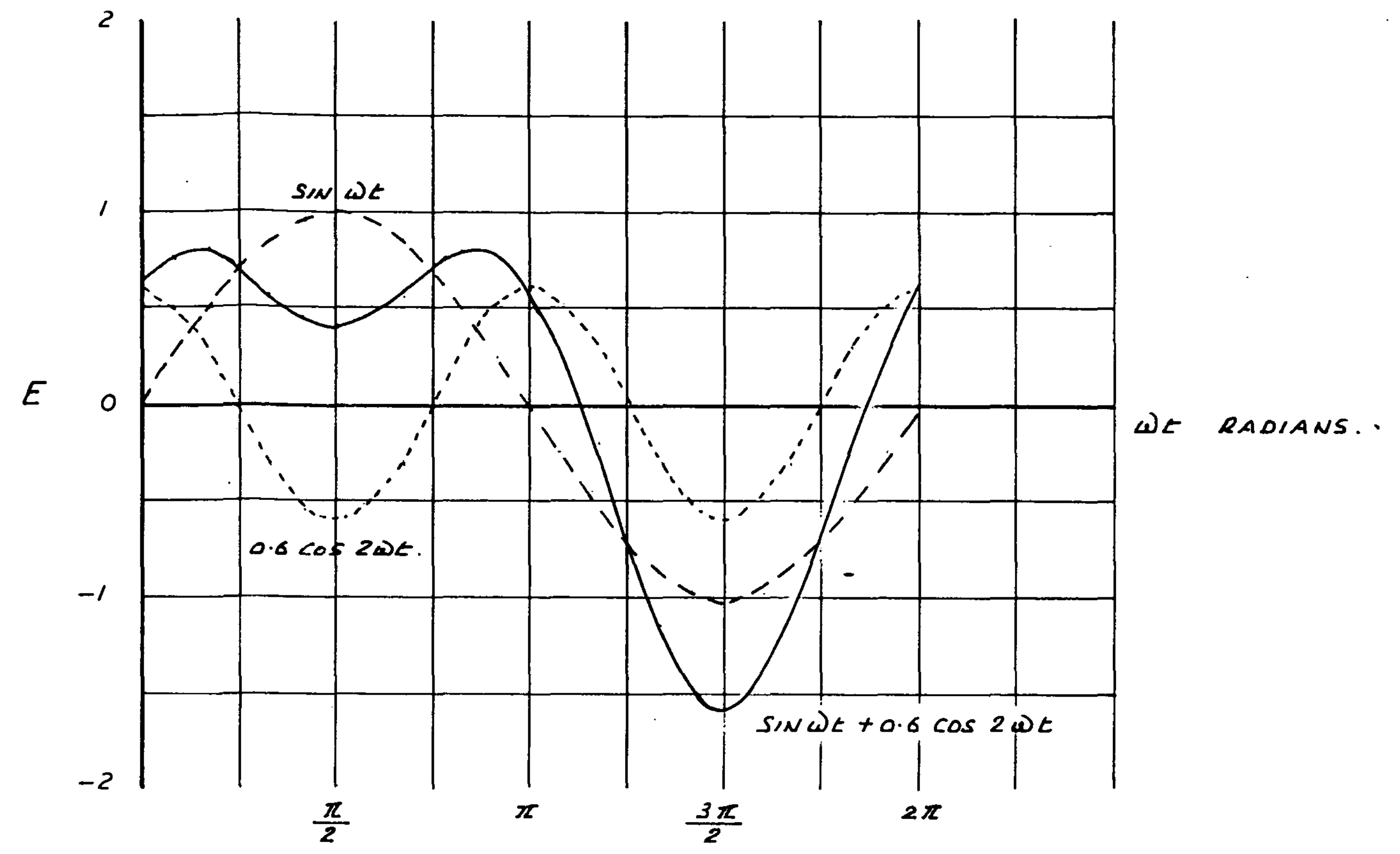


MFRI PEAK DETECTOR



THEORETICAL NORMALISED PEAK DETECTOR
OUTPUT I FOR NORMALISED MIXER OUTPUT OF $\sin \omega t + A \cos 2\omega t$

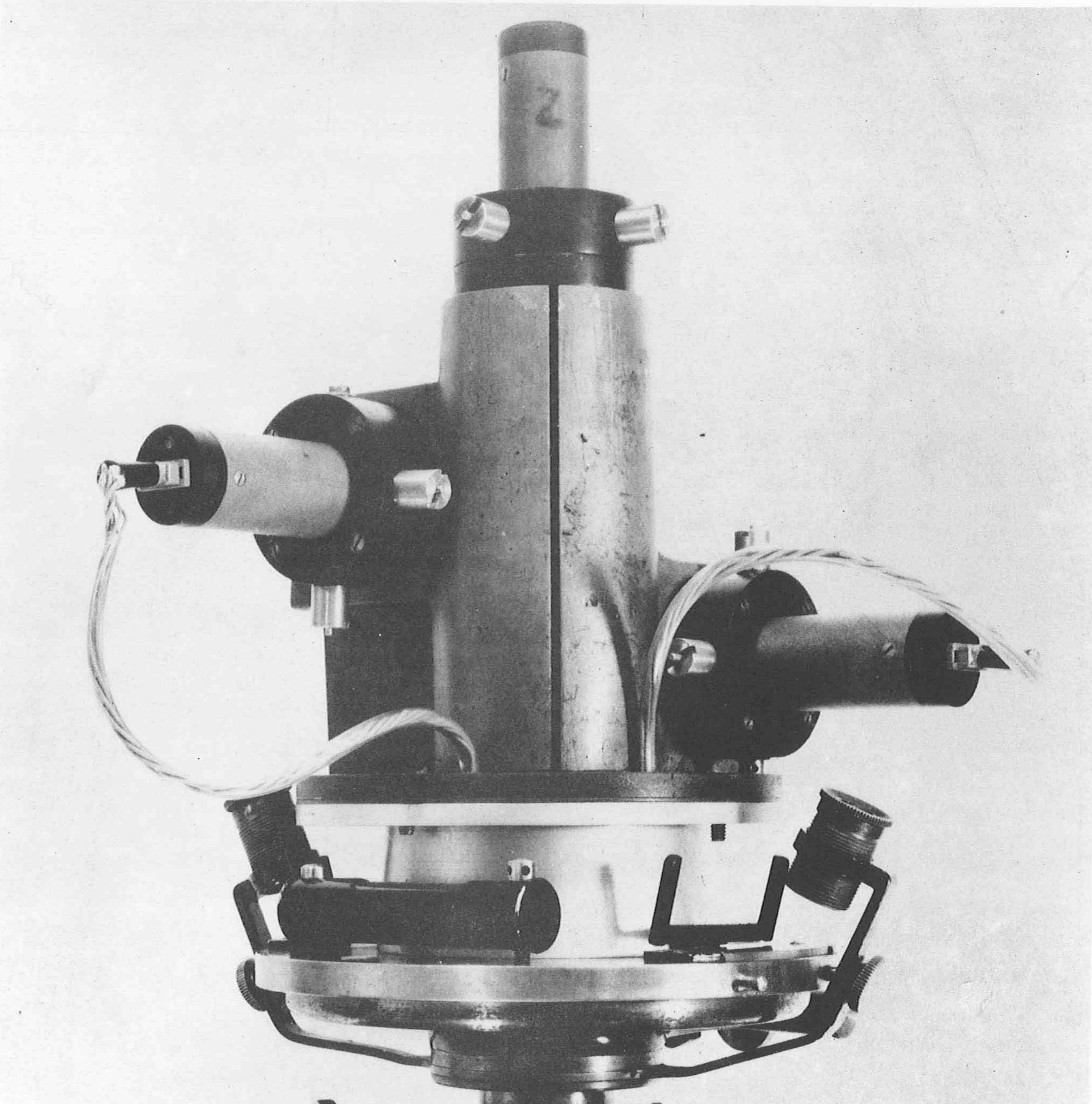
MFRI PEAK DETECTOR RESPONSE.



GRAPH OF EXPRESSION $E = \sin \omega t + 0.6 \cos 2\omega t$

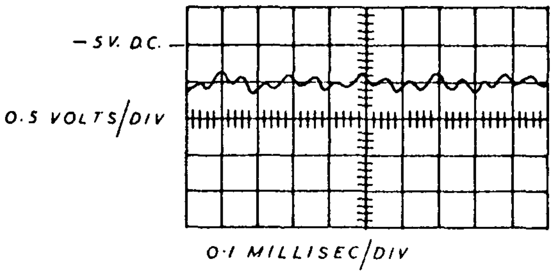
TO ACCOMPANY RECORD No 1971/48

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS	DRAWING No. MFRI	SHEET 16a	INSTRUMENT MFRI PEAK DETECTOR RESPONSE CURVES



TO ACCOMPANY RECORD 1971/48

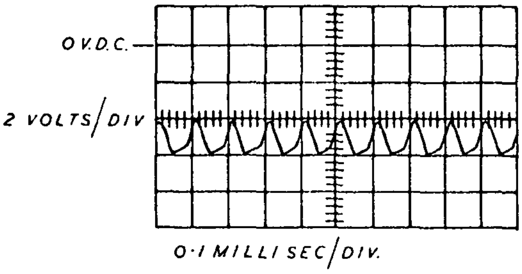
WAVEFORM No 1



LOCATION — AM1, Q1, BASE.

REMARKS — NULL SIGNAL

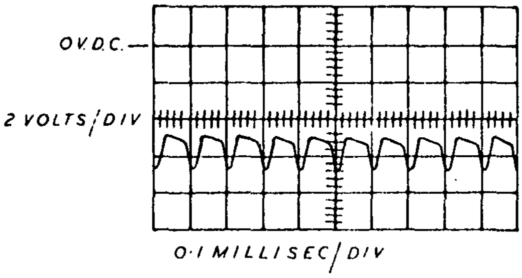
WAVEFORM No. 2



LOCATION — AM1, Q1, BASE.

REMARKS — VERY LARGE SIGNAL CAUSING RECORDER DEFLECTION TO THE RIGHT.

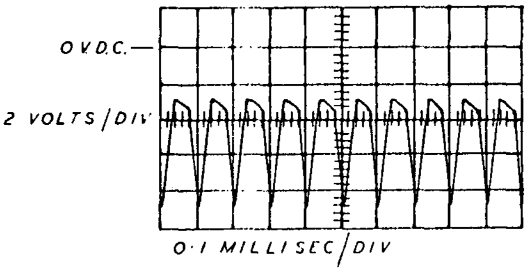
WAVEFORM No. 3



LOCATION — AM1, Q1, BASE.

REMARKS — VERY LARGE SIGNAL CAUSING RECORDER DEFLECTION TO THE LEFT.

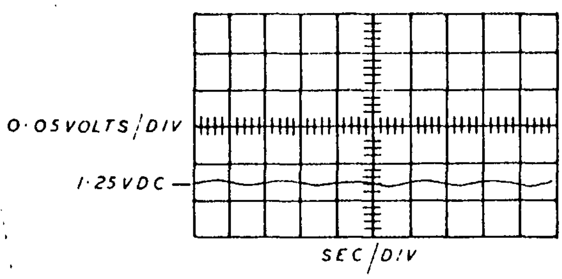
WAVEFORM No. 4



LOCATION — AM1, Q1, BASE.

REMARKS — DAMPING REDUCED PRODUCING INSTABILITY.

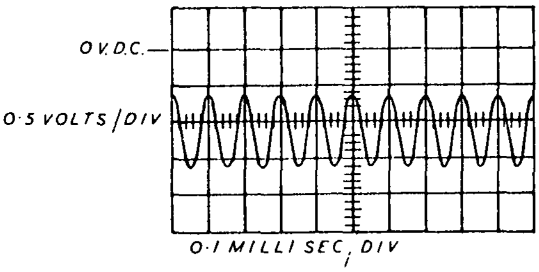
WAVEFORM No. 5



LOCATION — AM1, Q2, BASE.

REMARKS — NULL SIGNAL

WAVEFORM No. 6

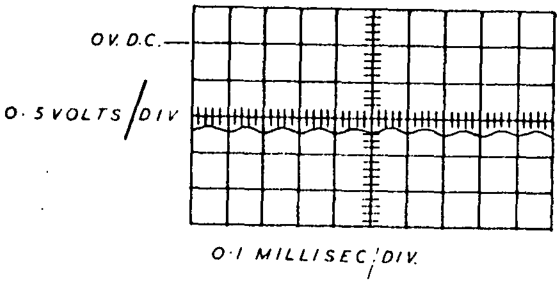


LOCATION — AM1, Q2, BASE.

REMARKS — VERY LARGE SIGNAL.

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS	DRAWING No. MFR1	SHEET 25	INSTRUMENT MFR1 WAVEFORMS

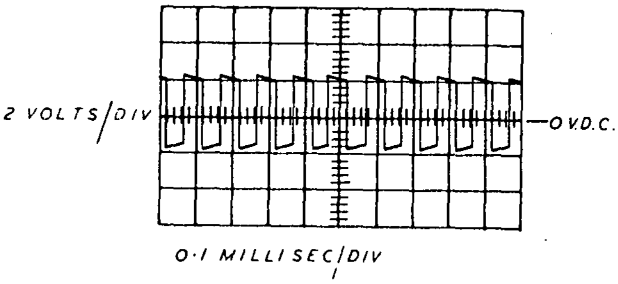
WAVEFORM No. 7



LOCATION — AM1, Q4, BASE.

REMARKS — NULL SIGNAL.

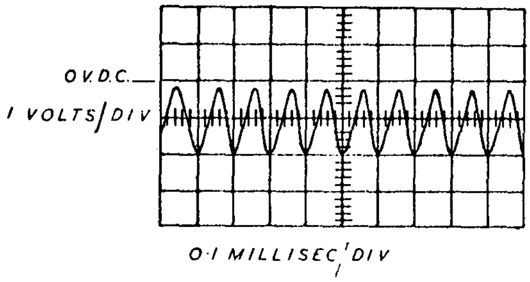
WAVEFORM No. 8



LOCATION — AM1, Q4, BASE.

REMARKS — VERY LARGE SIGNAL CAUSING CLIPPING.

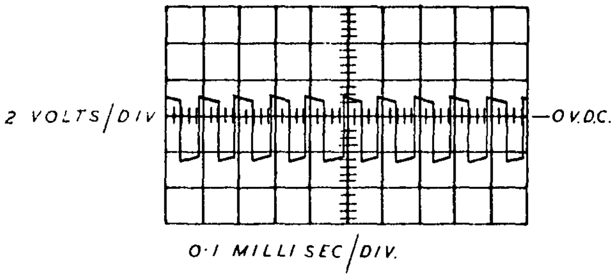
WAVEFORM No. 9



LOCATION — AM1, Q6, BASE.

REMARKS — NULL SIGNAL.

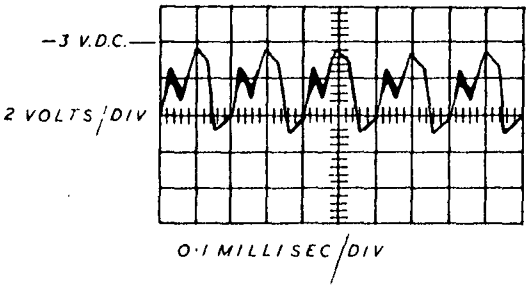
WAVEFORM No. 10



LOCATION — AM1, Q6, BASE.

REMARKS — VERY LARGE SIGNAL CAUSING CLIPPING.

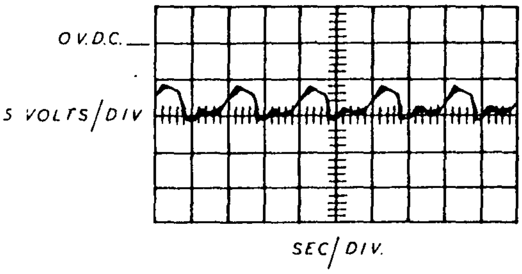
WAVEFORM No. 11



LOCATION — AM1, Q6, COLLECTOR.

REMARKS — NULL SIGNAL PP3 WITHDRAWN.

WAVEFORM No. 12



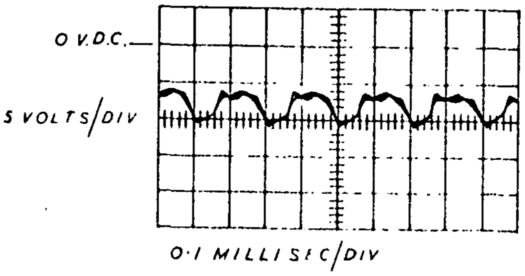
LOCATION — AM1 Q6 COLLECTOR

REMARKS — FULL SCALE DEFLECTION TO THE RIGHT. PP3 WITHDRAWN.

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS	DRAWING No. MFR1	SHEET 25	INSTRUMENT MFR1 WAVEFORMS

TO ACCOMPANY RECORD NO 1971/48

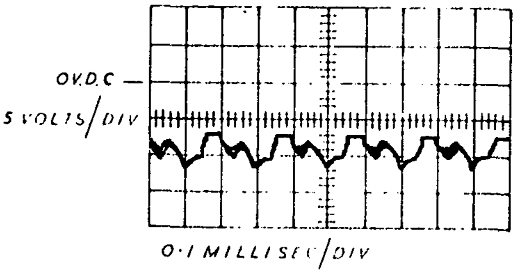
WAVEFORM No 13



LOCATION — AM1, Q6, COLLECTOR.

REMARKS — FULL SCALE DEFLECTION TO THE LEFT. PP3 WITHDRAWN.

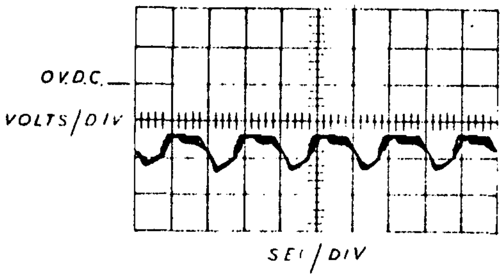
WAVEFORM No 14



LOCATION — AM1, T1, 6.

REMARKS — NULL SIGNAL PP3 WITHDRAWN.

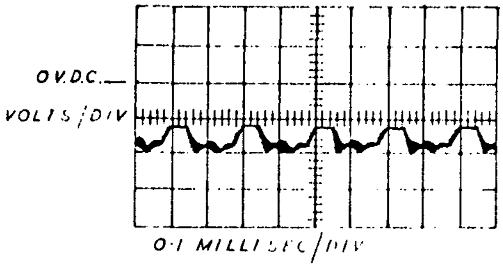
WAVEFORM No. 15



LOCATION — AM1, T1, 6.

REMARKS — FULL SCALE DEFLECTION TO THE RIGHT PP3 WITHDRAWN.

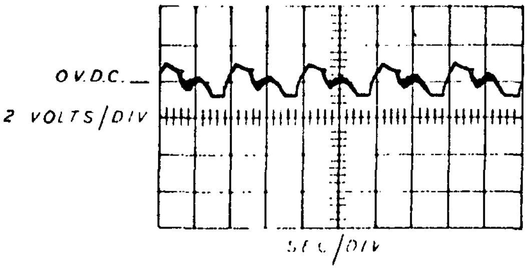
WAVEFORM No 16



LOCATION — AM1, T1, 6.

REMARKS — FULL SCALE DEFLETION TO THE LEFT PP3 WITHDRAWN.

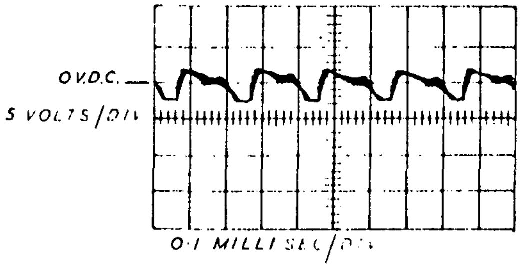
WAVEFORM No 17



LOCATION — AM1, T1, 7.

REMARKS — NULL SIGNAL PP3 WITHDRAWN.

WAVEFORM No 18



LOCATION — AM1, T1, 7.

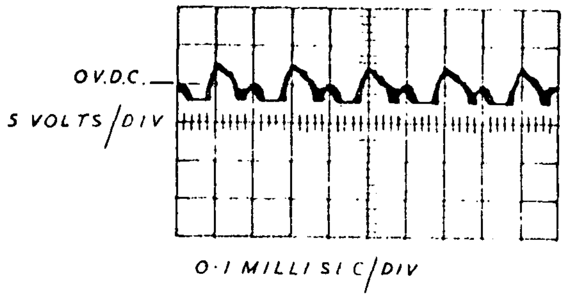
REMARKS — FULL SCALE DEFLECTION TO THE RIGHT PP3 WITHDRAWN.

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS	DRAWING No MFR1	SHEET 26	INSTRUMENT MFR1 WAVEFORMS.

TO ACCOMPANY RECORD NO 1971/48

PLATE 8

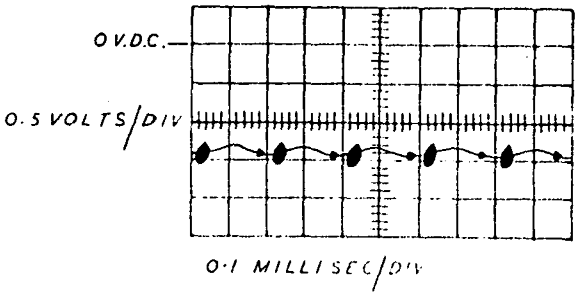
WAVEFORM No 19



LOCATION — AM1, T1, 7.

REMARKS — FULL SCALE DEFLECTION TO THE LEFT. PP3 WITHDRAWN.

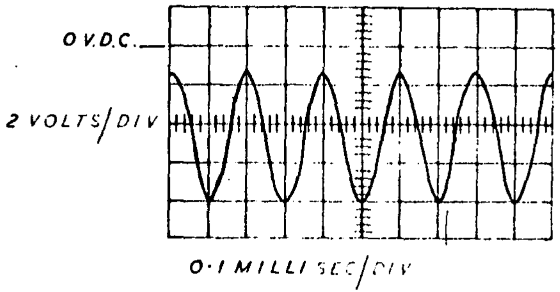
WAVEFORM No 20



LOCATION — D1, Q1, BASE.

REMARKS — DRIVE, OFF.

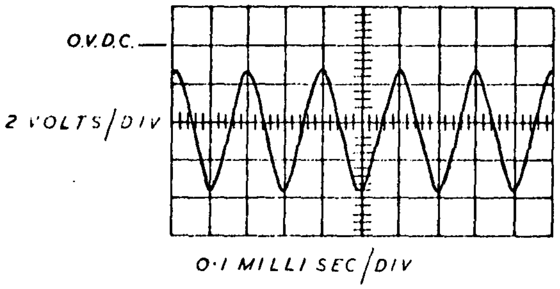
WAVEFORM No. 21



LOCATION — D1, Q1, COLLECTOR.

REMARKS — DRIVE, OFF.

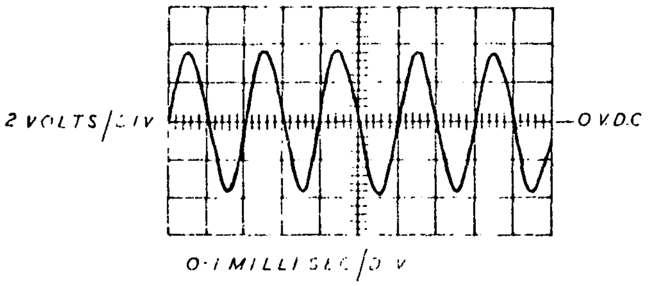
WAVEFORM No. 22



LOCATION — D1, Q3, EMITTER.

REMARKS — DRIVE, OFF.

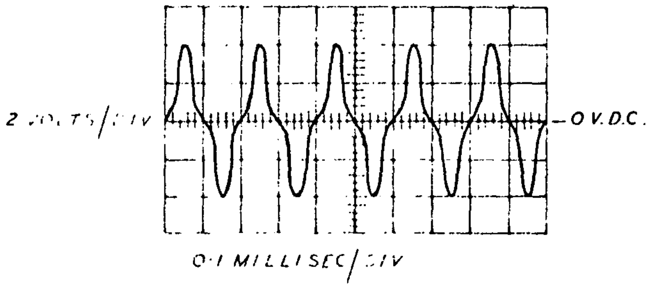
WAVEFORM No 23



LOCATION — D1, T1, 5.

REMARKS — DRIVE, OFF

WAVEFORM No 24



LOCATION — D1, T1, 5.

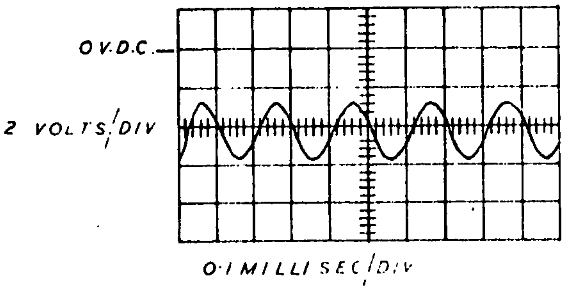
REMARKS — DRIVE, OFF

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS	DRAWING No.	SHEET	INSTRUMENT
	MFR1	26	MFR1 WAVEFORMS.

TO ACCOMPANY RECORD NO 1971/48

PLATE 9

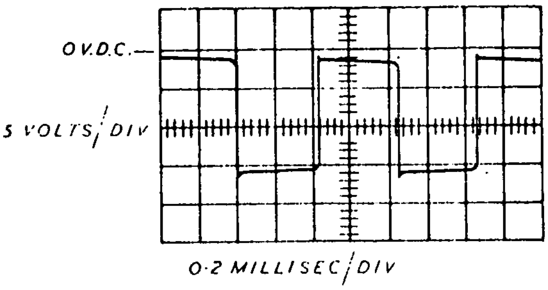
WAVEFORM No 25



LOCATION — D1, PHASE REF.

REMARKS —

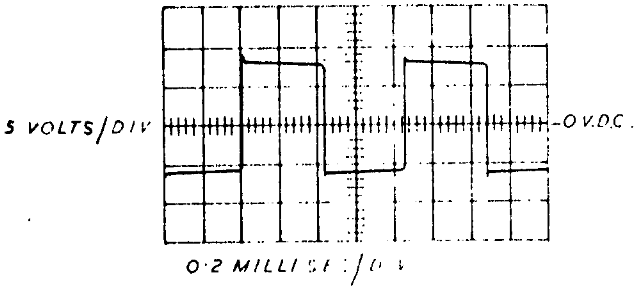
WAVEFORM No 26



LOCATION — PP3, Q1, COLLECTOR.

REMARKS —

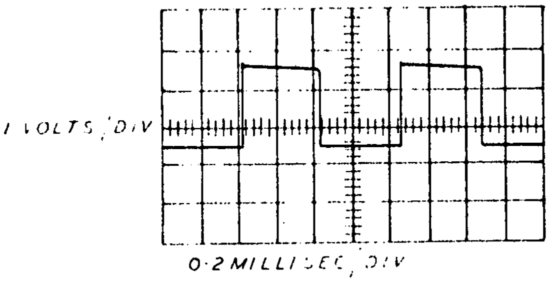
WAVEFORM No 27



LOCATION — PP3, Q2, COLLECTOR.

REMARKS —

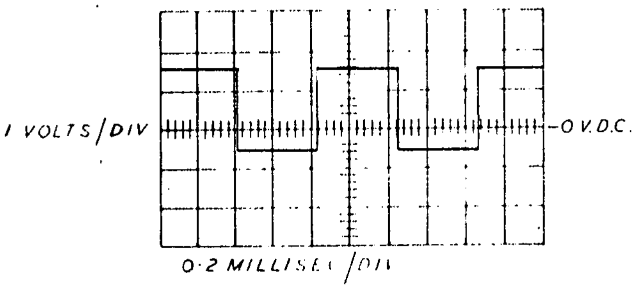
WAVEFORM No. 28



LOCATION — PP3, Q1, BASE.

REMARKS —

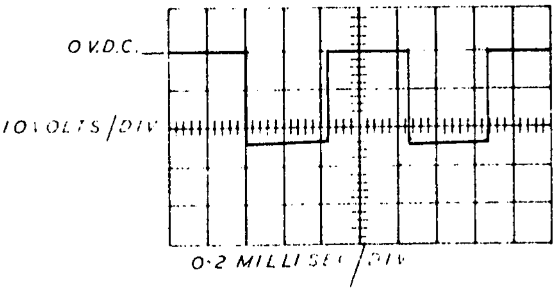
WAVEFORM No 29



LOCATION — PP3, Q2, BASE.

REMARKS — B/O SWITCH NORMAL.

WAVEFORM No 30



LOCATION — PP3, T1, 7.

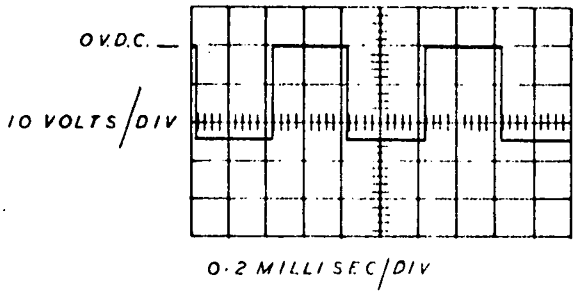
REMARKS — B/O SWITCH NORMAL.

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS	DRAWING No. MFR 1·	SHEET 27	INSTRUMENT MFR 1 WAVEFORMS

TO ACCOMPANY RECORD 1971/48

PLATE 10

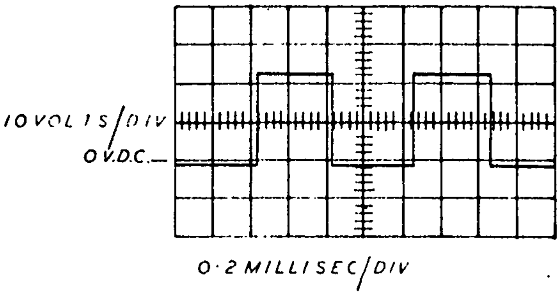
WAVEFORM No. 31



LOCATION ... PP3, T1, 8.

REMARKS _ B/O SWITCH NORMAL.

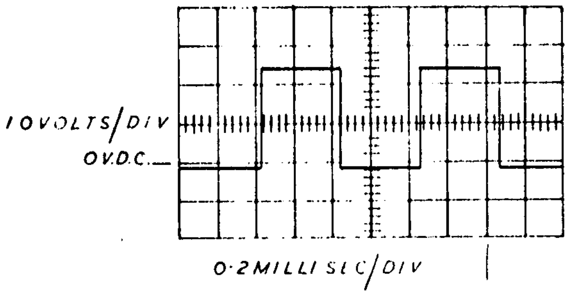
WAVEFORM No. 32



LOCATION ... PP3, T1, 9.

REMARKS ___ B/O SWITCH NORMAL

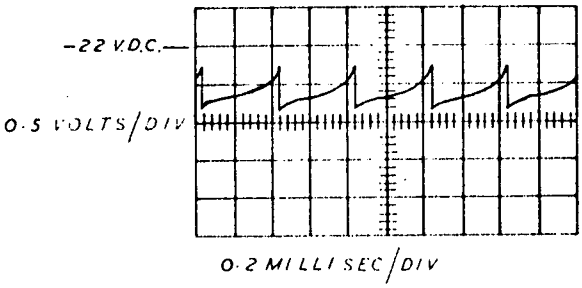
WAVEFORM No. 33



LOCATION... PP3, T1, 10.

REMARKS __ B/O SWITCH NORMAL

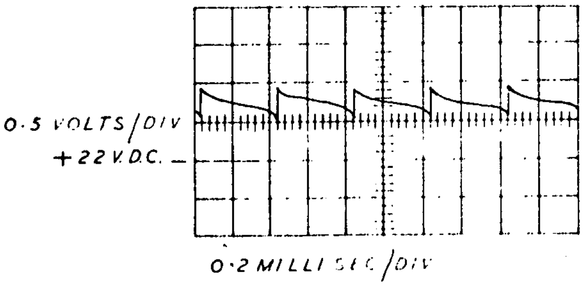
WAVEFORM No. 34



LOCATION.... PP3, CR2, CR 4.

REMARKS ___ B/O SWITCH NORMAL.

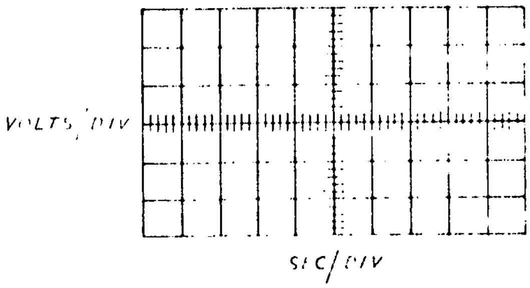
WAVEFORM No 35



LOCATION .. PP3, CR6, CR8.

REMARKS .. B/O SWITCH NORMAL

WAVEFORM No 36



LOCATION

REMARKS ...

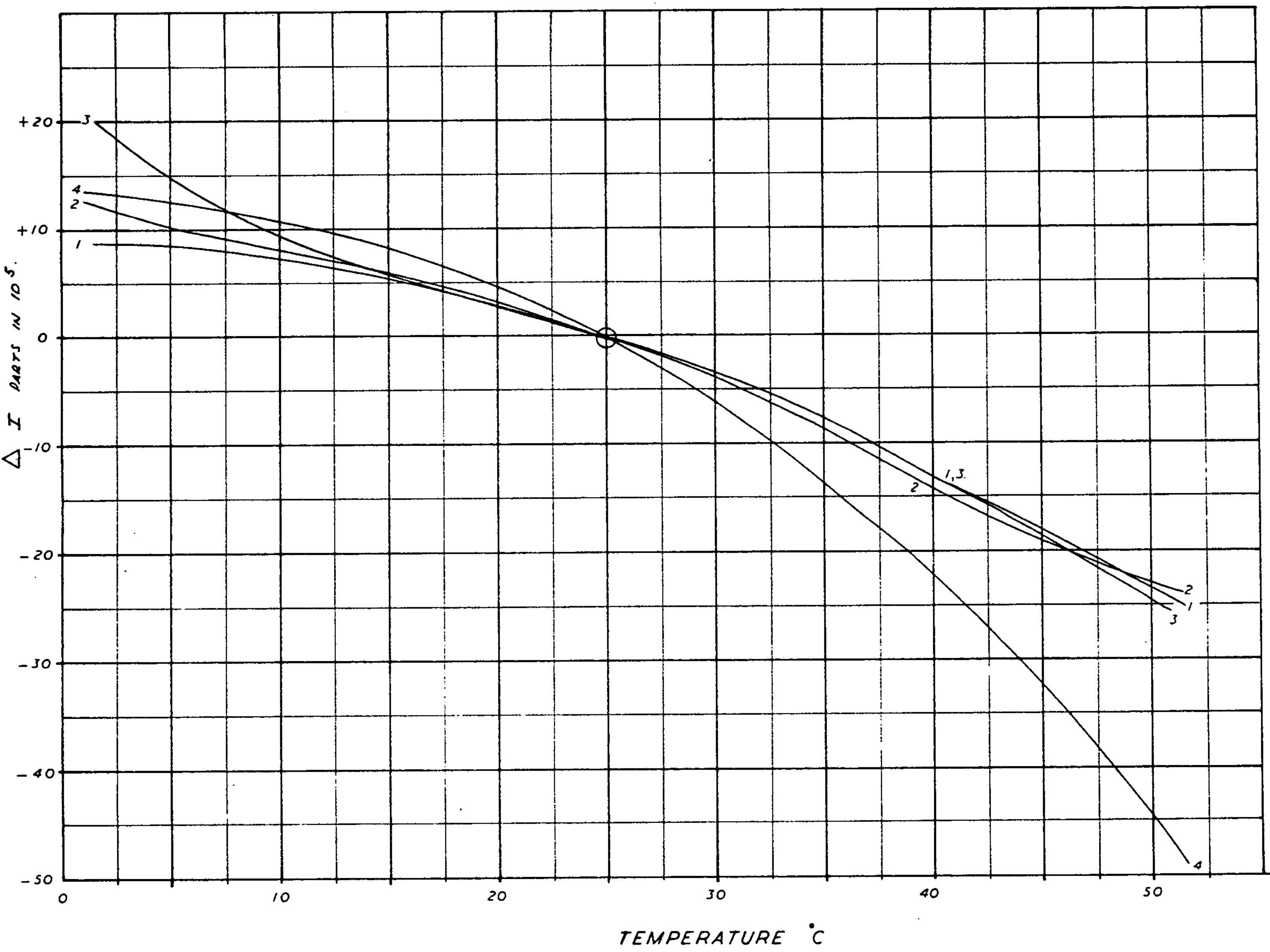
BUREAU OF MINERAL
RESOURCES
GEOLOGY AND GEOPHYSICS

DRAWING No. MFR 1.

SHEET 27

INSTRUMENT MFR 1
WAVEFORMS

TO ACCOMPANY RECORD NO 1971/48



CURVES FOR EACH OF THREE COMPONENTS AND SPARE

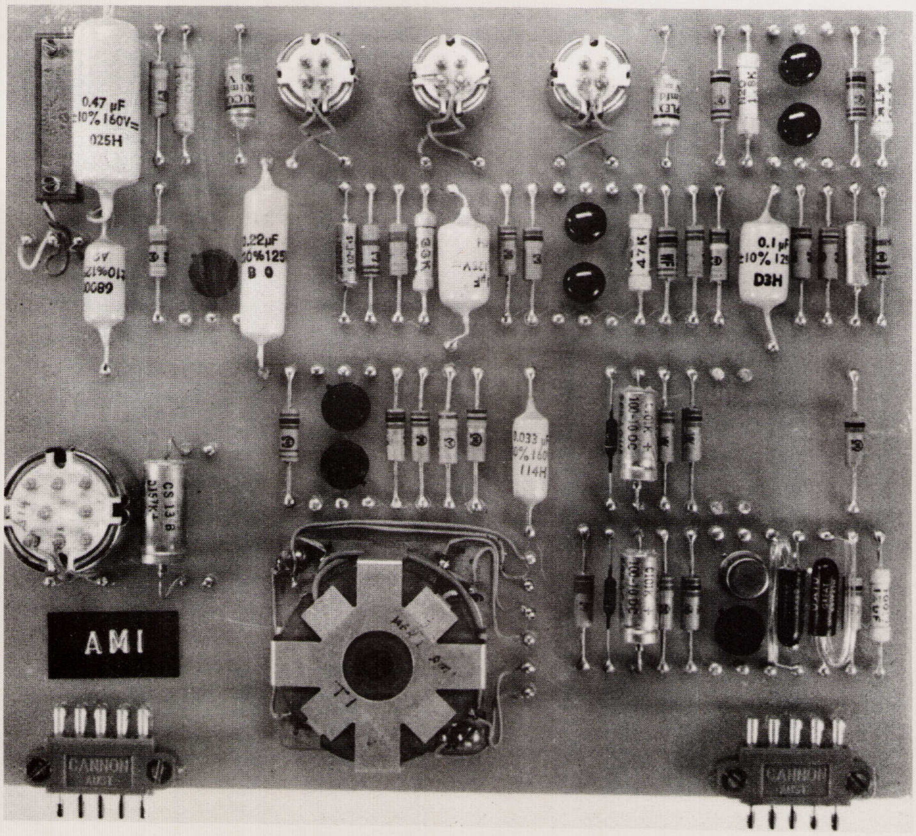
NOMINAL BASELINE 50 Kγ

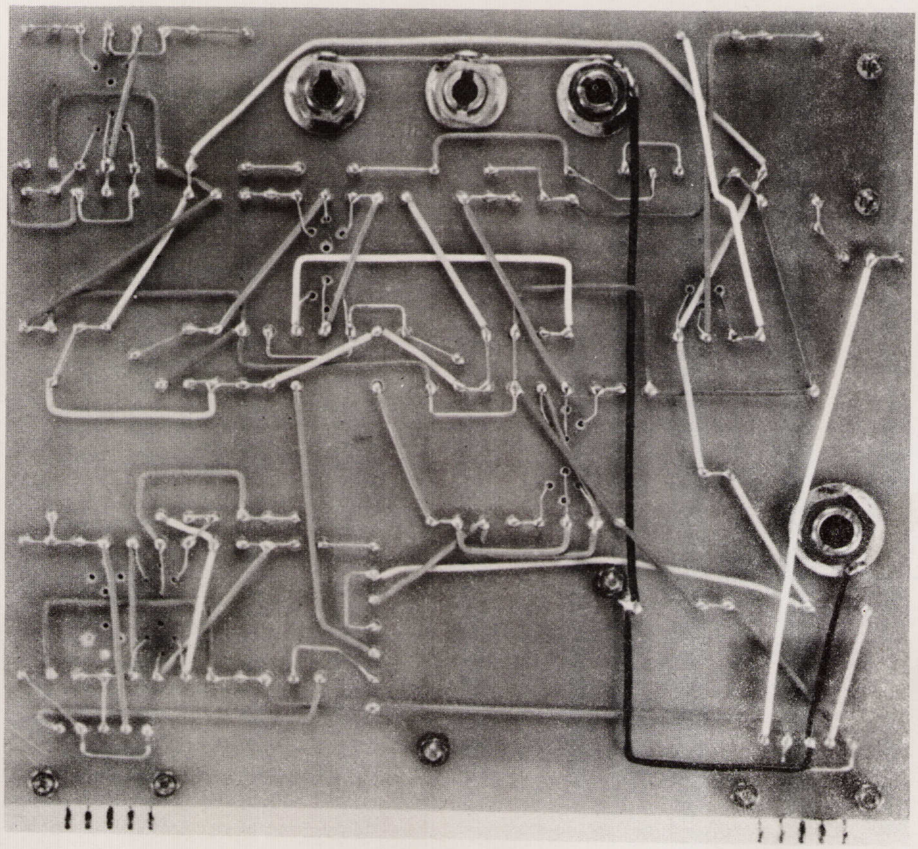
ESTIMATED MEASUREMENT ERROR ± 1 PART IN 10^5

TO ACCOMPANY RECORD NO 1971/48

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS	DRAWING No. MFR1	SHEET 16b	INSTRUMENT BASELINE CURRENT SUPPLY. TEMPERATURE DEPENDENCE.

PLATE 12





TO ACCOMPANY RECORD NO 1971/48

NAME	DATE	AMENDMENTS	ISSUE
N D J	27·10·64		1
N D J	24·5·65	——— MODIFIED & REDRAWN ———	2
N D J	16·10·65	——— MODIFIED & REDRAWN ———	3
R.C.	16.12.65	R34 & R35 ADDED. VALUES OF C1, C12, C13 & R5 ALTERED.	4.
R.C.	21.4.66.	WAVEFORM NUMBERS & D.C. VOLTAGES INSERTED. L1 ALTERED	5.
R.C.	28.3.69	VARIOUS ———	6

C12 C13 ——— SPRAGUE TANTALUM TYPE AL101K 100mF. VOCAB. BCK 03107.

COMPONENT LIST.

CONNECTORS. J1 J4 SOURIA 8140-02 MALE 5 PIN VOCAB. BKI 108

TRANSISTORS.

Q1. Q6 Q7 Q9	GERMANIUM PNP TYPE 2N404	VOCAB. BVT/2N404
Q2 Q3 Q4 Q5	SILICON PNP TYPE 2N3638	VOCAB. BVT/2N3638
Q8	GERMANIUM NPN TYPE 2N388	VOCAB. BVT/2N388

DIODES.

CR1 CR2.	SILICON DIODE TYPE OA200	VOCAB. BVD/OA200
CR3 CR4.	TO BE SELECTED.	

CAPACITORS.

C1	TANTALUM ELECTROLYTIC SPRAGUE TYPE AD15IK 150mF 15V.W.	VOCAB. BCK 03157.
C2	PHILIPS POLYESTER TYPE C296 125 V.W. 0.068 MFD	VOCAB. BCO 1683.
C3	PHILIPS POLYESTER TYPE C296 125 V.W. 0.47 MFD	VOCAB. BCO 1474
C4 C6	DUCON STYROSEAL TYPE DFB 6102 600 V.W. 1000 P.F. TO BE SELECTED TO 1% TOL. OF 950 P.F.	VOCAB. BCP 6102
C5	PHILIPS POLYESTER TYPE C296 125 V.W. 0.22 MFD. TO BE SELECTED TO 1% TOL. OF 0.238 MFD.	VOCAB. BCO 1224
C7 C10	PHILIPS POLYESTER TYPE C296 125 V.W. 0.1 MFD.	VOCAB. BCO 1104
C8 C9	TANTALUM ELECTROLYTIC SPRAGUE TYPE CS13AE 100K 10 MFD. 20 V.W.	VOCAB. BCK 03106
C11	PHILIPS POLYESTER TYPE C296 125 V.W 0.033 MFD.	VOCAB. BCO 1339

RESISTORS. FOLLOWING RESISTORS TO BE WELWYN 'METOX' F20.

R1	68K	BRB 56683	R2 R3 R6	10K.	BRB. 56103.
R4 R7 R9	2K	BRB 56202	R5	120K.	BRB. 56124.
R8	33K	BRB 56333	R10	15K	BRB. 56153
R11 R21 R30	22K	BRB 56223	R12 R18 R22 R26 R27 R31	1K	BRB. 56102.
R13 R32	3K	BRB 56302	R15	200K	BRB. 56204
R16	4.7K	BRB 56472	R17	1.8K	BRB 56182
R19 R23	47K	BRB 56473	R20 R24	3.3K	BRB 56332
R25	5.1K	BRB 56512	R28	11K	BRB 56113
R29	2.2K	BRB 56222	R33	100 OHMS.	BRB 56101
			R34 R35 TO BE SELECTED.		

POTENTIOMETER.

R14 BOURNS TRIMPOT TYPE 200L-1-101 100 OHMS. BPA 2101

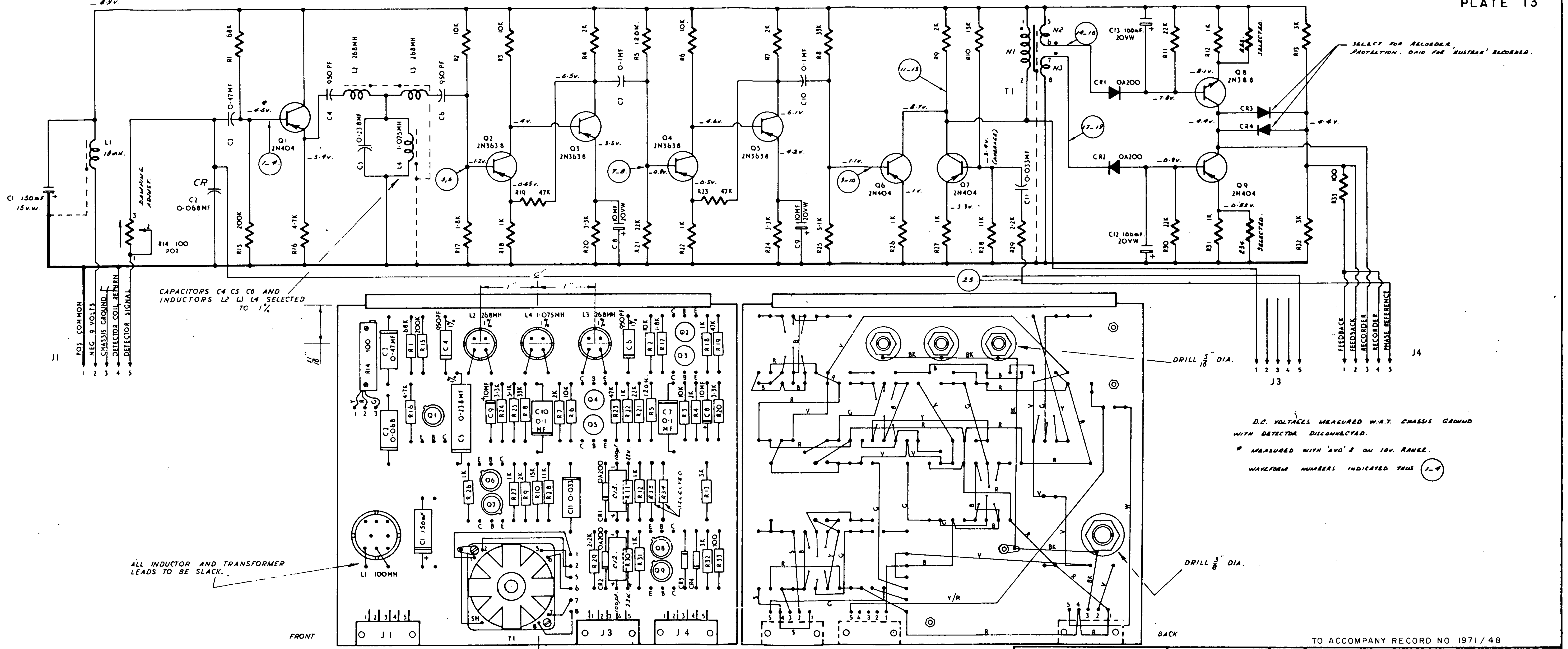
TRANSFORMER.

T1 VINKOR LA2130 SEE SPECIFICATION SHEET. REF. S10

INDUCTORS.

L1	VINKOR LA2406	18mH.	REF. S69.
L2 L3	VINKOR LA2732	268 MH	REF. S60
L4	VINKOR LA2732	1.075 MH	REF. S61

PLATE 13



D.C. VOLTAGES MEASURED W.R.T. CHASSIS GROUND WITH DETECTOR DISCONNECTED.

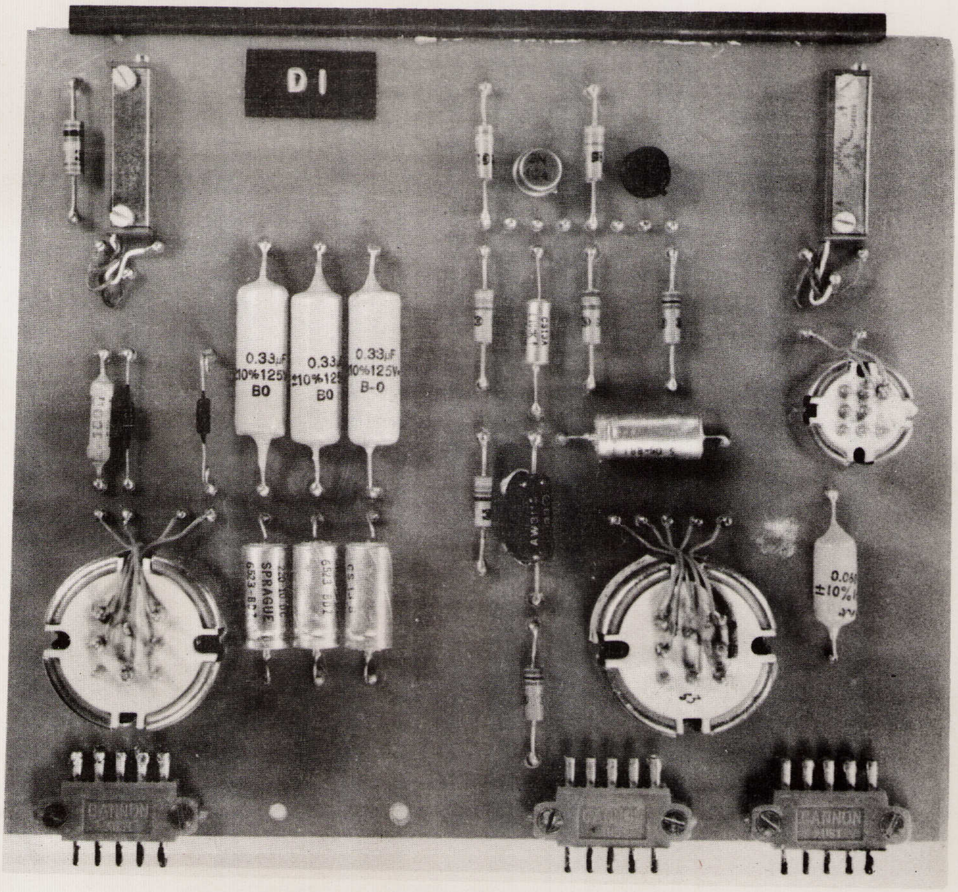
* MEASURED WITH 'AVO' 8 ON 10V. RANGE.

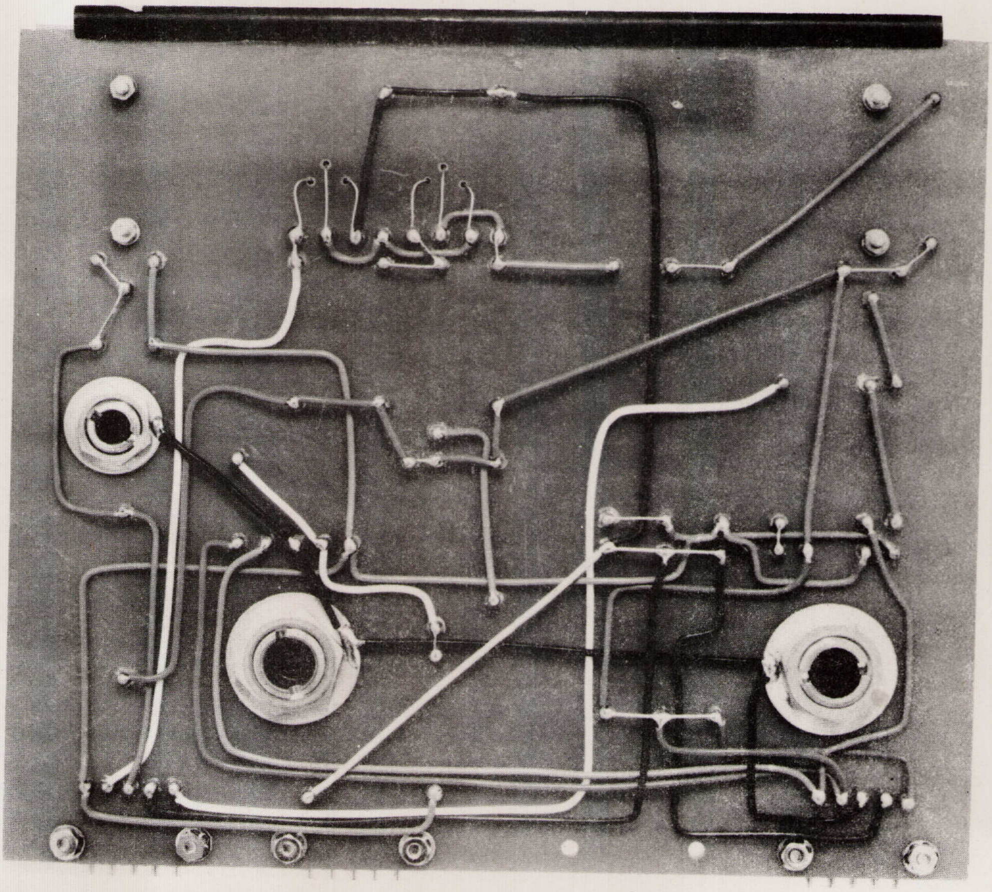
WAVEFORM NUMBERS INDICATED THUS (1-4)

TO ACCOMPANY RECORD NO 1971/48

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS	DRAWING No. MFR 1	SHEET 2	INSTRUMENT MFR1 AM1 FLUXGATE AMPLIFIER

PLATE 14





TO ACCOMPANY RECORD NO 1971/48

COMPONENT LIST.

CONNECTORS.
P1 P4 SOURIAU 8140-02 MALE 5 PIN
VOCAB. BKZ198

TRANSISTORS.
Q1 Q2 TRANSISTOR TYPE 2N404
VOCAB. BVT/2N404
Q3 TRANSISTOR TYPE 2N301A
VOCAB. BVT/2N301A

DIODE.
CR1 SILICON DIODE TYPE OA200
VOCAB. BVD/OA200

CAPACITORS.
C6 TANTALUM ELECTROLYTIC SPRAGUE
TYPE CS13AE680K
68 MFD 20VW VOCAB. BCK03680
C2 C3 C4 PHILIPS POLYESTER TYPE C296 125VW
0.33 MFD VOCAB. BC01334
C2 & C4 selected to 1% tolerance.
C5 TANTALUM ELECTROLYTIC SPRAGUE
TYPE CS13AE100K
10 MFD 20VW VOCAB. BCK03106
C7 PHILIPS POLYESTER TYPE C296 125VW
0.068 MFD VOCAB. BC01683

POTENTIOMETERS.
R7 BOURNS TRIMPOT TYPE 200L-1-201 5K. OHMS
VOCAB. BPA 2502.
R13 BOURNS TRIMPOT TYPE 200L-1-502 5K OHMS
~~VOCAB. BPA2502~~

RESISTORS.
Following resistors to be WELWYN "METOX" ½ WATT TYPE F20

R2	24K OHMS
R3 R8	4.7K OHMS
R6	910 OHMS
R9	62 OHMS
R10	1.5K OHMS
R11	2K OHMS
R14	200 OHMS
R15	100 "

R12 WELWYN TYPE AW3115 6 WATT W/W 10%
33 OHMS VOCAB. BRG26330

CHOKES.
L1 VINKOR TYPE LA2206 6·15 mH
See specification sheet for details
L2 VINKOR TYPE LA2506 28 mH
See specification sheet for details

TRANSFORMER.
T1 VINKOR TYPE LA2206
See specification sheet for details

CAPACITORS.
C1, C1a, C1b. — TANTALUM ELECTROLYTIC SPRAGUE.
TYPE CS13BC227K.
220 MFD. 10V.W. VOCAB. BCK 02227.

DIODE.
CR2. — GERMANIUM DIODE TYPE OA95
VOCAB. BVD/OA95

PLATE 15

Transistor Q3 & Resistor R1 mounted externally.

Potentiometer leads to be slack.

Fit shakeproof washers.

Drill ⅛" dia

Drill ½" dia. 2 holes.

Leave transformer & choke leads slack.

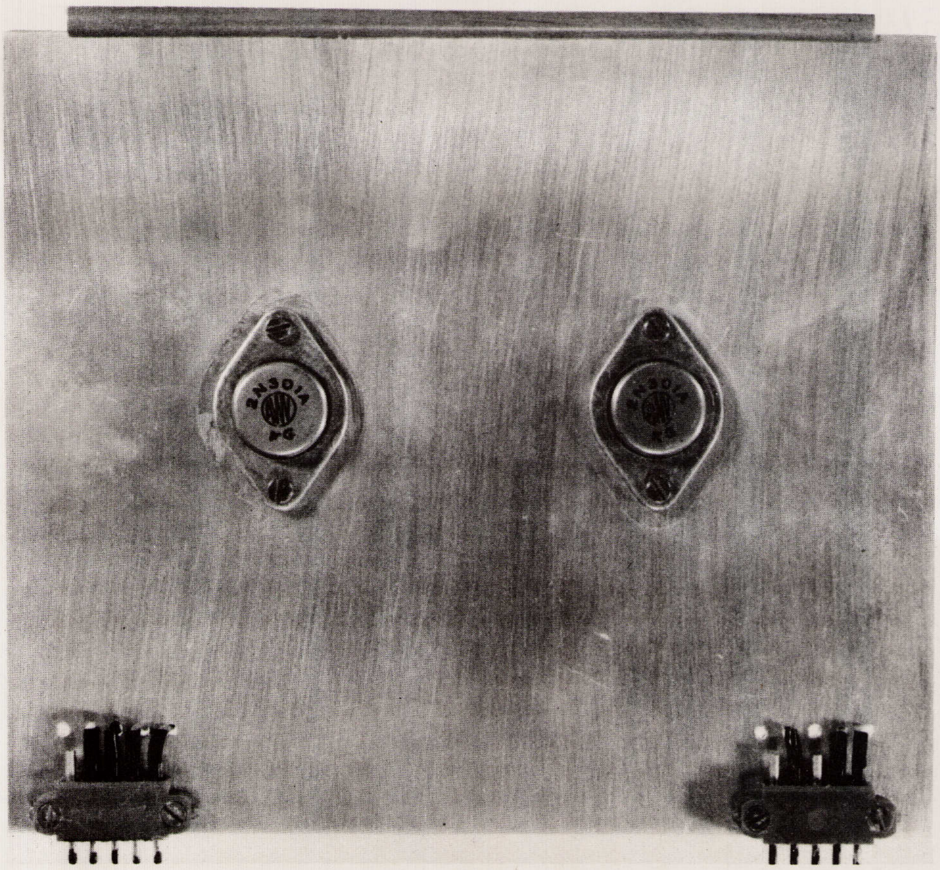
Resistor R1 R4 & R5 deleted.

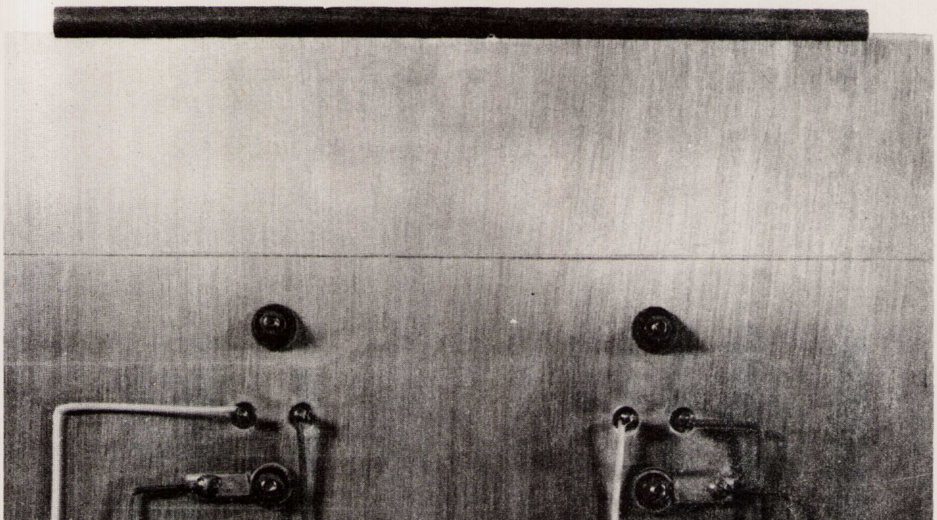
Resistors R1, R4 & R5 deleted.
VALUE OF C1 ALTERED.
C1a C1b CR2 & R15 ADDED.

TO ACCOMPANY RECORD NO 1971/48

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS	Drawing No. MFR1 SH.3	INSTRUMENT MFR1 D1 CONSTANT VOLTAGE DRIVER

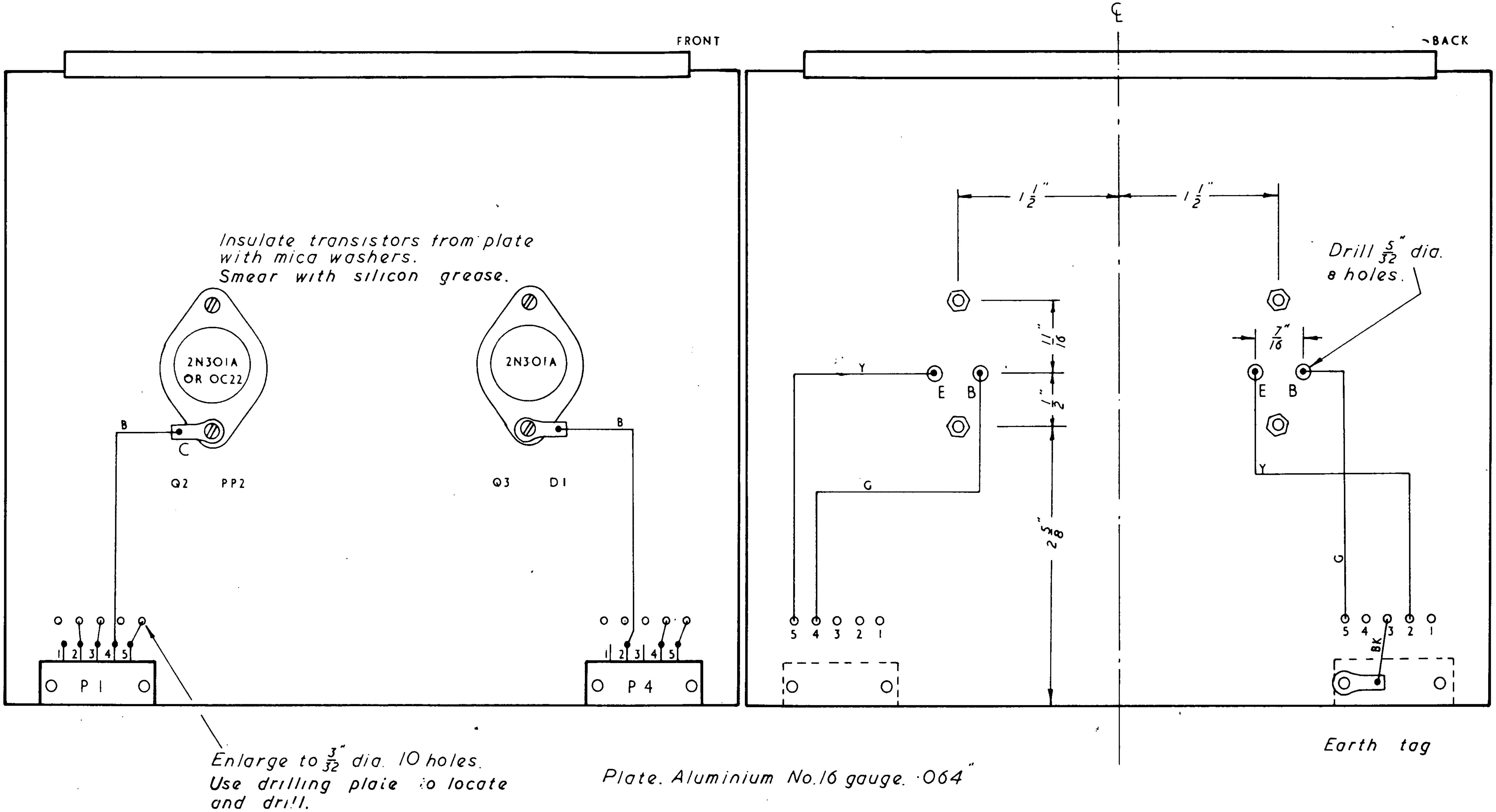
PLATE 16





TO ACCOMPANY RECORD NO 1971/48

PLATE 17



Insulate transistors from plate with mica washers.
Smear with silicon grease.

Drill $\frac{5}{32}$" dia.
8 holes.

Enlarge to $\frac{3}{32}$" dia. 10 holes.
Use drilling plate to locate and drill.

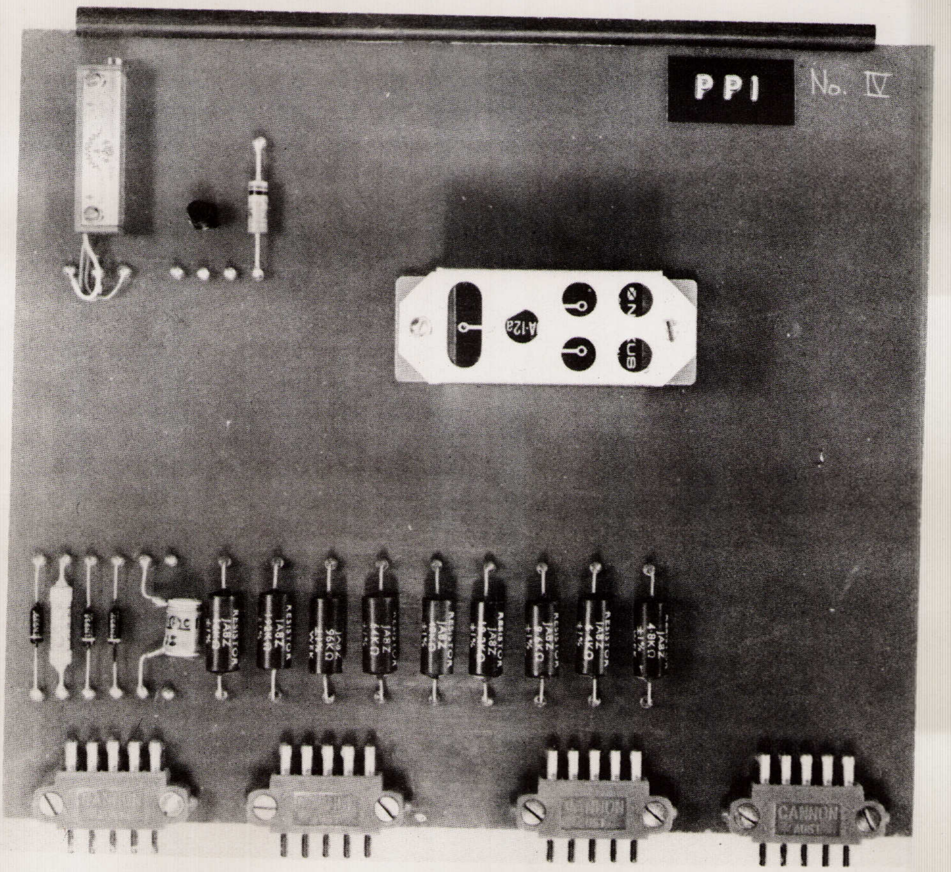
Plate. Aluminium No.16 gauge. ·064"

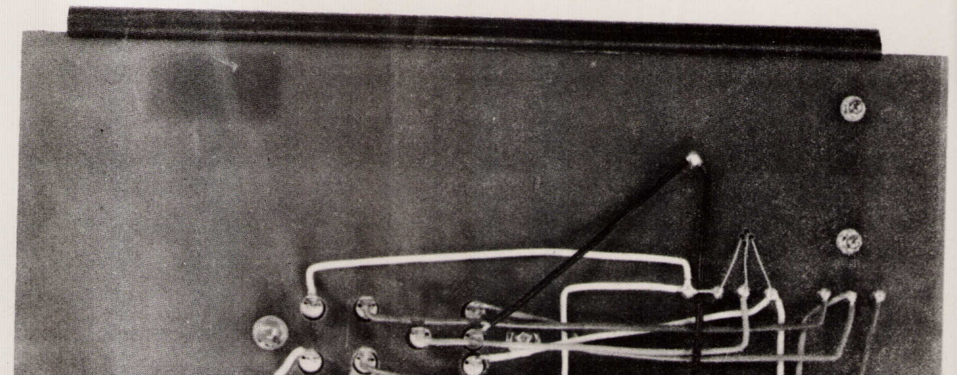
Earth tag

TO ACCOMPANY RECORD NO 1971/48.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS	Drawing No. MFR1 SH.7	INSTRUMENT MFR1 C1 HEAT SINK

PLATE 18





TO ACCOMPANY RECORD NO 1971/48

COMPONENT LIST.

CONNECTORS.

P1 P2 P3 P4 [illegible] 5 PIN. Vocab. 5KZ1[illegible]8

TRANSISTOR.

Q1 SILICON PNP TYPE 2N861 Vocab. AVT/2N861

DIODES.

CR1 CR2 TEMPERATURE COMPENSATED ZENER REFERENCE DIODE. MOTOROLA TYPE 1N935 500 mW.

CR3 TEMPERATURE COMPENSATED ZENER REFERENCE DIODE. MOTOROLA TYPE 1N939 500 mW.

RESISTORS.

R1	WELWYN METOX TYPE F20	½ WATT.	470 OHMS.	Vocab.	5RB56471
R2	WELWYN METOX TYPE F20	½ WATT.	390 OHMS	Vocab.	BRB 56391
R4	WELWYN METOX TYPE F20	½ WATT.	100K OHMS.	Vocab.	5RB56104

Following resistors to be "ALMA" precission loosewound type JA8Z. 1% TOL. Temperature coefficient less than plus or minus 0.0005% per degree C. Resistors FROM JACOBY MITCHELL, SYDNEY, AUST.

R5	16K OHMS
R6	4.8K OHMS
R7	6.4K OHMS
R8	9.6K OHMS
R9	19.2K OHMS
R10	48K OHMS
R11	64K OHMS
R12	96K OHMS
R13	192K OHMS
R14	1·92K OHMS

POTENTIOMETER.

R3 BOURNS TRIMPOT TYPE 200L-2-104 100K OHMS. Vocab. BPA2104

OPERATIONAL AMPLIFIER. NEXUS TYPE CDA-12A. Complete with socket and module retainer. Available ex Cannon Plugs, Melbourne.

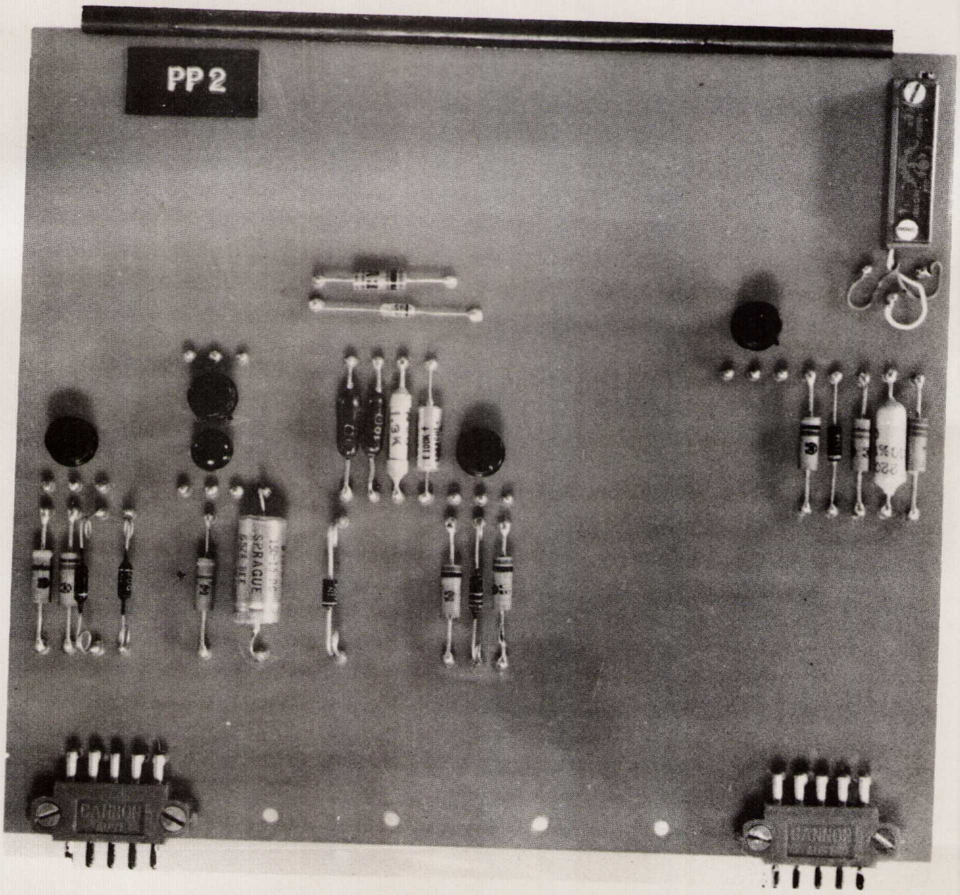
D.C. VOLTAGES MEASURED W.R.T. CHASSIS GROUND WITH DETECTOR DISCONNECTED AND B/O SWITCH AT NORMAL.

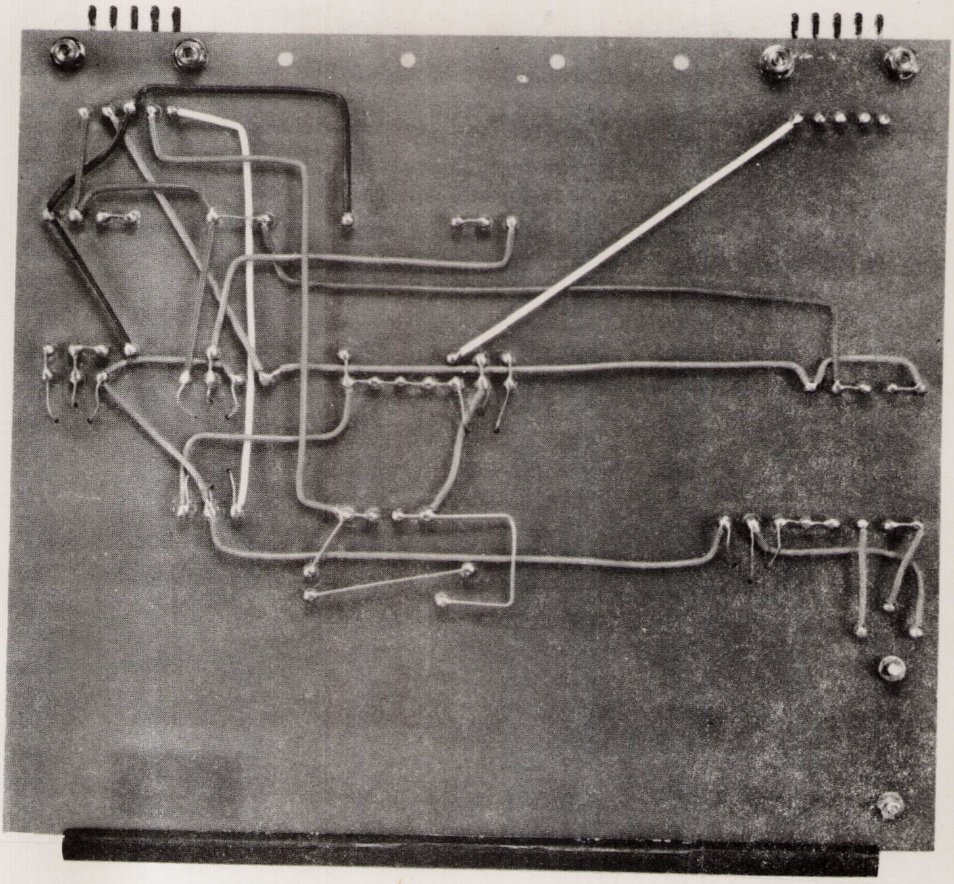
PLATE 19

TO ACCOMPANY RECORD NO 1971/48

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS	DRAWING No. MFR1	SHEET 4	INSTRUMENT MFR1 PP1 CONSTANT CURRENT SUPPLY

PLATE 20





TO ACCOMPANY RECORD NO 1971/48

COMPONENT LIST.

P1 P4	SOURIAU 8140-02 MALE 5 PIN VOCAB. BKZ198

TRANSISTORS.

Q1 Q4	TRANSISTOR TYPE T2309
Q2	TRANSISTOR TYPE 2N301A VOCAB. BVT/2N301A
Q3 Q6	TRANSISTOR TYPE 2N404 VOCAB. BVT/2N404

DIODES.

CR1	SILICON DIODE TYPE 1N4004 VOCAB. BVD/1N4004
CR2 CR5	SILICON ZENER DIODE TYPE 1N753A VOCAB. BVD/1N753A
CR3 CR4	SILICON DIODE TYPE OA200 VOCAB. BVD/OA200

CAPACITORS.

C1	TANTALUM ELECTROLYTIC SPRAGUE TYPE CS13AE100K 10 MFD 20VW VOCAB. BCK03106
C2	TANTALUM ELECTROLYTIC SPRAGUE TYPE CS13BD157K 150mF. 15V.D.C. VOCAB. BCKC3157
C3	PHILLIPS POLYESTER TYPE C296. 0·022mF. VOCAB. BC01223 AA/A 22K. 125V.

Add following TRANSISTOR.

Q5	SILICON PNP TYPE 2N3638 VOCAB. BVT/2N3638

RESISTORS.
Following resistors to be WELWYN "METOX" TYPE F20 ½ WATT.

R1	SELECT		
R2 R7	10K OHMS		
R4	470 OHMS		
R5	12K OHMS	R12	1K OHMS
R6	300 OHMS		
R8	4.7K OHMS		
R9	2.2K OHMS		
R11	5.1K OHMS		

Following resistors to be WELWYN TYPE AW3101 3 WATT W/W

R3	1 OHMS	
R3A	10 OHMS	VOCAB. BRE27100

POTENTIOMETER.

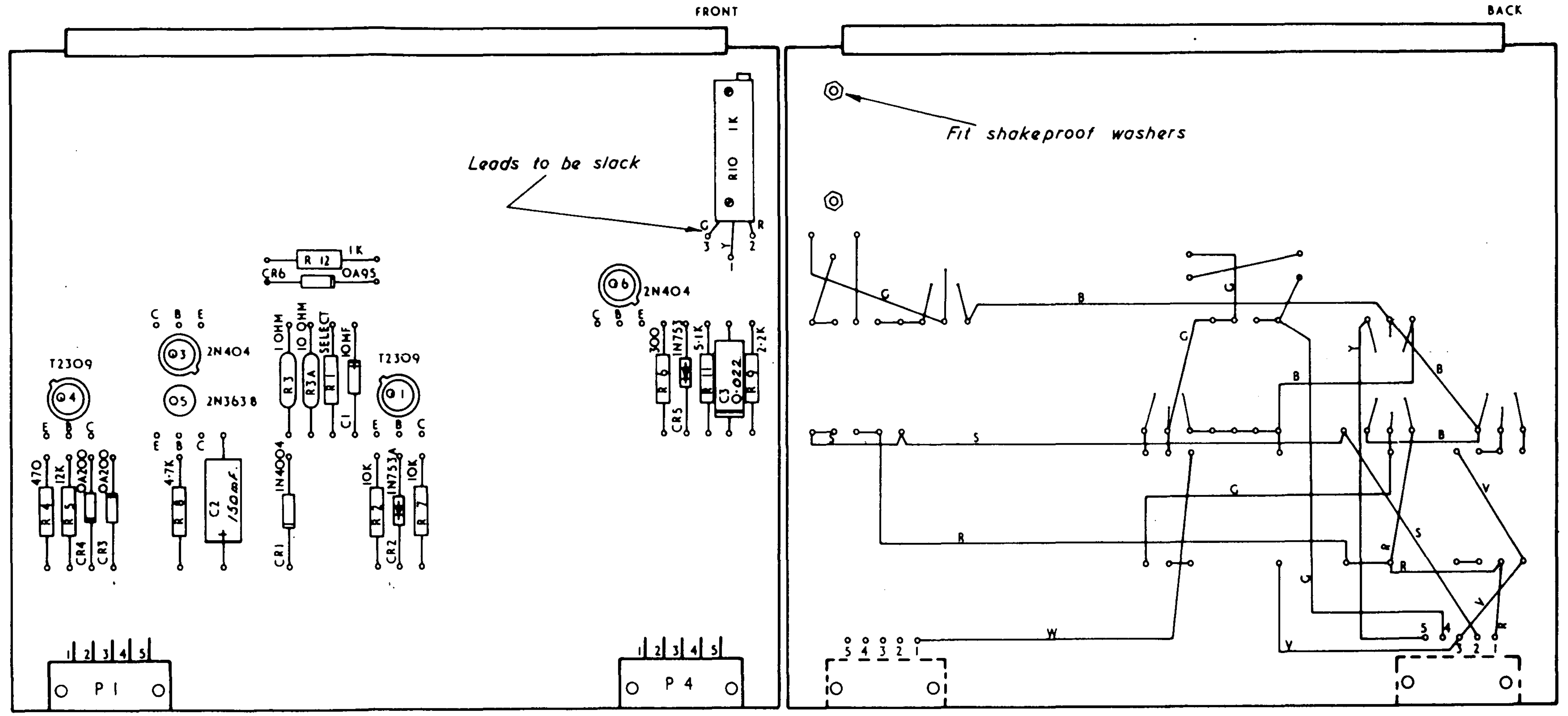
R10	BOURNS TRIMPOT TYPE 200L-1-102 1 K OHMS VOCAB. BPA2102

DIODE.

CR6	GERMANIUM DIODE TYPE OA95 VOCAB. BVD/OA95

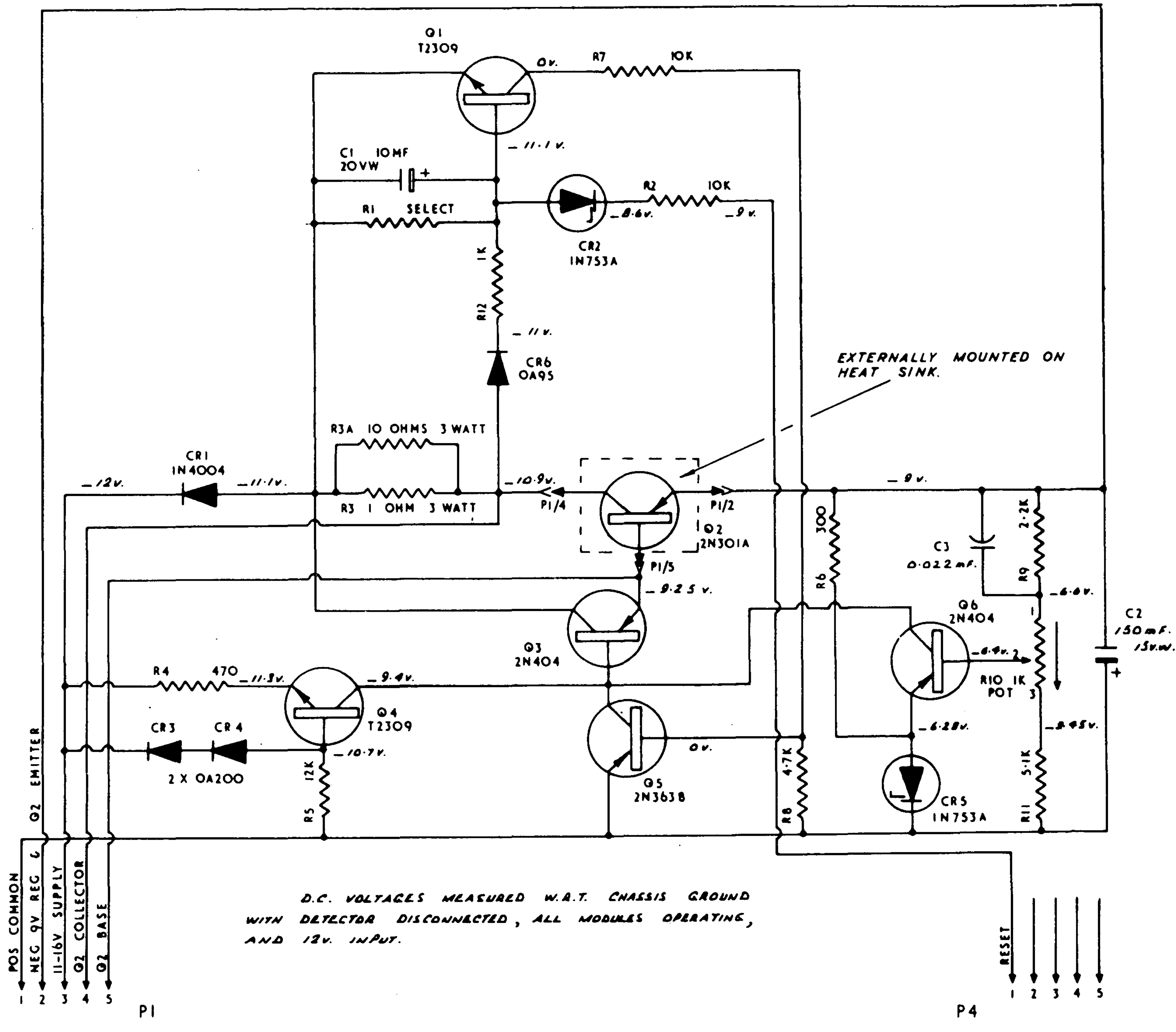
	DATE	NAME
Orig.	13 · 10 · 64	N D J
Amend.	7 · 10 · 65	N D J
	21-4-66.	R. Can.

PLATE 21



Leads to be slack

Fit shakeproof washers

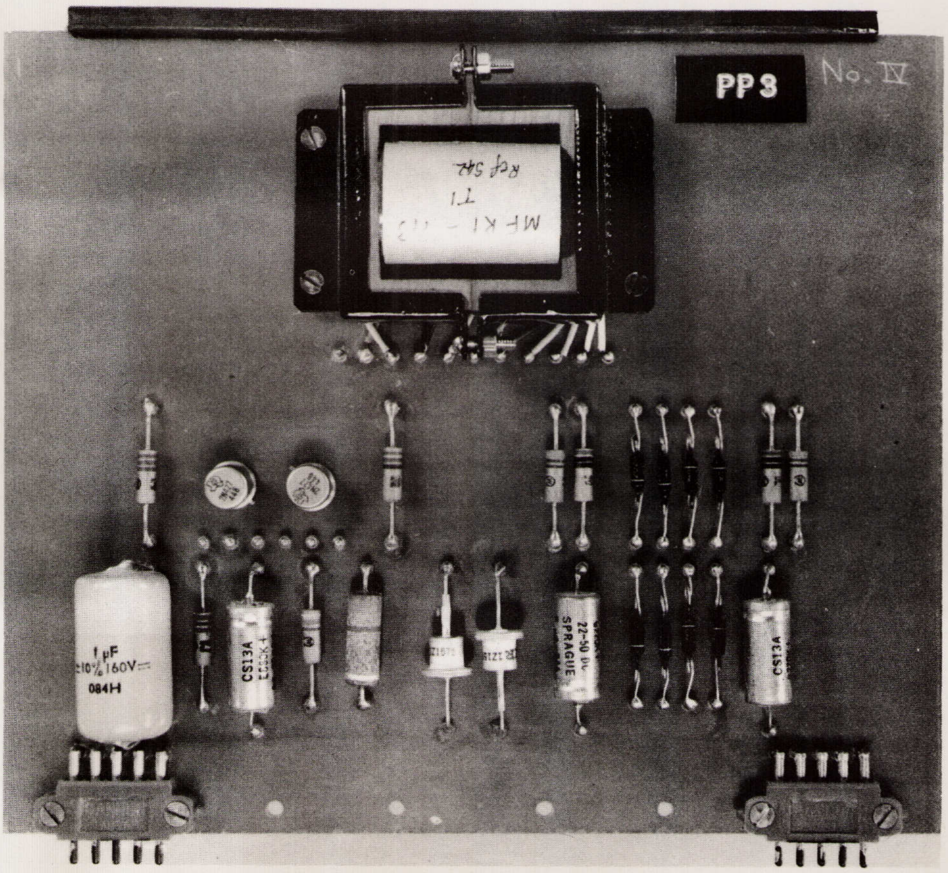


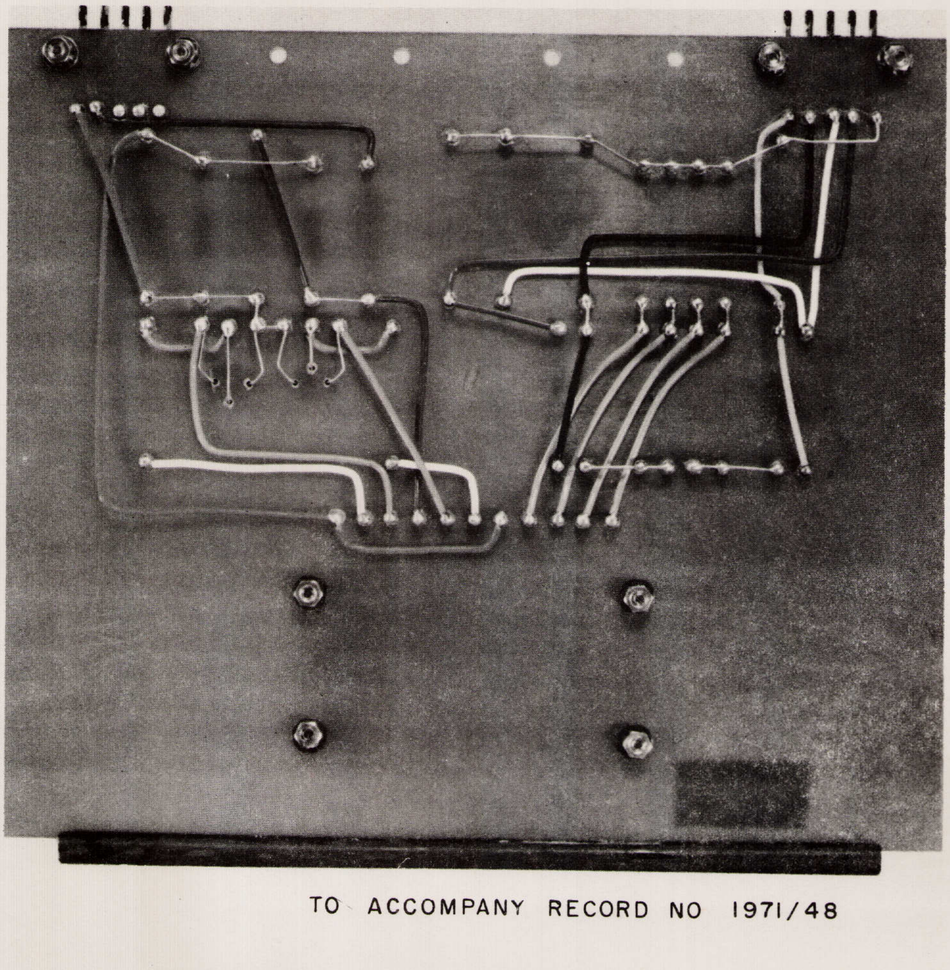
D.C. VOLTAGES MEASURED W.R.T. CHASSIS GROUND WITH DETECTOR DISCONNECTED, ALL MODULES OPERATING, AND 12v. INPUT.

TO ACCOMPANY RECORD 1971/48

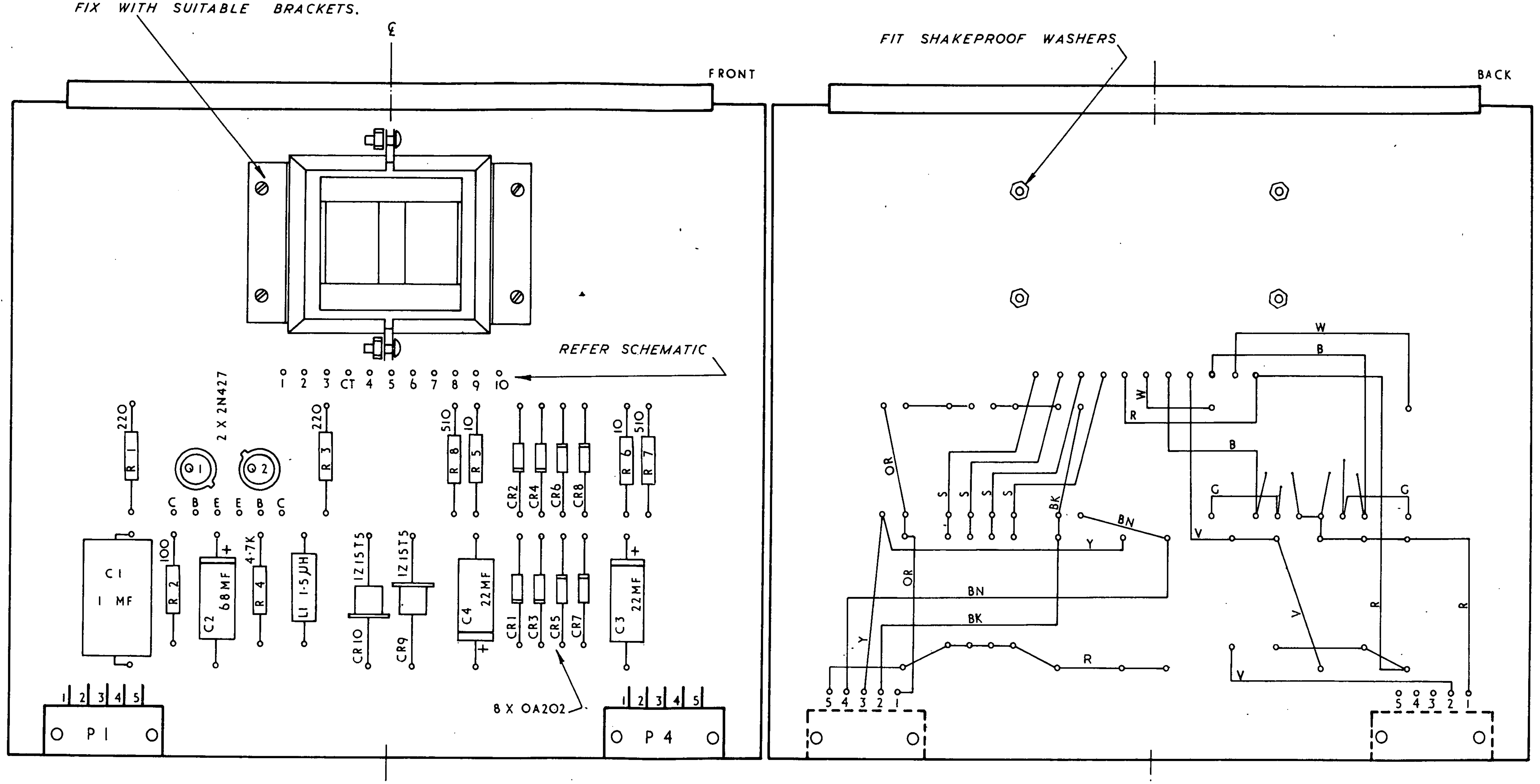
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS	Drawing No. MFR1 SH.5	INSTRUMENT MFR1 PP2 9 VOLT REGULATED POWER SUPPLY

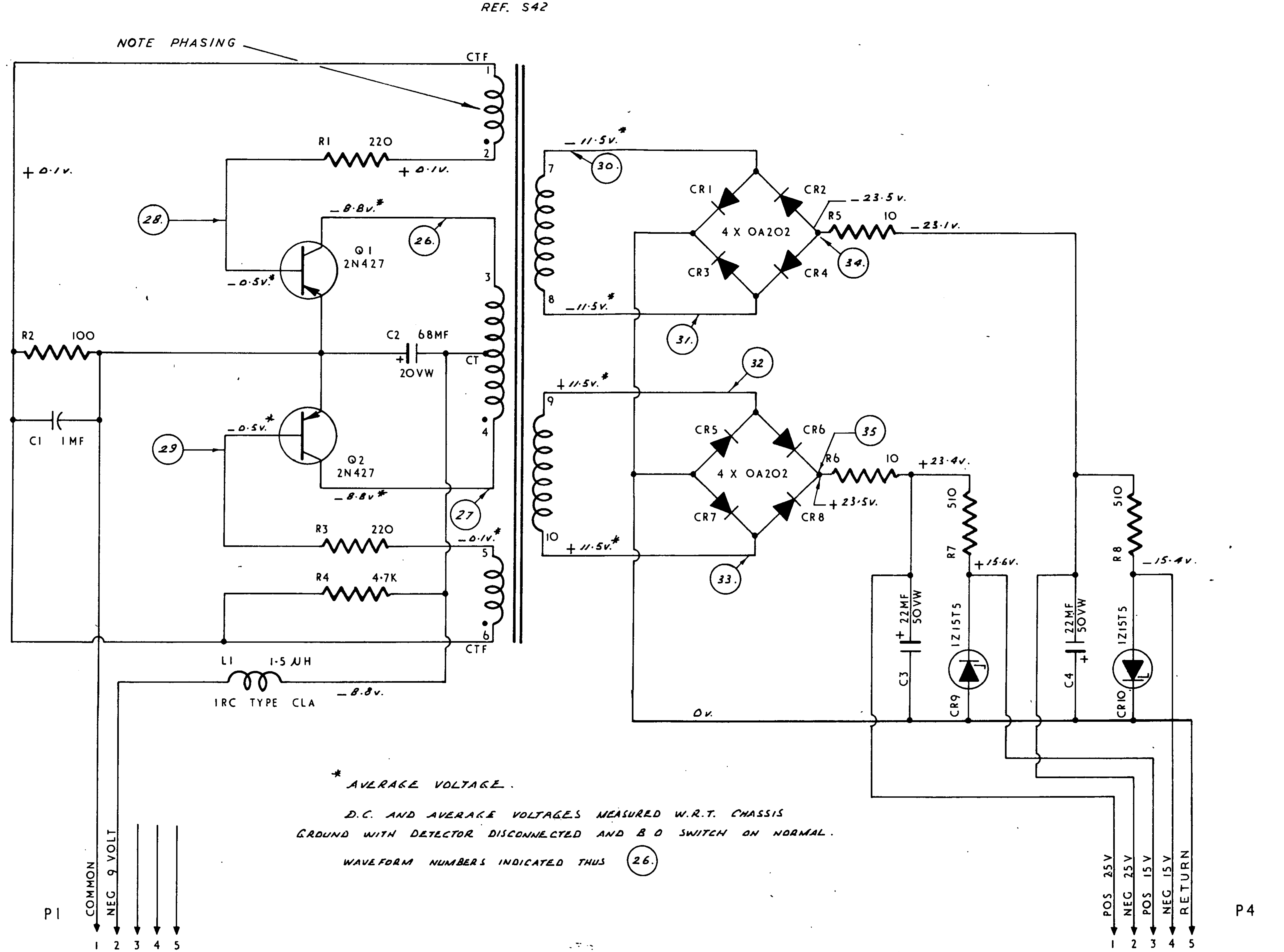
PLATE 22





TO ACCOMPANY RECORD NO 1971/48





* AVERAGE VOLTAGE.

D.C. AND AVERAGE VOLTAGES MEASURED W.R.T. CHASSIS GROUND WITH DETECTOR DISCONNECTED AND B O SWITCH ON NORMAL.

WAVEFORM NUMBERS INDICATED THUS (26.)

COMPONENT LIST.

CONNECTORS.

P1 P4	SOURIAU 8140-02 MALE 5 PIN VOCAB. BKZ 198

TRANSISTORS.

Q1 Q2	TRANSISTOR TYPE 2N427 VOCAB. BVT/2N427

DIODES.

CR1 to CR8	SILICON DIODE TYPE OA202 VOCAB. BVD/OA202
CR9 CR10	SILICON ZENER DIODE TYPE 1Z15T5 VOCAB. BVD/1Z15T5

CAPACITORS.

C1	PHILIPS POLYESTER TYPE C296 125VW 1 MFD VOCAB. BCO 1105
C2	TANTALUM ELECTROLYTIC SPRAGUE TYPE CS 1 3AE 680K 68 MFD 20VW VOCAB. BCK03680
C3 C4	TANTALUM ELECTROLYTIC SPRAGUE TYPE CS 1 3AG 220 K 22 MFD 50VW VOCAB. BCK05226

RESISTORS.

Following resistors to be WELWYN "METOX" 1/2 WATT TYPE F 20

R1 R3	220 OHMS
R2	100 OHMS
R4	4.7K OHMS
R5 R6	10 OHMS
R7 R8	510 OHMS

CHOKE.

L1	I.R.C. TYPE CLA	1.5 micro-Henry

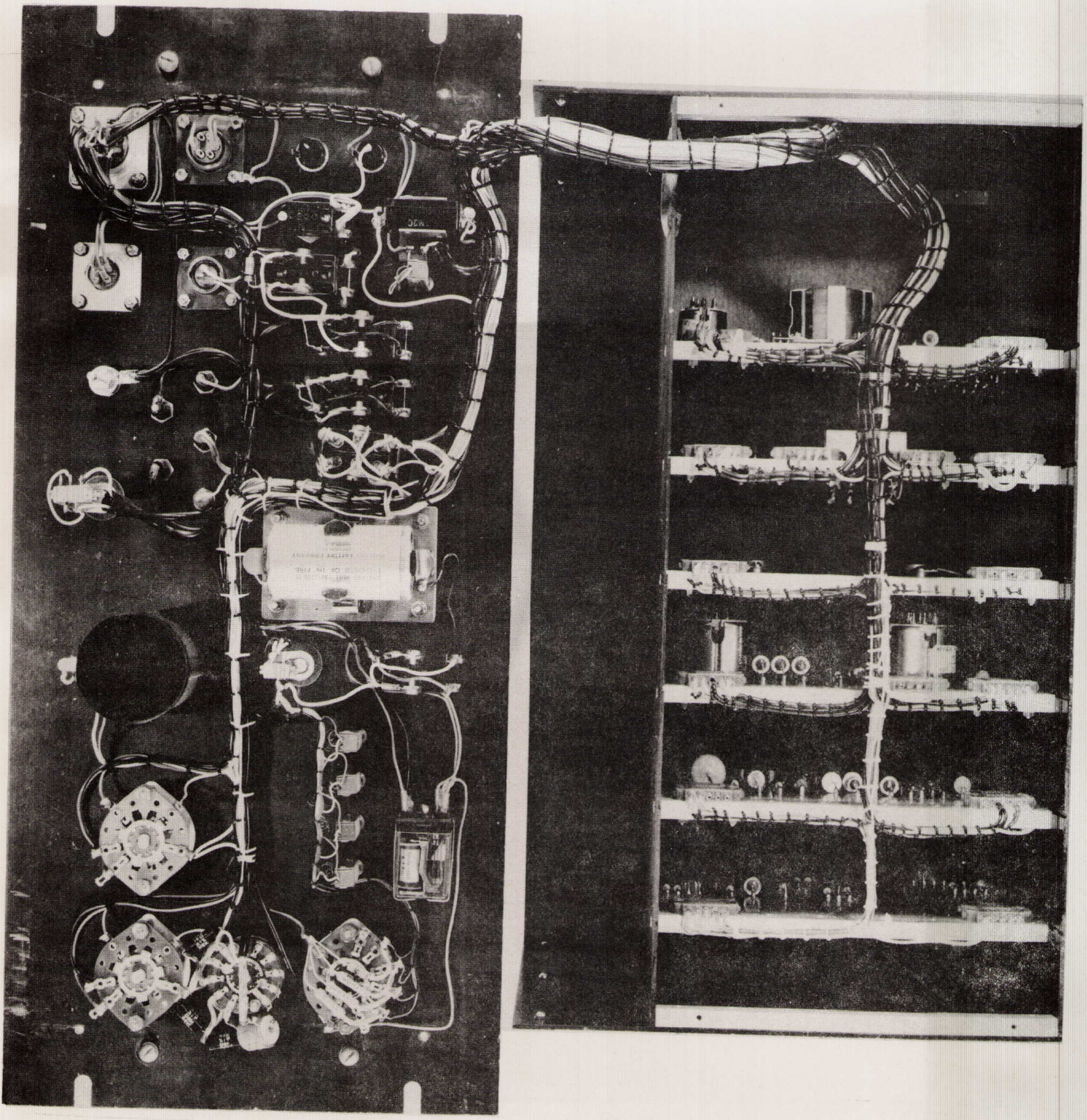
TRANSFORMER.

T1	PHILIP 2 x 'E' CORE 5690736/3A1 See specification sheet for details.

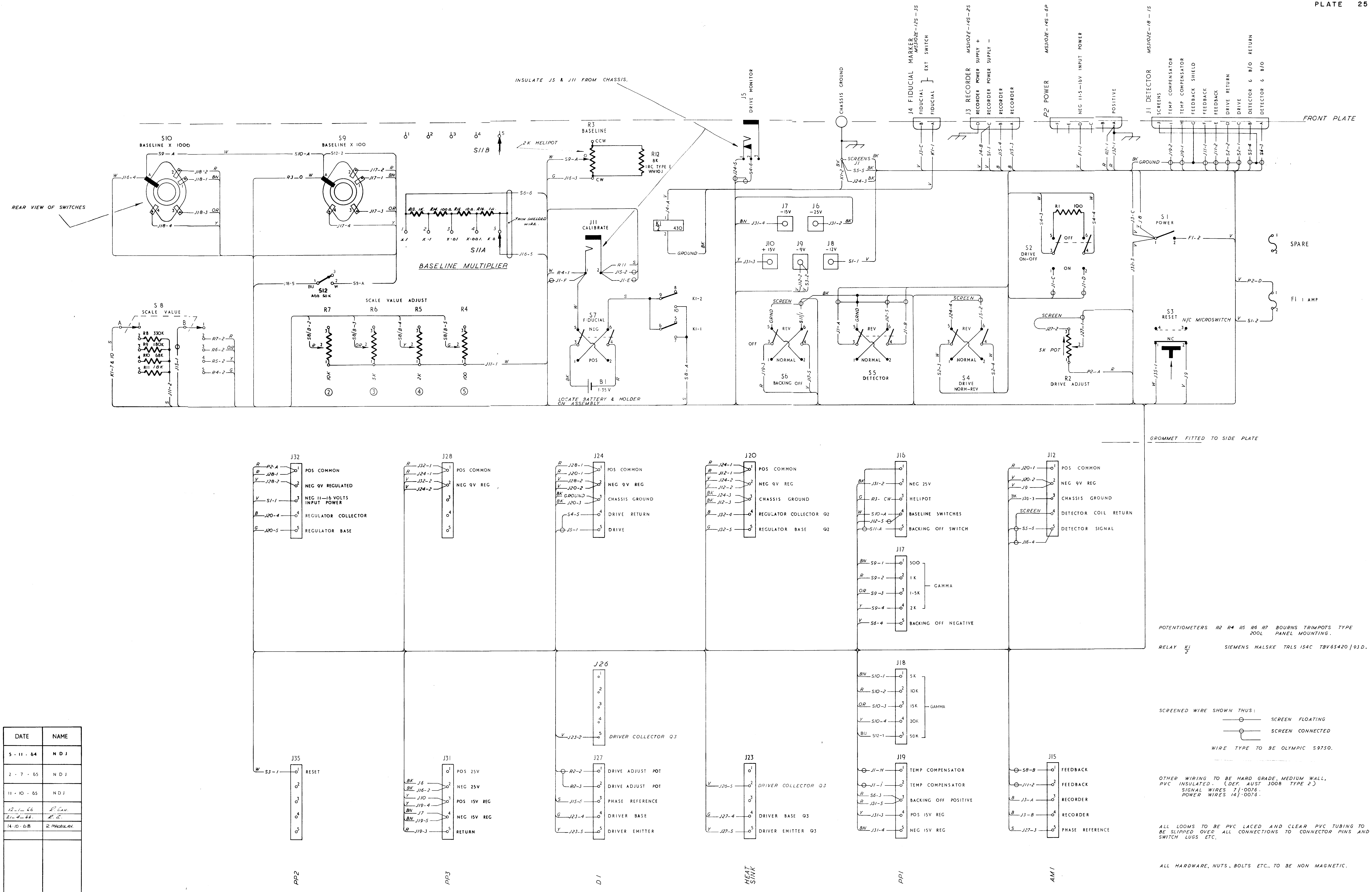
TO ACCOMPANY RECORD NO 1971/48

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS	Drawing No. MFR1 SH.6	INSTRUMENT MFR1 PP3 DC CONVERTER

PLATE 24



TO ACCOMPANY RECORD NO 1971/48



POTENTIOMETERS R2 R4 R5 R6 R7 BOURNS TRIMPOTS TYPE 200L PANEL MOUNTING.

RELAY $\frac{K1}{2}$ SIEMENS HALSKE TRLS 154C TBV65420/93D.

SCREENED WIRE SHOWN THUS:

SCREEN FLOATING

SCREEN CONNECTED

WIRE TYPE TO BE OLYMPIC S9750.

OTHER WIRING TO BE HARD GRADE, MEDIUM WALL, PVC INSULATED. (DEF. AUST 3008 TYPE 2)
SIGNAL WIRES 7/·0076.
POWER WIRES 14/·0076.

ALL LOOMS TO BE PVC LACED AND CLEAR PVC TUBING TO BE SLIPPED OVER ALL CONNECTIONS TO CONNECTOR PINS AND SWITCH LUGS ETC.

ALL HARDWARE, NUTS, BOLTS ETC., TO BE NON MAGNETIC.

	DATE	NAME
ORIG	5 · 11 · 64	N D J
AMEND	2 · 7 · 65	N D J
	11 · 10 · 65	N D J
	12-1-66	R. GAN.
	21-4-66.	R. G.
	14·10·68	R MACAULAY.

BINDING M.

NOTE. UNDER VIEW OF CHASSIS

TO ACCOMPANY RECORD NO. 1971/48

BUREAU OF MINERAL RESOURCES
GEOLOGY AND GEOPHYSICS
485 BOURKE STREET, MELBOURNE, VICTORIA
GEOPHYSICAL LABORATORIES, FOOTSCRAY

MATERIAL

SCALE

DATE 5·11·64

NAME NDJ

INSTRUMENT MFR1 C1

CHASSIS WIRING DIAGRAM

DRAWING No. MFR1 SH. 8

3 COMPONENT FLUXGATE. MFR1. COMPONENT LIST.

Note that the following lists requirements for one section only; for complete 3 component unit, 3 off of each item listed are required.

The following components are mounted on front panel.

Connectors.

J1. DETECTOR. Cannon box mounting receptacle type MS3102E-18-1S. 10 pins, socket insert. Vocab. BKA15
J2. POWER. Cannon box mounting receptacle type MS3102E-14S-6P. 6 pins, pin insert. Vocab. BKA10
J3. RECORDER. Cannon box mounting receptacle type MS3102E-14S-2S. 4 pins, socket insert. Vocab. BKA5
J4. FIDUCIAL. Cannon box mounting receptacle type MS3102E-12S-3S. 2 pins, socket insert. Vocab. BKA1.
J5. DRIVE MONITOR. Bulgin jack type J12. (insulate from chassis)
J11. CALIBRATE. Bulgin jack type J11. (insulate from chassis)
J6 J7 J8 J9 J10. MONITOR VOLTAGES. Belling & Lee socket type L1317. Colour 4 black, 1 red. Vocab.BHS94B/ BHS94R

GROUND TERMINAL. Gallard screw down type 2C. Colour black. Vocab. BHT6B

Relay. K1/2 Siemens Halske type Trls 154c Tbv65420/93d. Vocab. BSY1/2 complete with socket type Tstv 24c Vocab. BSY1/05 and retaining bail type Tstv 24T8 Vocab. BSY1/03.

Battery. B1. Mallory type No.RM-42R. 1.35 volts. Vocab. BBM142

Fuses and fuse holders.

F1 & SPARE. Fuse, glass tube, aircraft type Belling & Lee. Miniature 5/8" long x 3/16" dia. 1 amp. 2 off required. Vocab. BFM102.
HOLDERS. Panel mounting, front loading, Belling & Lee type L575. 2 off required. Vocab. BFX2.

Switches.

S1. POWER ON-OFF. Cutler Hammer toggle switch type 8295 K7. SP.ST Vocab. BST11.
S2. DRIVE ON-OFF. Cutler Hammer toggle switch type 8375 K8. DP.DT Vocab. BST13.
S3. RESET. Den Dee micro-switch type FM2C. Solder lug terminals. Available ex Den Dee Instrument Co. Huntingdale, Victoria.
S4. DRIVE NORM-REV. Cutler Hammer toggle switch type 8375 K8. DP.DT Vocab. BST13.
S5. DETECTOR NORM-REV. Cutler Hammer toggle switch type 8375 K8. DP.DT Vocab. BST13.
S6. B/O NORM-OFF-REV. Cutler Hammer toggle switch type 8375 K8. DP.DT Vocab. BST13.
S7. FIDUCIAL. Cutler Hammer toggle switch type 8375 K8. DP.DT Vocab. BST13.
S8. SCALE VALUE. Oak wafer switch 1 section 2 pole 6 position. Vocab. BSW1.
S9 S10. BASELINE X100. X1000. Oak rotary switch special type 1 section double sided. Manufactured by MSP to BMR specifications.
S11. BASELINE MULTIPLIER USINE JEAN RENAUD TYPE SM 1 SECTION, 2 POLE, 5 POSITION.
S12. SWITCH TOGGLE ALCO SPDT. MST 115D. BST 22

(continues on PLATE 27)

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Drawing No. MFR1 SH.8A

INSTRUMENT MFR1 C1

CHASSIS COMPONENT LIST

TO ACCOMPANY RECORD NO 1971/48

(continued from PLATE 26)

Potentiometers.

R3 BASELINE. 10 turn model A Helipot. Resistance 2K ohms. Available ex George Sample Electronics, Melb.
complete with Beckman Duo-dial model RB. Vocab. BHK37.

R2 DRIVE ADJ. Bourns Trimpot type 200L-1-502M. Panel mounting. 5K ohms.

R4 R5 R6 R7. SCALE VALUE ADJ. Bourns Trimpots type 200L-1. Panel mounting.
(2) 200L-1-103M 10K ohms. (3) 200L-1-502M 5K ohms.
(4) 200L-1-202M 2K ohms. (5) 200L-1-101M 100 ohms.

Resistors. Following resistors to be Welwyn "METOX" ½ watt type F20.

R1 100 ohms. (mounts on "OFF" position of S2)
R8 330K ohms
R9 180K ohms
R10 68K ohms
R11 18K ohms
(mount on switch S8/A)

R12 PRECISSION WIRE WOUND RESISTOR IRC TYPE "E" WW10J 8K OHMS
R13 ALMA WIRE WOUND TYPE JABZ 1K.
R14 " " " " " 100 Ω.
R15 " " " " " 10 Ω.
R16 I.R.C. " " " WW10J 1 Ω.
MOUNTED ON SWITCH S11.

Following connectors required for module card mounting.
Souriau 8140-01 Female 5 pin. 15 off required. Vocab. BKZ197

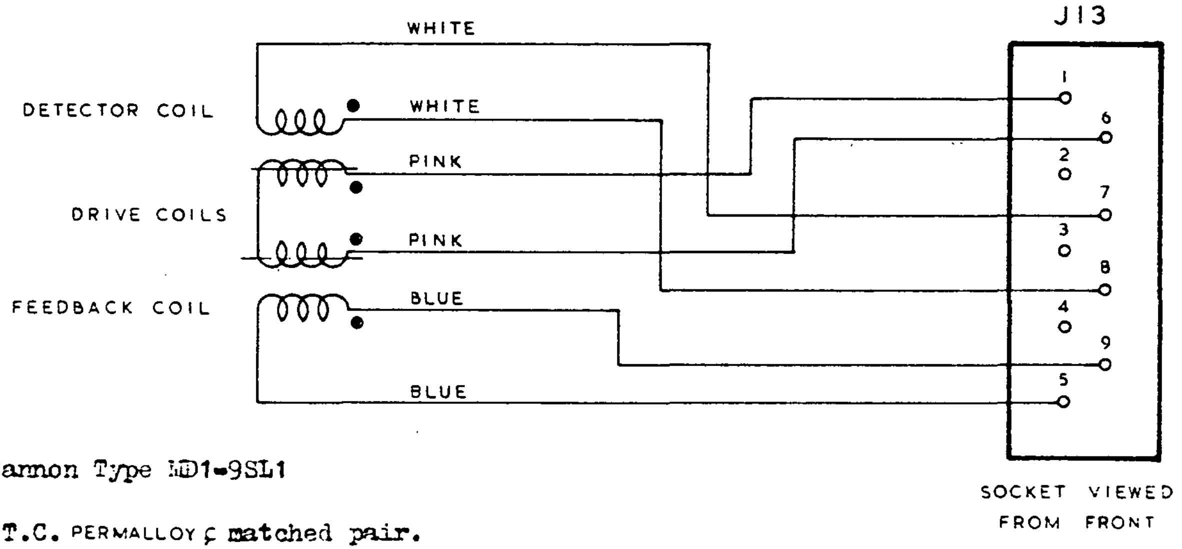
Following dust caps with chain required for Cannon box mounting receptacles.
MS25043-18C 1 off. Vocab. BKA261
MS25043-14C 2 off. Vocab. BKA115
MS25043-12C 1 off. Vocab. BKA259

Knobs. For rotary switches. Use type Usine Metallurgique Doloise DM29BAB. Black with arrow.
Shaft size 6.35 mm. 3 off required. Vocab. BHK311.

If above type not available, use suitable alternative.

CONSTRUCTION.

1. **Drive coils each consisting of approximately 400 turns** 30 B&S **double solderite close wound in single layer on glass former** 4 7/8" long, are potted in special potting resin (**low thermal expansion from British United Industries**)in silicone rubber mould with semi-circular section. Flat surfaces of potted coils are then glued together with potting resin. Coils are joined at one end and the other ends are terminated with pink habitual wire.
2. Detector coil, 2 layer 32 B&S double solderite close wound (approx. 920 turns.),wound on drive coils and painted with potting resin. Attach a layer of 2 mil paper while resin is sticky. Terminate with white habitual wire.
3. Feedback coil, 1 layer 25 B&S double solderite close wound (approx. 220 turns.). Paint with potting resin. Terminate with blue habitual wire.
4. Assembly fastened with Araldite in 5 1/4"by 3/4" O.D. paper bakelite tube.
5. Cores are then inserted inside formers and Zircon powder added to prevent cores moving. After testing, Araldite ends of detector to retain cores.

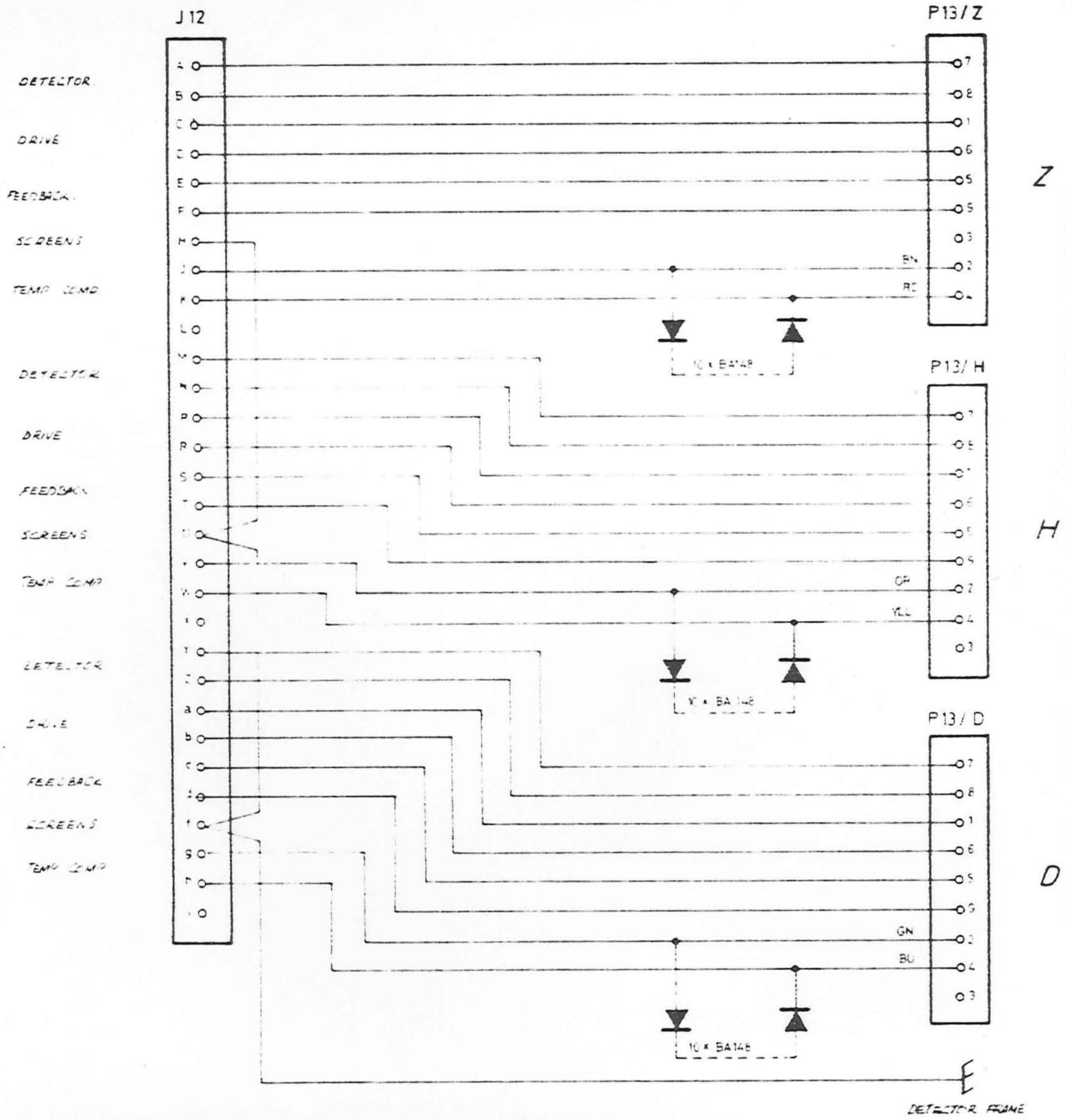


J13........ Cannon Type MD1-9SL1

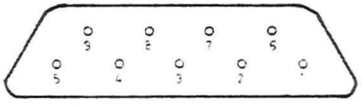
Cores.......S.T.C. PERMALLOY ç matched pair.
B.M.R. S/C B16685.

Coil Resistances.....Drive...3.2 ohms.
Detector...15.5 ohms.
Feedback...0.90 ohm.

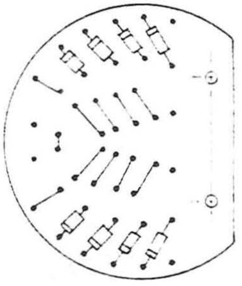
DRAWING No.	SHEET	INSTRUMENT
MFR I	29	DT.I. DETECTOR CONSTRUCTION DETAIL.



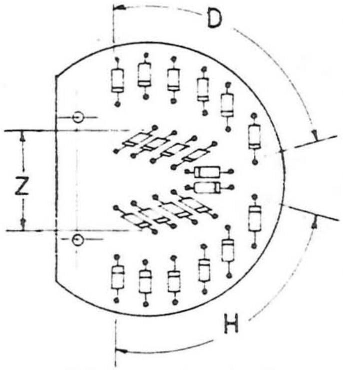
WIRING —— HABITUAL
P12 —— CANNON TYPE KO2-21-30 PN
P13 —— " " MD1-9 PL1.



PIN LAYOUT ON P13 VIEWED FROM FRONT



REAR VIEW OF DIODE MOUNTING CARD



TOP VIEW OF DIODE MOUNTING CARD.

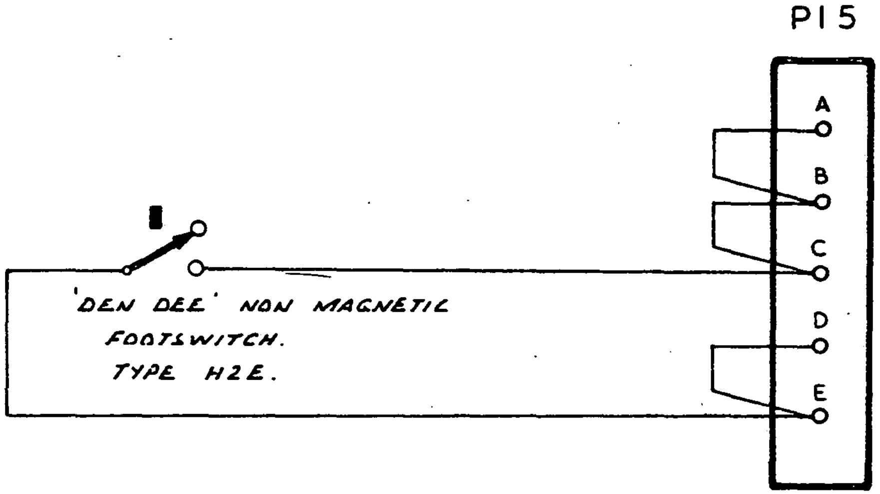
DRAWING No.	SHEET	INSTRUMENT MFR 1
MFR 1	21	DETECTOR ASSY. WIRING

TO ACCOMPANY RECORD No 1971/48

PLATE 29

PLATE 30

TO ACCOMPANY RECORD NO 1971/48



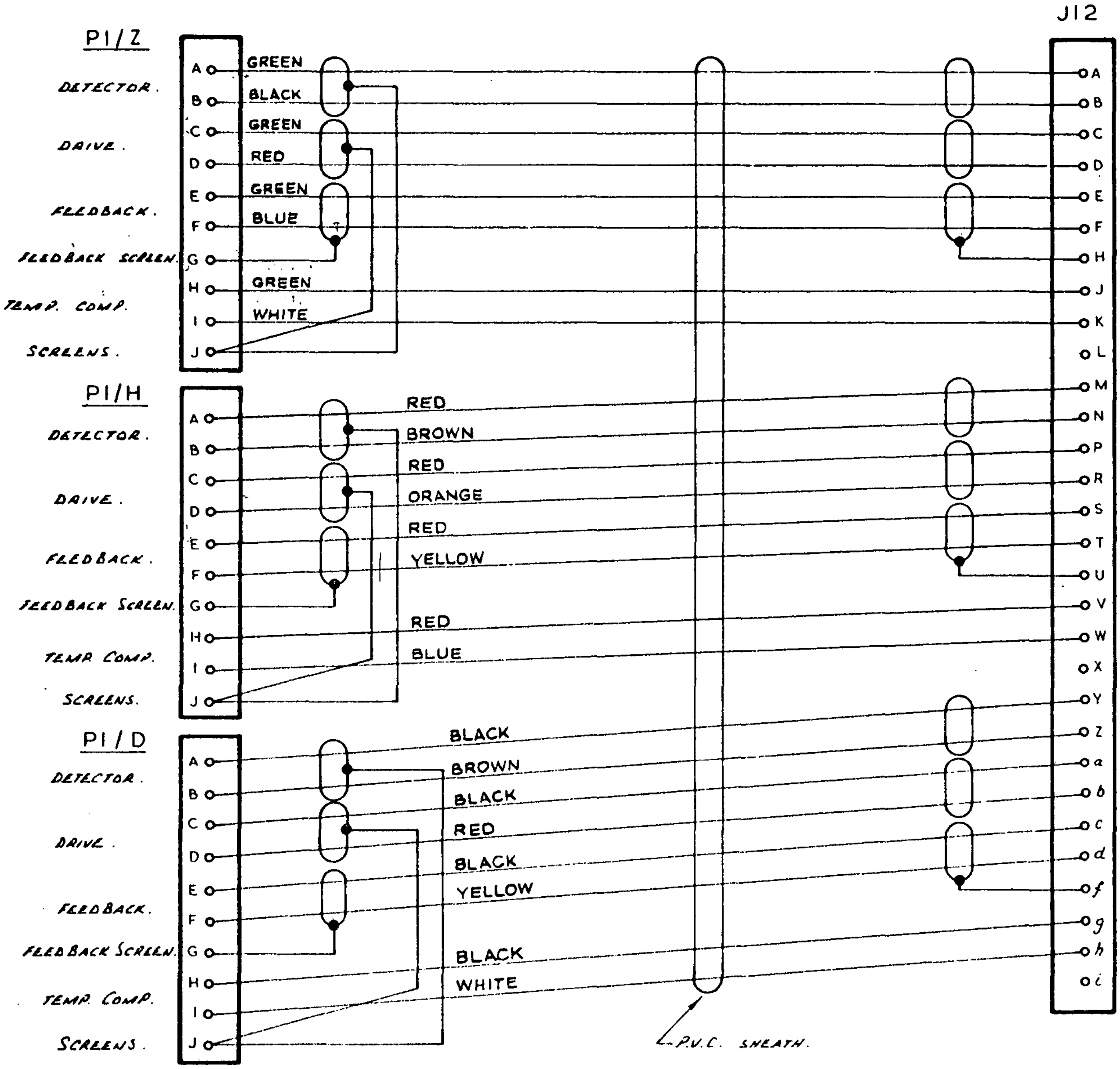
P15 —— CANNON TYPE MS3102E_14S_5P.
C/W DUST CAP AND CHAIN TYPE MS25043_14C.

BUREAU OF MINERAL RESOURCES,
GEOLOGY AND GEOPHYSICS

Drawing No.
MFR1. SH. 22.

INSTRUMENT MFR1
NON-MAGNETIC FOOTSWITCH.

PLATE 31



P1 — Cannon Type MS3106E_18_1P
c/w Dust Cap and Chain
Type MS25042_18C.

J12 — Cannon Type KO8_21_30SN.

DRAWING No.
MFR I

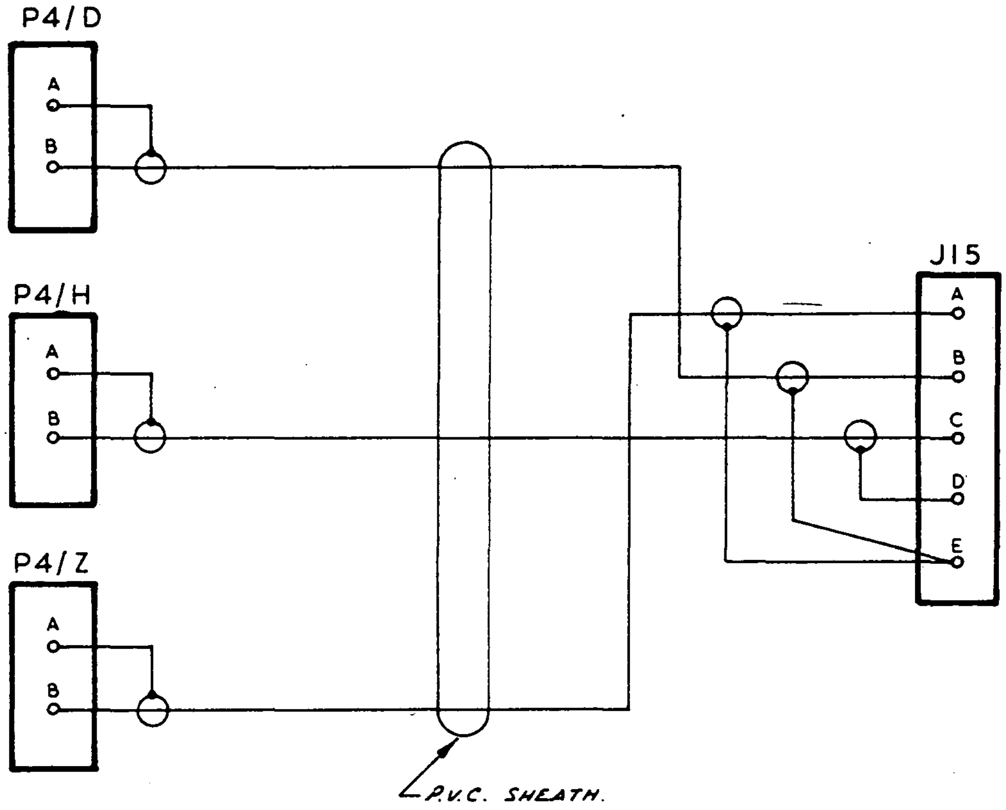
SHEET
20

INSTRUMENT
MFR I
DETECTOR CABLE

TO ACCOMPANY RECORD NO 1971/48

P4 ___ CANNON TYPE MS3106E – 12S – 3P.
C/W DUST CAP & CHAIN MS25042 – 12C.

J15 ___ CANNON TYPE MS3106E – 14S – 5S.
C W DUST CAP & CHAIN MS25042 – 14C.



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Drawing No. MFRI 23

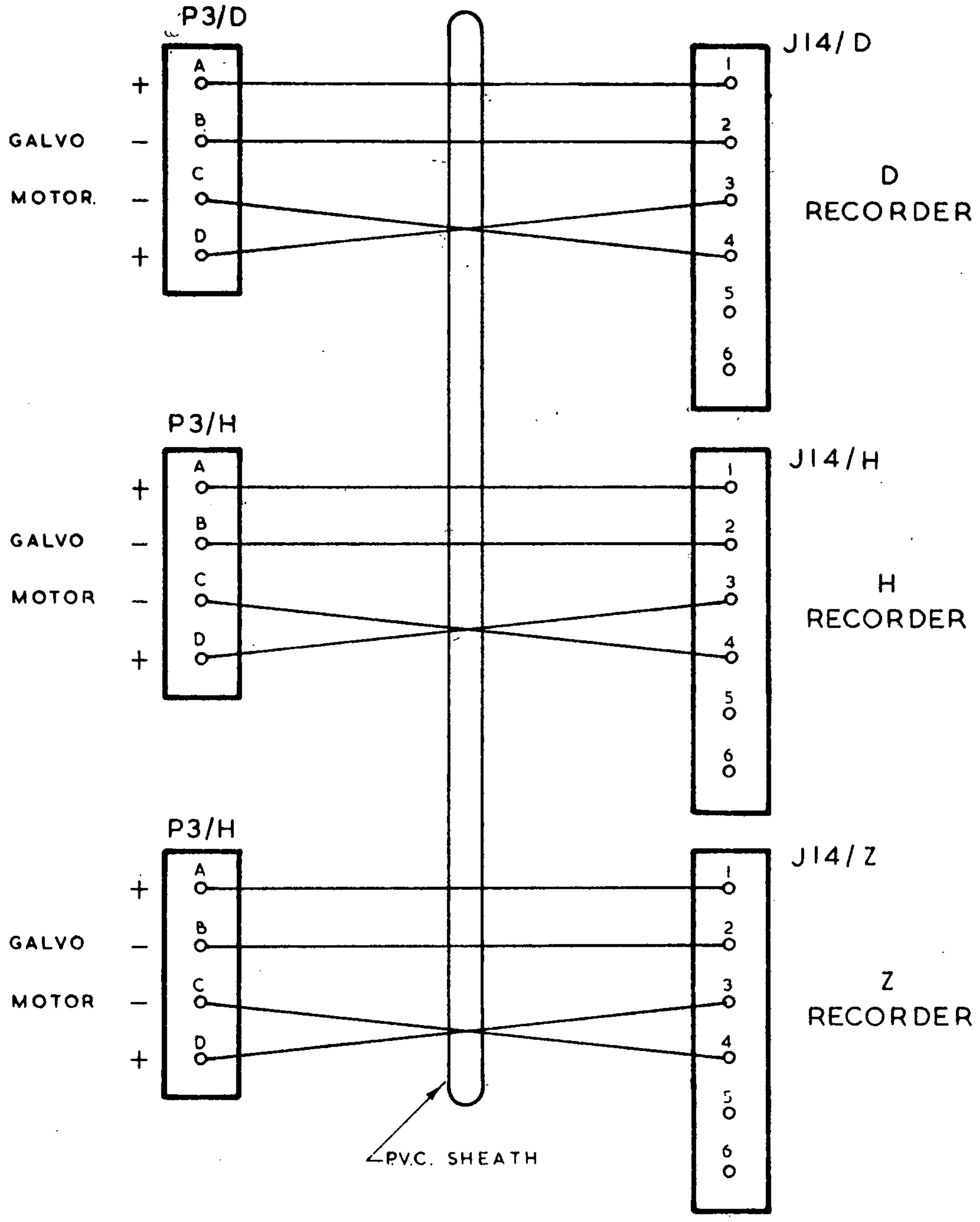
INSTRUMENT MFRI

FOOTSWITCH CABLE

TO ACCOMPANY RECORD NO 1971/48

PLATE 32

PLATE 33



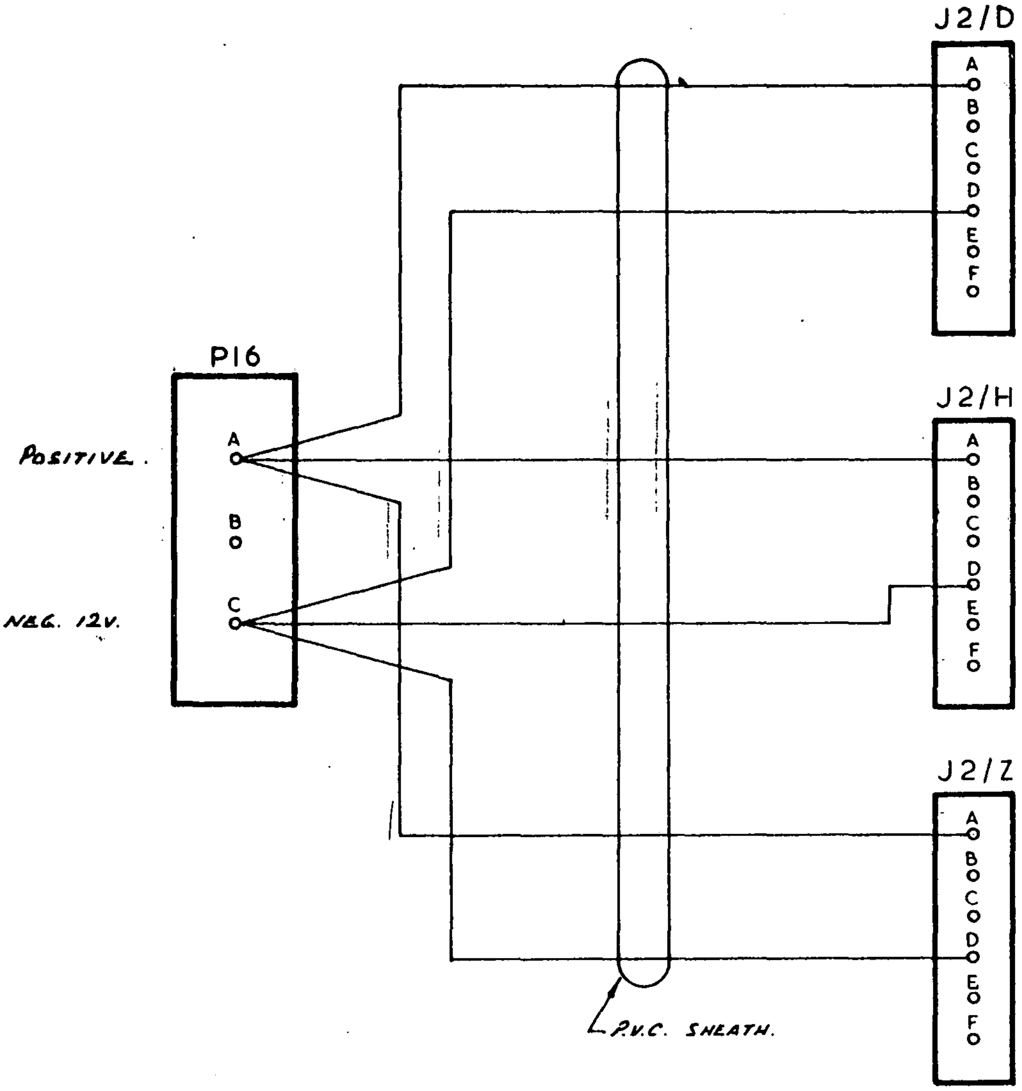
P3 — CANNON TYPE MS 3106E — 14S — 2P.
C/W DUST CAP AND CHAIN TYPE MS25042 — 14C.

J14 — JONES TYPE S — 3306 — CCT.

TO ACCOMPANY RECORD NO 1971/48

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS	Drawing No. MFR1 19	INSTRUMENT MFR 1 RECORDER CABLE

PLATE 34



J2 — CANNON TYPE MS3106E – 14S – 6S.
C/W DUST CAP AND CHAIN TYPE MS 25042 – 14C.

P13 — CANNON TYPE MS 3106E – 14S – 7P.
C/W DUST CAP AND CHAIN TYPE MS25042 – 14C.

TO ACCOMPANY RECORD NO 1971 / 48

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Drawing No. MFR1 24

INSTRUMENT MFR1
POWER CABLE

3 COMPONENT FLUXGATE MAGNETOMETER. MFR1.

CHOKE AND TRANSFORMER DETAILS.

MODULE AM1. AMPLIFIER.

Chokes. L1. VINKOR TYPE LA2406. CASE DT2184. BOBBIN DT2204.
300 turns No.31 B & S double solderite wire. Inductance 18mH . D.C res. 6 ohms.
Reference S69.

L2,L3. Vinkor Type LA2732. Case DT2181. Bobbin DT2202
748 turns No. 40B&S. Inductance 268mH. D.C. res. 420ohms
Reference S60.

L4. Vinkor Type LA 2732. Case DT2181. Bobbin DT2202.
49 1/2 turns No.27 B&S. Inductance 1.075mH D.C. res. 1.8ohms

Transformer. T1. VINKOR TYPE LA2130. MOUNTING PARTS SQUARE PRINTED CIRCUIT BASE DT2233.
MOUNTING CLIP DT2234. SPARE PINS IF NECESSARY DT2207.
Primary. 578 turns No.36 B & S double solderite wire equally spaced on each section.
Secondary. 578 turns No.36 B & S double solderite wire per half secondary.
Provide 4 turns of .005" paper insulation between primary and secondary.
Provide electrostatic shield between primary and secondary of .0015" copper. This shield to be sandwiched between paper insulation. Reference S10.

(continues on PLATE 36)

(Continued from PLATE 35)

MODULE D1. DRIVER.

Chokes. L1.

VINKOR TYPE LA2206. CASE DT2186. BOBBIN DT2205.
Primary. 155 turns No.31 B & S double solderite wire.
Secondary. 310 turns No.31 B & S double solderite wire.
Provide .002" paper insulation between primary and secondary.
Inductance 6·15mH, Reference S2.

L2.

VINKOR TYPE LA2506. CASE DT2183. BOBBIN DT2178.
442 turns No.35 B & S double solderite wire. Inductance 28mH. D.C res. equal to or less than 40 ohms. Reference S4.

Transformer. T1.

VINKOR TYPE LA2201. CASE DT2186. BOBBIN DT2205.
Primary. 203 turns No.32 B & S double solderite wire.

Secondary. 272 turns No.29 B & S double solderite wire.
Provide electrostatic shield between primary and secondary of .0015" copper.
Provide .002" insulation between primary and shield, and shield and secondary.
Reference S3.

MODULE PP3. DC CONVERTER.

Transformer. T1.

PHILIPS 2 x "E" core 5690736/3A1. FORMER. Use 2 turns of pressphan .005" wound on mandrill of same section as centre limb of core. Allow approx. 1/32" above both dimensions for coil to fit on core.
Primary. 58 + 58 turns No.25 B & S double solderite wire.
Feedback. 12 + 12 turns No.30 B & S double solderite wire.
Secondary No.1. 185 turns No. 34 B & S double solderite wire.
Secondary No.2. 185 turns No.34 B & S double solderite wire.

Primary and Feedback windings are both wound bifilar and are wound side by side on the first layer; ie, 4 wires wound at one time.

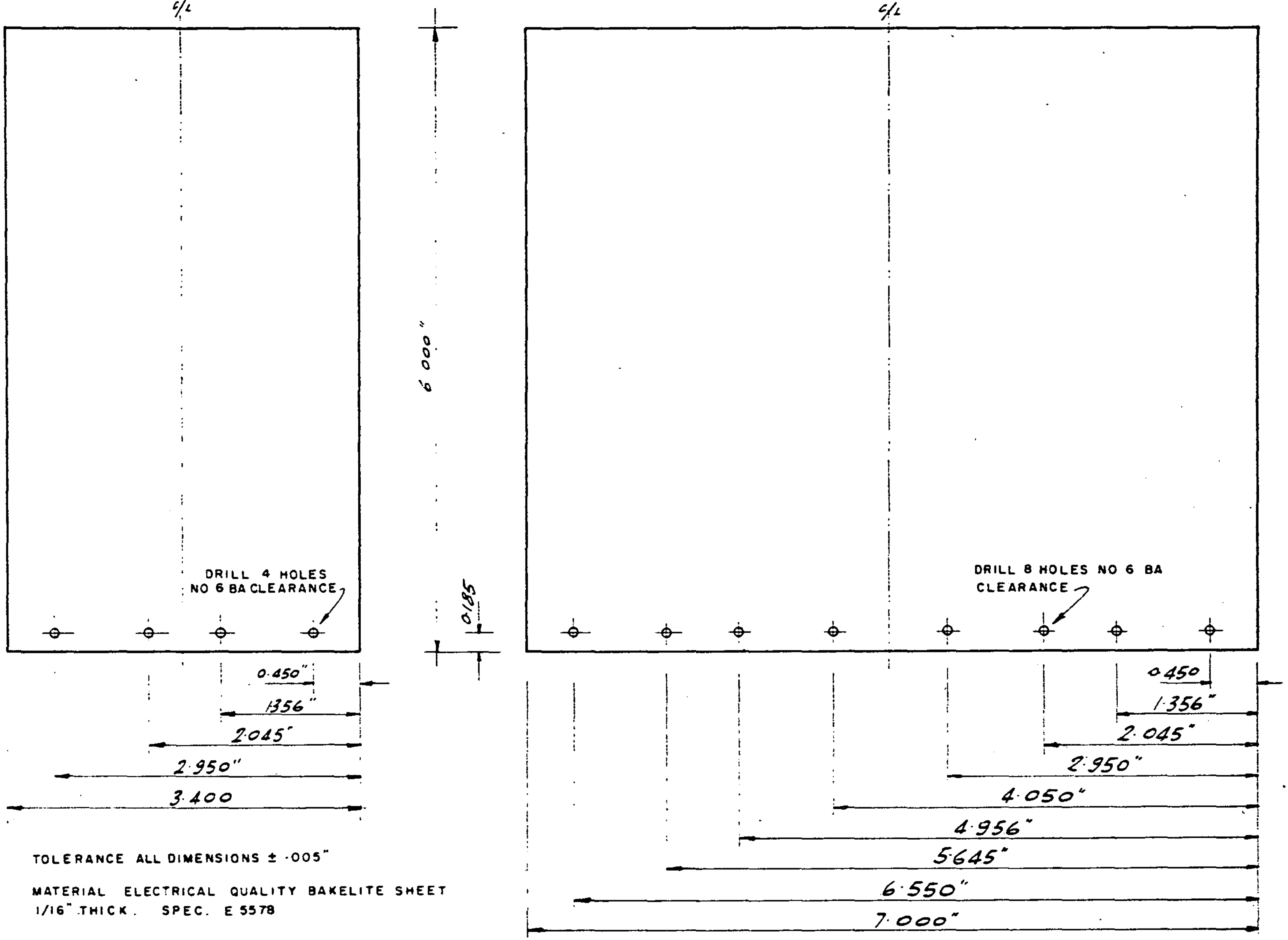
Frequency 1 Kc/s. Power level 5 watts maximum.

Reference S42.

Note. All chokes and transformers to be impregnated with silicone varnish type DP2613.
(MS994 plus catalyst LS15)

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS
Drawing No. MFR1 SH14
INSTRUMENT MFR 1
CHOKE & TRANSFORMER SPECIFICATIONS
TO ACCOMPANY RECORD NO 1971/48

PLATE 37

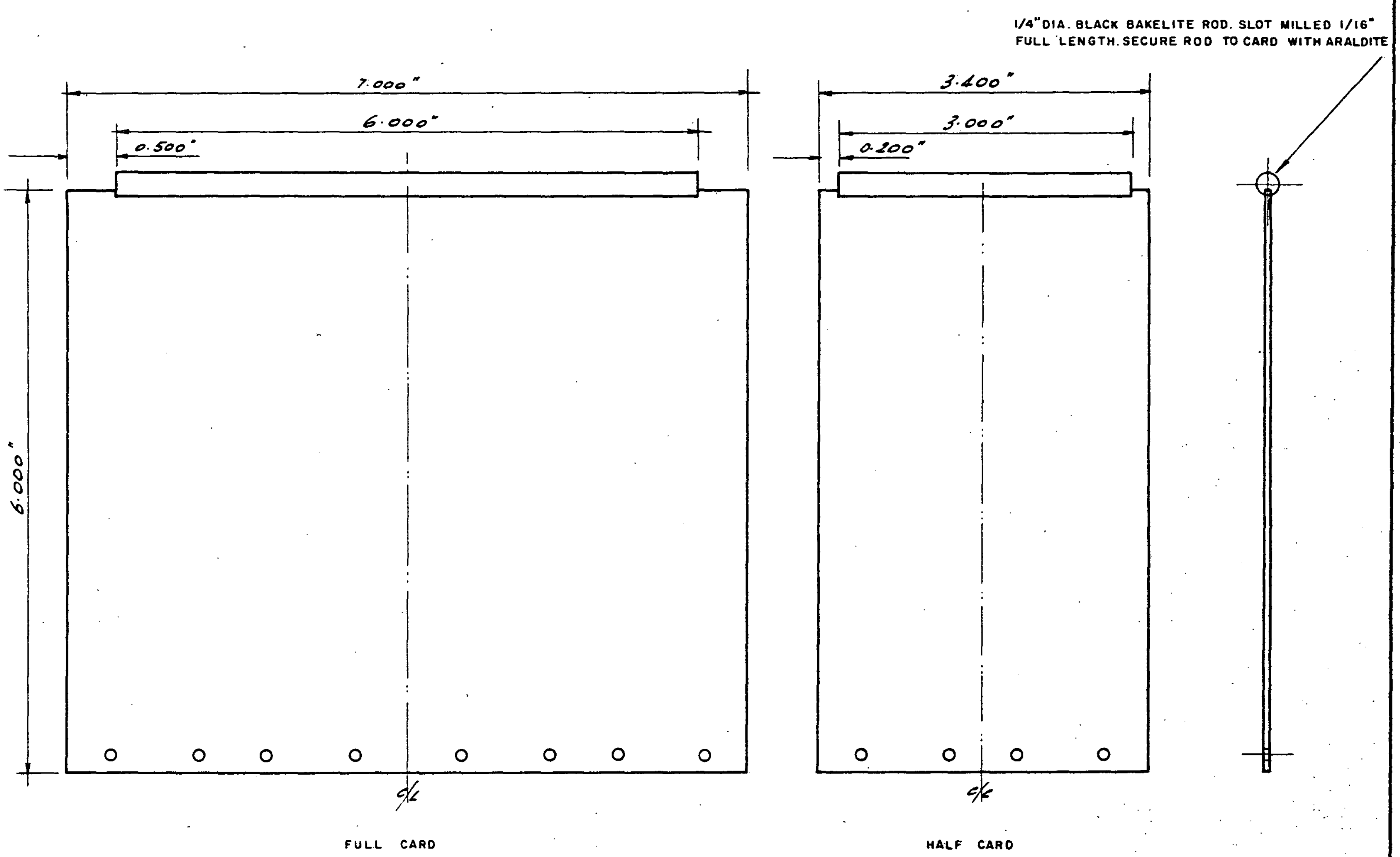


TOLERANCE ALL DIMENSIONS ± ·005"

MATERIAL ELECTRICAL QUALITY BAKELITE SHEET
1/16" THICK. SPEC. E 5578

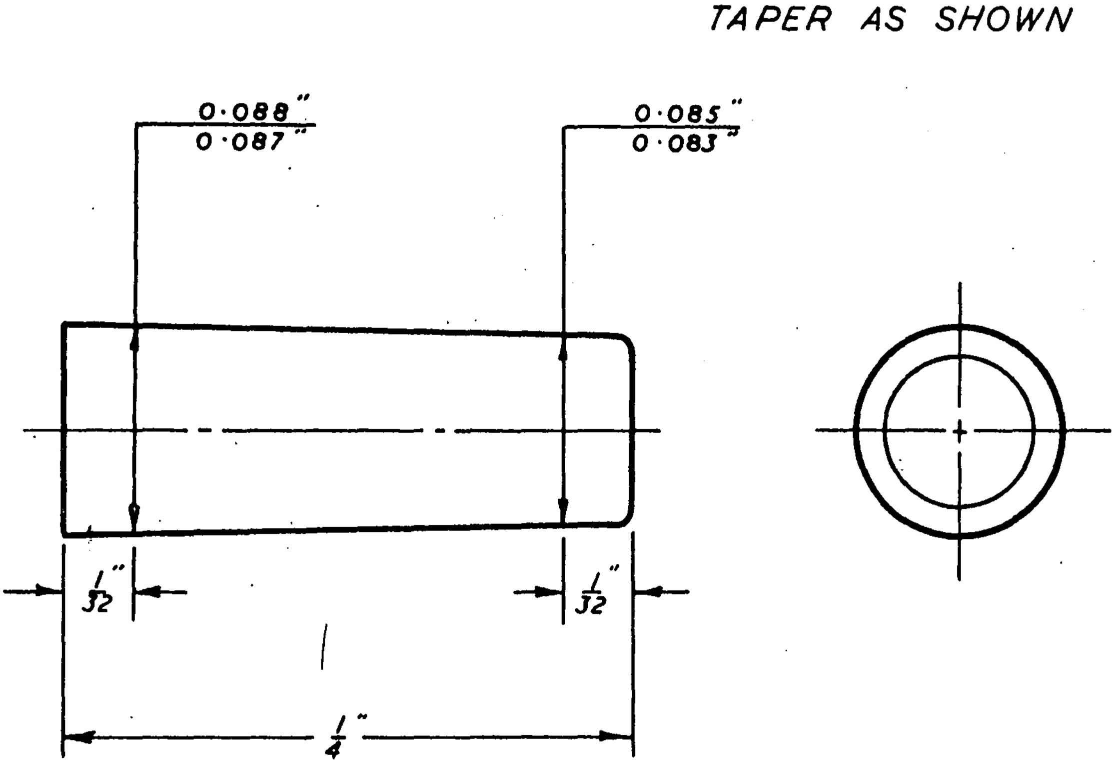
INSTRUMENT: BAKELITE CARDS FOR COMPONENT MOUNTING

TO ACCOMPANY RECORD NO 1971/48



INSTRUMENT : BAKELITE CARDS HANDLE LOCATIONS

PLATE 39



MATERIAL. BRASS TUBING. WALL THICKNESS 0·005"

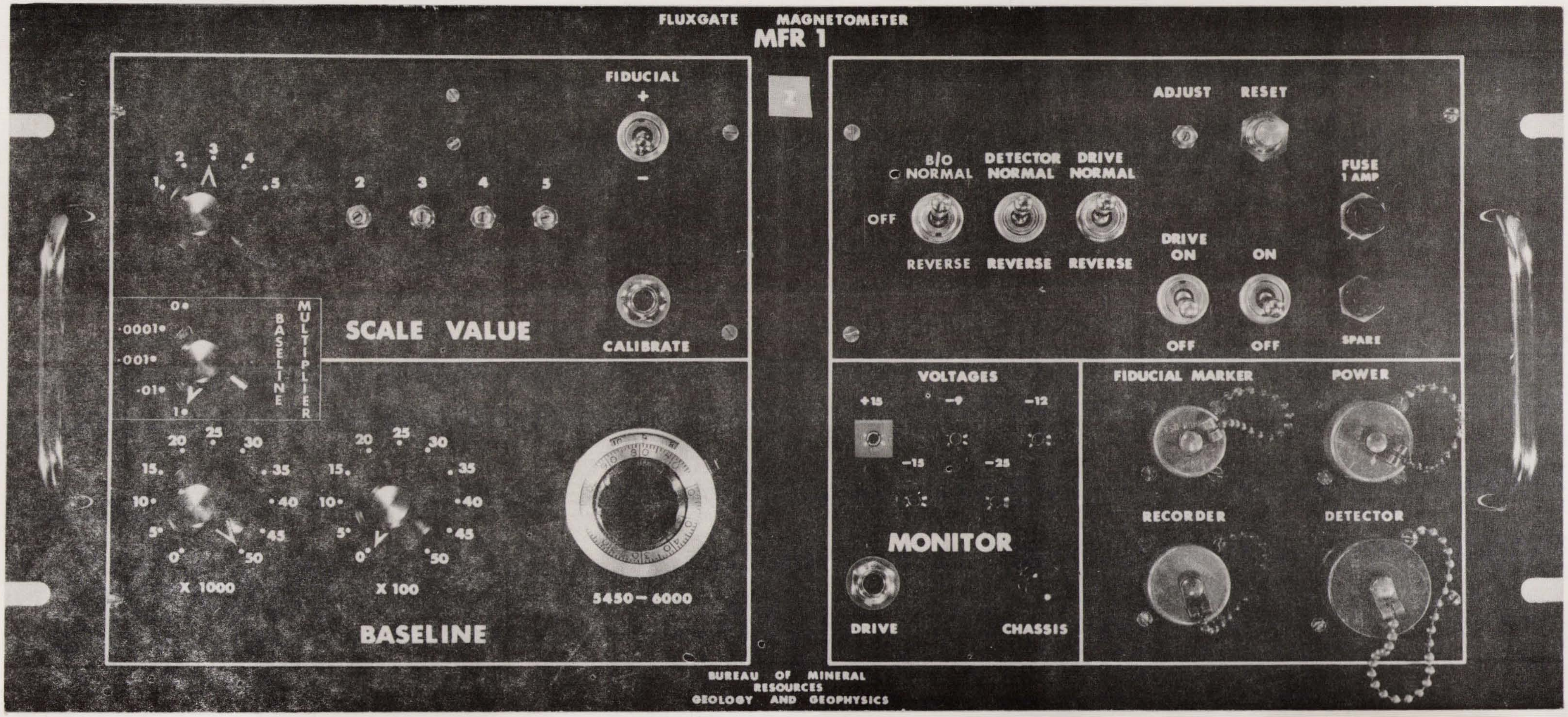
FINISH. BRIGHT ANNEALED.

scale. 12:1 approx.

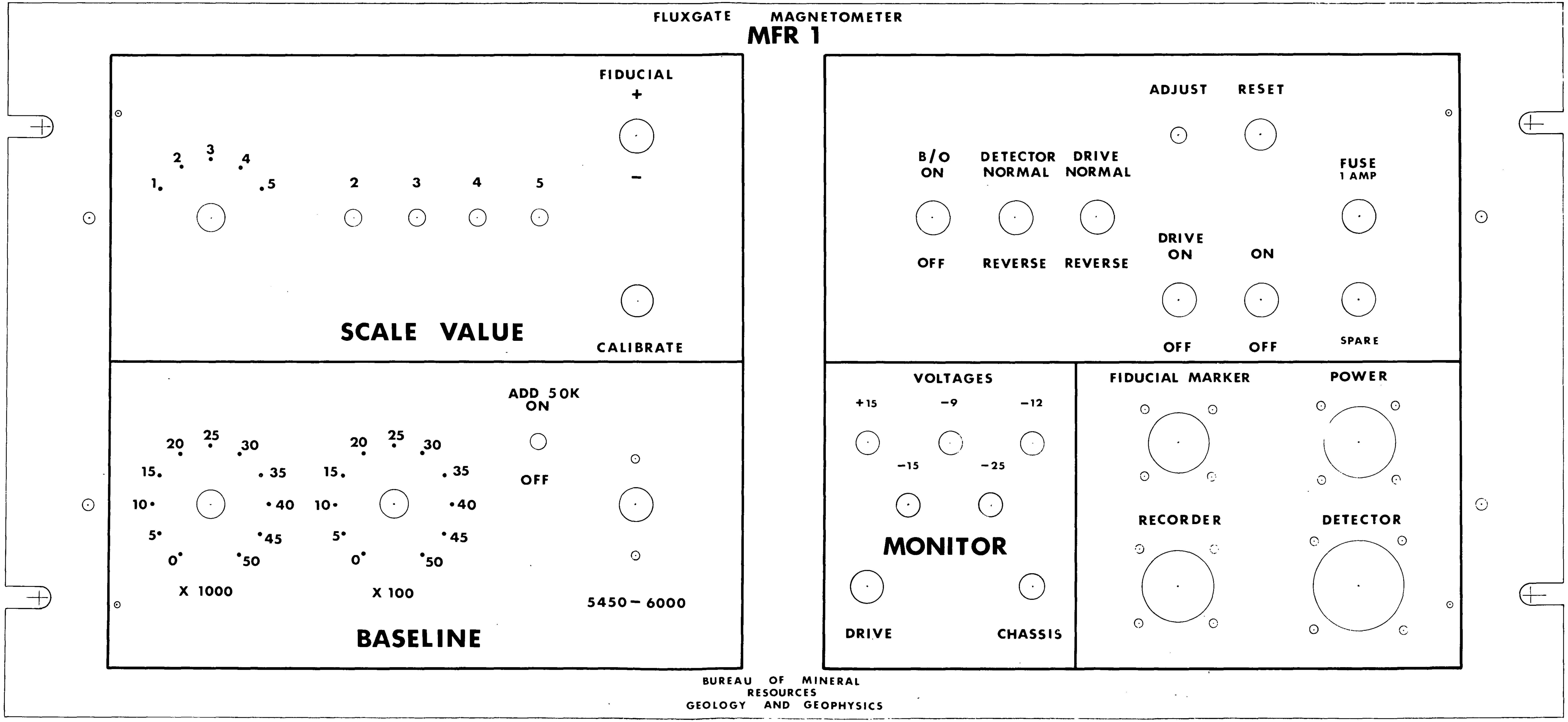
TO ACCOMPANY RECORD NO 1971/48

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS	Drawing No. Z2 SH.4	INSTRUMENT TERMINAL PIN EYELET TYPE 1518

PLATE 40



TO ACCOMPANY RECORD NO 1971/48



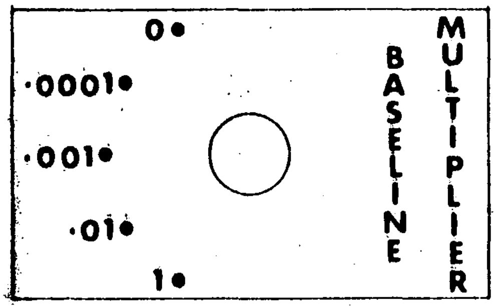
BINDING

DRG. NO. MFRI SH. 9A

ALL LETTERING WHITE FILL

TO ACCOMPANY RECORD 1971/48

PLATE 42



TO ACCOMPANY RECORD NO 1971/48

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS	Drawing No MFR1 18.	INSTRUMENT 3 COMPONENT FLUXGATE. SWITCH PLATE DESIGNATION.