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VOLTAGE REGULATOR TYPE PVR1 FOR VULCANOLOGICAL TELEMETRY SYSTEM

by

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CONTENTS

			Page
	SUMMARY		
1.	INTRODUCTION		1
2.	SPECIFICATIONS		1
3.	BLOCK DIAGRAM AND DESCRIPTION		2
	3.1	Regulating section	2
	3.2	Protection circuit	3
	3.3	Short circuit protection	4
4.	CIRCUIT DESIGN		5
	4.1	Voltage reference V_R	5
	4.2	Difference amplifier	6
	4.3	Driver amplifier	6
	4.4	Series regulator	6
	4.5	Constant current source	7
	4.6	Voltage divider	7
	4.7	Frequency response	8
	4.8	Output resistance	8
	4.9	Circuit breaker	10
	4.10	Reverse polarity diode	10
	4.11	Protection circuit voltage references	10
	4.12	SCR switch	10
	4.13	Switched current sources	11
	4.14	Chassis ground	11
5.	COMPONENTS		12
	5.1	Semiconductors	12
	5.2	Capacitors	12
	5.3	Resistors	12
	5.4	Connectors	12
	5.5	Hook-up wire	12
6.	CONSTRUCTION		12
7.	PERFORMANCE		14
	7.1	Load regulation	14
	7.2	Line regulation	14
	7.3	Output resistance	15
	7.4	Temperature coefficient	15
	7.5	Turn-on time	15

		Page
	7.6 Protection times	15
	7.7 Standing current	15
8.	MAINTENANCE	15
9.	INSTALLATION	16
10.	OPERATING INSTRUCTIONS	16

ILLUSTRATIONS

Plate 1.	Block diagrams and circuit breaker response curve	(Drawing No. G82/3-96)
Plate 2.	Circuit diagram and layout	(G82/3-97)
Plate 3.	List of components	(G82/3-99)
Plate 4.	Heatsink layout	(G82/3-98)
Plate 5.	Performance curves	(G82/3-100)

SUMMARY

A transistorised voltage regulator was designed and constructed for incorporation in a system to be installed in a tunnel in proximity to the volcano Vulcan, near Rabaul, to provide a warning of volcanic activity by telemetering seismic information to an observatory. The regulator ensures a constant operating voltage for the transmitter.

Stress was placed on electrical reliability and the ability of the unit to withstand a tropical environment. The performance of the unit was satisfactory and complied with all the required specifications.

1. INTRODUCTION

This report describes a transistorised voltage regulator designed by the Geophysical Design and Development Group of the Bureau of Mineral Resources for the Vulcanological Group. The regulator is incorporated in the system shown in Plate 1a. The system is installed in a tunnel in proximity to the volcano Vulcan, near Rabaul, and provides warning of volcanic activity by telemetering seismic information to an observatory.

The function of the voltage regulator is to ensure consistent operating voltage for the transmitter regardless of variations in battery voltage during the charge/discharge cycle.

Because public safety is involved, the regulator must be reliable electrically and able to withstand the tropical and corrosive environment. A spare unit was also requested to minimise the time 'off the air' in the event of a failure.

2. SPECIFICATIONS

The specifications laid down by the Vulcanological Group were:

1. Output voltage, V_o = 23.5 ± 0.5 volts
2. Maximum load current, $I_{o\ max}$ = 3.0 amps
3. Maximum input voltage, $V_{in\ max}$ = 35.1 volts
4. Minimum input voltage, $V_{in\ min}$ = 25.2 volts
5. Input ripple voltage, $V_{in\ R}$ = 1 volt peak
6. Maximum operating temperature, $T_{A\ max}$ = 50° C
7. Positive side of the supply to be grounded
8. Efficiency to be as high as possible
9. Physical construction to give maximum reliability and protection combined with ease of maintenance.

The range of V_{in} (Specifications 3 and 4) is the range in terminal voltage of the 21-cell nickel-cadmium battery during its charge/discharge cycle. To allow for the voltage drop that must always occur across a regulator, 21 cells are the minimum number practicable.

Because semiconductor regulators are prone to catastrophic failure if input and output ratings are exceeded, the following specifications were added by the Design and Development Group.

10. If the output short circuited, regulator must turn off within 0.1 millisecond and stay off until manually reset.
11. If the input voltage exceeds 39 $\pm$ 2 volts, regulator must turn off within 200 milliseconds and stay off until manually reset.
12. All circuits must be protected against reversal of input polarity.

No requirement was given for regulation, but it was considered that sufficient regulation would occur for a maximum output resistance given by:

13. $R_{o\ max} = 0.1$ ohm

This would result in a drop of 0.3 volt from no load to full load.

For design purposes, the minimum operating temperature was chosen as:

14. $T_{A\ min} = 0^{o}$ C
15. In some installations there is a need for the regulator to control the voltage at the load, rather than at its own output terminals; e.g., to eliminate effects of wiring resistance. An optional remote sensing facility was specified to fulfil this need.

3. BLOCK DIAGRAM DESCRIPTION

For discussion, the unit is divided into two sections: the regulation section; and the protection circuit.

3.1 Regulating section

A block diagram of the regulating section is shown in Plate 1b.

The following is a brief system analysis:

The output of the difference amplifier is current I_1 given by

$$I_1 = K_1 (V_A - V_R) + I_S \qquad (1)$$

where

K_1 is the transconductance of the difference amplifier,

V_R is the reference voltage,

V_A is a voltage derived from the output voltage V_o by divider R_1R_2.

$$V_A = V_o\, R_1/(R_1 + R_2) \tag{2}$$

Output of the driver amplifier is

$$I_2 = K_2\, I_1 \tag{3}$$

where K_2 is the driver amplifier current gain. I_2 combines with a constant current I_5 to give

$$I_3 = I_5 - I_2 \tag{4}$$

which drives the series regulator power amplifier, which, provided V_{in} is sufficiently large, has an output current

$$I_4 = K_3 I_3 \tag{5}$$

where K_3 is the current gain of the series regulator. I_4, flowing through $R_1 + R_2$ in parallel with any external load resistance R_L, produces the output voltage

$$V_o = I_4 R_L (R_1 + R_2) \;/\; (R_L + R_1 + R_2) \tag{6}$$

Note that because of the direction of current flow, V_o must be negative with respect to ground, thus meeting Specification 7.

Combining equations (1) to (6) gives

$$V_o = \frac{(K_1K_2K_3V_R - K_2K_3I_S - K_3I_5)\; R_L\; (R_1 + R_2)/(R_L + R_1 + R_2)}{1 + K_1K_2K_3R_1R_L/(R_L + R_1 + R_2)} \tag{7}$$

For the product $K_1K_2K_3$ very large, this reduces to

$$V_o = V_R\;\; (R_1 + R_2) \;/\; R_1 \tag{8}$$

which implies that V_R must also be negative with respect to ground, and that V_o is approximately constant and independent of R_L and V_{in}.

The expression $K_1K_2K_3R_1R_L/(R_L + R_1 + R_2)$ is the loop gain, and from feedback theory, the output resistance is approximately

$$R_o \approx (R_1 + R_2) \;/\; K_1K_2K_3R_1 \tag{9}$$

$$\approx V_o \;/\; K_1K_2K_3V_R \tag{10}$$

In the practical system the gain 'constants' K_1, K_2, and K_3 vary with operating conditions and the circuit design must take this into account.

3.2 Protection circuit

A block diagram of the protection circuit is shown in Plate 1c.

Input voltage V_{in} is applied via a circuit breaker which opens for currents in excess of 5 amps. The breaker must be manually reset and doubles as an on/off switch.

If the input polarity is reversed, the reverse polarity diode conducts heavily, clamping the reverse voltage applied to the circuit to less than 2 volts until the circuit breaker opens.

Two alternative means of overvoltage protection are provided:

When Link 1 is closed and Link 2 is open, the SCR switch will close as soon as V_{in} exceeds reference V_{RV1}. A high current flows, opening the circuit breaker. The operation of the SCR is almost instantaneous, so that the only delay is that required for circuit breaker operation (the circuit breaker delay curve is shown in Plate 1d). The entire unit is thus isolated from the excessive voltage.

If, instead, Link 2 is closed and Link 1 opened, a current source will turn on as soon as $V_{in} - V_{RV2}$ exceeds V_o. The current source is connected to the driver stage of the regulator and causes it to absorb all the current from the constant current source, thus turning the series regulator off. The current from the current source increases in proportion to the quantity $V_{in} - V_{RV2} - V_o$. When the series regulator commences to turn off, V_o is reduced, giving an increased output from the current source and turning off the series regulator still further. This causes V_o to drop further and the action is regenerative, until the series regulator is turned right off. If desired, a time constant may be imposed on the operation of this circuit, in order that short transients will not turn the regulator off. This is the only advantage over the first alternative protection circuit. A considerable disadvantage is that there is no protection for the protection circuits because the circuit breaker does not operate.

For the proposed application the first alternative is recommended.

3.3 Short circuit protection

Short circuits are usually detected by sensing the voltage developed across a resistance in the input lead. Such a technique is not desirable for this unit because of the small differences between $V_{in\ min}$ and V_o. A series resistor would make the difference even smaller, degrading the regulation performance.

The technique adopted here senses the drop in V_o when the short circuit is applied. This method has been used in a number of previous BMR designs, such as the TZA1 Digital Scanner, MNS1 Proton Magnetometer, and NCD2 Crystal Clock.

Protection is provided by a second current source which starts to turn on when V_o falls below V_{RS}. The operation is identical with that of the overvoltage protection circuit. Again a time constant may be incorporated, but it is generally undesirable as, in the event of a short circuit, the series regulator must be turned off as quickly as possible. V_{RS} must be derived from V_{in} rather than V_o, so that the regulator remains turned off. A small time constant is therefore required, slightly larger than the regulator turn-on time constant, to prevent the protection circuit operating when V_{in} is applied.

If Link 2 is closed, it is apparent that both current sources will ultimately be turned on, irrespective of whether an overvoltage or a short circuit initiated the protetcion. Either current source acting alone will turn the regulator off, but the action is faster with both operating.

Resetting after any of the protection circuits operate can only be achieved by removing and re-applying V_{in}. This is conveniently accomplished by manual operation of the circuit breaker.

4. CIRCUIT DESIGN

Circuit design is conservative, worst case design being used throughout, except for the case of output resistance as will be subsequently explained. Brief details of major design considerations are given below and the circuit diagram is shown in Plate 2. A list of components is given in Plate 3.

4.1 Voltage reference V_R

A temperature compensated zener diode type IN939 is used. This is one of a family of zeners giving a reference of 9.0 volts $\pm$ 5% at a current of 7.5 milliamps. At this current, variation of voltage with temperature is less than 3 millivolts over the range 0° C to 75° C. The variation in V_o caused by temperature dependence of V_R is, from equation 8, for temperature T_A between 0° C and 50° C,

$$\Delta V_o = \Delta V_R \, V_o \,/\, V_R \qquad (11)$$
$$\leq 0.008 \text{ volts}$$

To maintain the zener current constant, it is derived from V_o via a wire-wound resistor.

4.2 Difference amplifier

A balanced differential amplifier is used. This has two advantages over the single-sided amplifier: (1) the current through the reference zener is kept constant, and (2) temperature effects, such as variation of base-to-emitter voltage, tend to cancel. The latter advantage is enhanced by utilising a dual transistor, i.e. two transistors fabricated on the same silicon chip and packaged in the same case. In the 2N3811, the base-to-emitter voltages are matched to within 5 millivolts at 25° C and change by less than 1 millivolt over the operating temperature range. The ratio of d.c. current gains is better than 0.9. This precise matching, together with the low temperature coefficient of the reference voltage, ensures that V_o will be virtually temperature independent.

It may be shown that the transconductance of the difference amplifier is

$$K_1 \approx I_1 \,/\, 52 \text{ mhos} \qquad (12)$$

where I_1, in milliamps, is the current in that collector which feeds the base of the driver.

Standing current is set by the common emitter resistor R_E and voltage reference:

$$I_S \approx V_R \,/\, 2R_E = 2.5 \text{ milliamps} \qquad (13)$$

4.3 Driver amplifier

This is a simple common-emitter amplifier using a power transistor type 2N3715. The amplifier current gain is simply the transistor current gain, i.e.

$$K_2 = \beta_{2N3715} \qquad (14)$$

4.4 Series regulator

This is a 7.5-amp transistor type 2N3447. Maximum power dissipation is

$$P_{R\,max} = I_{o\,max} (V_{in\,max} - V_o) \qquad (15)$$
$$= 35 \text{ watts}$$

When mounted on the heat sink specified, thermal resistance from transistor junction to surrounding air is 3.5° C/watt, giving a maximum junction temperature of 170° C, for am ambient of 50° C; in practice this will be reduced because the heat sink is in thermal contact with the case. As the maximum allowable junction temperature for the 2N3447 is 200° C, specification 6 is satisfied. Series regulator current gain is

$$K_3 = \beta_{2N3447} \qquad (16)$$

4.5 Constant current source *

A voltage reference of 6.8 volts nominal, derived from a IN754A zener diode, is applied to the base of a 2N3791 power transistor. The 56-ohm emitter resistor sets the collector current at 110 milliamps nominal, with a range set by component tolerances of 98 to 122 milliamps, i.e.

$$0.098 \leqslant I_5 \leqslant 0.122 \text{ amp} \qquad (17)$$

Maximum transistor dissipation is approximately 3.2 watts, occurring when V_{in} is maximum.

In many regulators a resistor from the series regulator base to the common line is used rather than a constant current source. Although such a system is simpler, it suffers from the following disadvantages:

(i) Current gain of the driver amplifier is reduced.

(ii) Current flowing through the resistor is a function of V_{in}, which requires the driver to operate over a wider current range.

(iii) For high V_{in}, power dissipation in the resistor is high.

4.6 Voltage divider

The design of the divider used to obtain V_A is not critical, provided that its resistance $R_1 + R_2$ is low enough to prevent loading effects by the difference amplifier. Making $R_1 + R_2$ too low, however, causes unnecessary drain. The resistance values chosen draw

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* This application of a constant current source was first used in BMR circuits in 1962 by J. K. Newman in the MFD3 Fluxgate Magnetometer.

only 10 milliamps. A 22-turn trimming potentiometer forms part of the divider. Its function is to vary $(R_1 + R_2)/R_1$ so that exact adjustment of output voltage can be obtained (cf. equation 8).

Note that the divider is not connected directly across the output, but via remote sensing leads. This allows the voltage to be sampled right at the load, thereby regulating against voltage drops in the connecting leads. If this facility is not required, the remote sensing leads should be bridged to the output leads externally in the connector. Connection through resistors is provided internally, so that operation of the regulator can be checked with the connector removed. Generally, V_o will alter slightly when the remote sensing leads are disconnected.

The resistance seen by the base of the difference amplifier looking into the voltage divider is about 560 ohms with the potentiometer centred. A resistance of this value is inserted in the opposite base lead to minimise temperature unbalance. Temperature and ageing effects are also reduced by using wire-wound resistors in the divider.

4.7 Frequency response

No specification was laid down and no analysis was performed, but the response is governed by the various responses of the transistors used. The lowest of these is about 0.3 Mc/s for a gain reduction of 50%.

To reduce the remote possibility of high-frequency oscillation the high-frequency open-loop gain is reduced by a bank of capacitors across the output. These also serve to reduce the output impedance of the regulator. Radio frequency bypassing is not included because it is more effectively applied right at the load.

Depending on the impedance of the power supply, high-frequency closed-loop gain may be improved by the capacitor bank at the input.

4.8 Output resistance

Worst case design was not used to achieve Specification 13, i.e. $R_{o\ max} = 0.1$ ohm, for the following reasons:

(a) Because of the possible scatter in transistor gains, and their variations with operating current and temperature, the value of loop gain in equation 9 can vary from 2900 to 550,000, as shown in Table 1. The minimum required for $R_{o\ max} = 0.1$ ohm is 23,800. As it is unlikely that all worst case conditions will occur simultaneously the existing circuit was considered to be satisfactory, provided R_o is actually measured for each unit constructed. If R_o is found to be marginal, higher gain transistors can be substituted before the regulator is placed into service, though the likelihood of this is not great as is shown in the following argument.

(b) The values of β in equations 14 and 16 and the value of I_1 in equation 13 vary with operating current. Thus the output resistance, calculated from the loop gain obtained from these equations, is actually the incremental value ΔR_o, i.e. the magnitude of the slope of the $V_o:I_o$ curve at the particular value of I_o used to determine K_1, K_2, and K_3. The $V_o:I_o$ curve for this type of regulator is monotonic, so that

$$R \leqslant \Delta R_{o\ max} \qquad (18)$$

where R_o is the output resistance at any current and I_o and $\Delta R_{o\ max}$ is the maximum incremental output resistance encountered along the curve, and will occur either at $I_o = 0$, or $I_o = I_{o\ max}$.

It is therefore reasonable to suppose that there is a high probability of meeting Specification (13) if the typical value of the possible range for $\Delta R_{o\ max}$ is less than 0.1 ohm.

In this unit, the largest contribution to loop gain variation comes from the variation of K_1, which adopts its minimum value when $I_o = I_{o\ max}$. Thus $\Delta R_{o\ max}$ will occur at $I_o = 3$ amps. The typical value of loop gain at $I_o = 3$ amps and $T_A = 25^\circ$ C is 110,000, giving $\Delta R_{o\ max\ typ} = 0.022$ ohm. There is therefore a high probability that an output resistance of 0.1 ohm or less will be obtained without special selection of transistors.

TABLE 1. Variation of K_1, K_2, and K_3

I_o	T_A	K_3	K_2	K_1	$K_1K_2K_3R_1$
3 A	0° C	35_{min}	30_{min}	0.003_{min}	2,900
20 mA	50° C	90_{max}	150_{max}	0.014_{max}	550,000
3 A	25° C	85_{typ}	90_{typ}	0.016_{typ}	110,000

4.9 Circuit breaker

A magnetically operated, hydraulically damped breaker is used for fast, temperature independent and repeatable switching characteristics. Resistance of the breaker is 0.036 ohm, and the response curve is shown in Plate 1d.

4.10 Reverse polarity diode

This 12F10 rectifier can withstand a 200-amp peak surge current, which will never be exceeded provided the resistance of the power supply and leads is at least 0.13 ohm. Manufacturer's data indicate a minimum cell resistance of approximately 0.01 ohm. A 21-cell battery will therefore have a resistance of 0.2 ohm, which will limit the surge current to a safe value.

4.11 Protection circuit voltage references

These are all simple zener diode references with 5% tolerance. V_{RV1}, V_{RV2}, and V_{RS} are 39 volts (IN2992RB), 15 volts (IN965B), and 22 volts (IN2985RB) respectively, giving overvoltage protection when V_o falls below about 22 volts.

4.12 SCR switch

When V_{in} rises sufficiently to cause the IN2992RB zener to conduct, the voltage on the SCR gate becomes positive with respect to the cathode and the SCR turns on, effectively placing the 2.2-ohm resistor, in its cathode circuit, across the supply. Sufficient current is then drawn to trip the circuit breaker.

The 2N2574 SCR has a forward current rating of 25 amps, which cannot be exceeded for $V_{in} < 50$ volts.

4.13 Switched current sources

These are almost identical, each comprising a 2N3798 transistor with the appropriate voltage supply to the base and V_o applied to the emitter. Each will turn on if its base voltage is more negative than its emitter voltage. When turned on, each will supply sufficient current to enable the driver to turn the series regulator off.

A silicon diode between base and emitter ensures that the 5-volt reverse bias rating for these transistors cannot be exceeded. These diodes have a secondary effect of allowing current to flow from the voltage reference through base and emitter resistors to the output line when the protection circuits are off. Thus, both base and emitter are held fairly close to V_o. However, this does not interfere with circuit operation as these diodes become reverse biased as soon as the reference voltage becomes more negative than V_o.

The values of time constant capacitor connected to each base were determined experimentally. The turn-on time of the regulator was found to be about 0.5 millisecond, so a minimum time constant of about one millisecond is required to ensure that the protection circuit does not operate when the unit is turned on. The resistance determining the time constant is the parallel combination of base and emitter resistors, i.e. about 6.3 Kohm. A minimum value of 0.16 microfarad is therefore required for a time constant of one millisecond. To allow for component tolerances a value of 0.18 microfarad is used. This value should never be exceeded for the short circuit protection and represents the minimum value for the over-voltage protection.

4.14 Chassis ground

Although a positive ground was specified, the chassis is left floating, and can be earthed to either side of the supply via the input connector. However, it is stressed that the only line common to input and output is the positive line to which chassis ground should normally be connected.

Reverse polarity (cathode to case) versions of the 10-watt zener diodes are used. Should the mica insulating washers break down, there will be no effect on regulator operation if a positive ground is used, and, for a negative ground, the resultant short circuit will trip the circuit breaker without detriment to the regulator.

5. COMPONENTS

Only the most reliable types of components are used, and all are operated well short of their maximum ratings (a list is given in Plate 3). Where possible, devices meeting MIL or DEF specifications were selected, these specifications giving some assurance of reliability under adverse environmental conditions.

5.1 Semiconductors

Silicon types are used throughout. In the case of the Motorola ML2 series of zener diodes a copy of the Military Lot Acceptance Data is held by the Design and Development Group for each device.

5.2 Capacitors

Electrolytics are of the solid tantalum type to MIL-C-26655. Other capacitors are of the polyester foil type.

5.3 Resistors

Half-watt resistors are of the metal oxide film type to DEF 5115-1. Resistors of higher rating are wire wound with vitreous enamel coating and are Australian-made equivalents to various MIL types.

The 22-turn adjustment potentiometer is described as a high-temperature, humidity-proof device and meets or exceeds all requirements of MIL-C-27208A.

5.4 Connectors

These conform to MIL-C-5015 Class E (environmental) specifications.

5.5 Hook-up wire

PTFE insulated wire to MIL-W-16878D is used throughout.

6. CONSTRUCTION

Following normal practice, most electronic components are mounted on one side of a fibre glass board, being soldered to silver plated brass pins inserted through the board. Intercomponent wiring occupies the other side of the board (see Plate 2 for layout and wiring details).

After being cut to size, the board was thoroughly dried under high power lamps and the cut edges coated with epoxy resin to prevent any possible moisture absorption, which could lead to long term insulation breakdown, or support fungal growth.

Heat dissipating components, except for the series regulator, are mounted in similar fashion on a stainless steel plate, using PTFE-insulated lead-through pins (see Plate 4 for layout and wiring details). Bolts through the plate support the fibre glass card, the whole assembly being housed in a stainless steel case.

The circuit breaker and the input and output connectors are mounted on the front of the case and the heat sink with the series regulator on the rear. A guard is built around the heat sink to ensure physical and electrical protection, without impeding ventilation. Lead-through pins inserted in the rear of the case provide connections for the series regulator. The case sits on four Neoprene buffers.

When mounting the circuit breaker it was found convenient to file two small flanges down each side of its plastic housing. These were also sealed with epoxy resin. To prevent moisture ingress through the control lever aperture in the circuit breaker, a perspex cover is bolted over the aperture and the control lever operated by a stainless steel push rod sealed with a neoprene O ring. Although friction from this O ring prevents the lever from dropping down when the breaker trips, there is no effect on the internal tripping action. A layer of silicone grease seals the perspex against the front panel. The rear of the circuit breaker was sealed in polythene to prevent ingress of encapsulant.

An airtight case was requested, but as a hermetic seal is difficult to engineer and presents maintenance problems, it was decided that the box would be dust tight and the electronic assembly encapsulated in silicone resin. In view of the fact that all components are designed to withstand severe environmental conditions and that self heating of the components will help to reduce moisture, this was considered a reasonable compromise. Thus the lid of the case can be easily removed for maintenance and potentiometer adjustment.

The case is fabricated from 18/8 stainless steel, which, as well as resisting atmospheric corrosion, does not suffer from bimetallic corrosion against any other common metals. Metals such as brass, nickel, and cadmium, however, may corrode against stainless steel under extreme conditions of moisture, so the use of screws made from or plated with these metals has been avoided on the outside of the case, and stainless steel or nylon screws have been used.

Before encapsulation, the entire regulator was cleaned with Freon TF solvent and subsequent handling restricted to the outside of the case. The case was entirely filled with a low-temperature curing silicone resin compound, marketed by Dow Corning under the trade name of 'Sylgard' 184. When cured, the resin is resilient and can easily be removed if necessary. Complete encapsulation in this manner ensures protection for connectors, wiring, etc., which would not be protected if only the component board were encapsulated.

7. PERFORMANCE

Measurements of the performance of the first regulator that was constructed are detailed below; the unit was found to meet the specifications required. Measurements on the second unit were not as detailed, but the performance should be similar.

7.1 Load regulation

Plate 5a shows curves of the variation of V_o with I_o, for ambient temperatures of 0° C, 25° C, and 50° C, and V_{in} in the range 26.1 to 35.1 volts. Below about 26.1 volts, there is a slight departure from these curves where V_o becomes a function of I_o and T_A. The departure for $V_{in} = 25$ volts is indicated.

Curvature suggested by the plotted points has been ignored because the possible error in voltage measurement was $\pm$ 0.01 volt and $\pm$ 2% of measured value for the error in current.

7.2 Line regulation

Plate 5b shows the value of V_{in} for which V_o departs from the curves of Plate 5a by 0.01 volt. The cause of this variation is primarily the departure from ideal transistor action in the series regulator as it approaches saturation.

7.3 Output resistance

The slopes of the curves in Plate 5a give an output resistance of 0.022 ohm at 0° C increasing to 0.029 ohm at 50° C. Lack of curvature indicates that $\Delta R_o = R_o$. This would suggest that the loop gain does not change greatly over the range 0 to 3 amps, and is around the typical value expected (see section 4.8). Taking certain precautions, it was found that up to 6 amps could be delivered from this unit without significant increase in output resistance. However, in normal service the load current should never exceed 3 amps.

7.4 Temperature coefficient

Plate 5a gives a coarse display of behaviour with temperature. An accurate measurement for a constant load of 1.5 amps is plotted in Plate 5c. The average coefficient is found to be 0.9 millivolt per degree C or 0.004% per degree C.

7.5 Turn-on time

After applying V_{in}, V_o reaches its final value in approximately 0.5 millisecond, the build-up being roughly linear.

7.6 Protection times

Short circuiting the output caused the series regulator to turn off in 0.08 millisecond. Applying 39 volts to the input tripped the circuit breaker in 0.13 second. Applying 25 volts with reversed polarity to the input tripped the circuit breaker in 0.05 second.

7.7 Standing current

Apart from the load current, the regulator itself draws current from the supply, ranging from 0.17 amp for V_{in} = 25 volts to 0.24 amp for V_{in} = 35 volts.

8. MAINTENANCE

Should it be necessary to replace a component, the silicone encapsulating resin can be easily cut away and later replaced with new resin. For trouble shooting purposes, normal voltages are shown on the circuit diagram. The only periodic maintenance required is:

(1) A regular check of the output voltage and adjustment if necessary. (The adjustment potentiometer is accessible when the lid is removed.) After initial ageing of the components, checking at half-yearly intervals should be adequate.

(2) Regular inspection of the connectors for corrosion.

9. INSTALLATION

The regulators should be connected to the battery via pins B (negative) and D (positive) of the input plug. Pin C is the chassis ground pin and should be bridged to either pin B or pin D as requires (see section 4.14). Output wiring to the load is via pins B (negative) and D (positive) of the output connector. If remote sensing is not required (see section 4.6) bridge pin A to pin B and pin C to pin D on the output plug. To use the remote sensing facility, run a cable connecting pin A to the negative side of the load and pin C to the positive side. The voltage at the load will then be regulated to 23.5 volts. If the resistance of the output wiring is significant, say 0.5 ohm, then at 3 amps there would be 1.5 volts dropped between regulator and load. With remote sensing giving 23.5 volts at the load the regulator output would need to be 25.0 volts. For low battery voltage this would not be possible, and the load voltage would need to be adjusted down to about 22 volts for good regulation. This is undesirable and can be avoided by reducing the resistance of the output leads, i.e. the wire gauge should be as low as possible. The remote sensing leads only carry 10 milliamps and may be of high gauge wire.

10. OPERATING INSTRUCTIONS

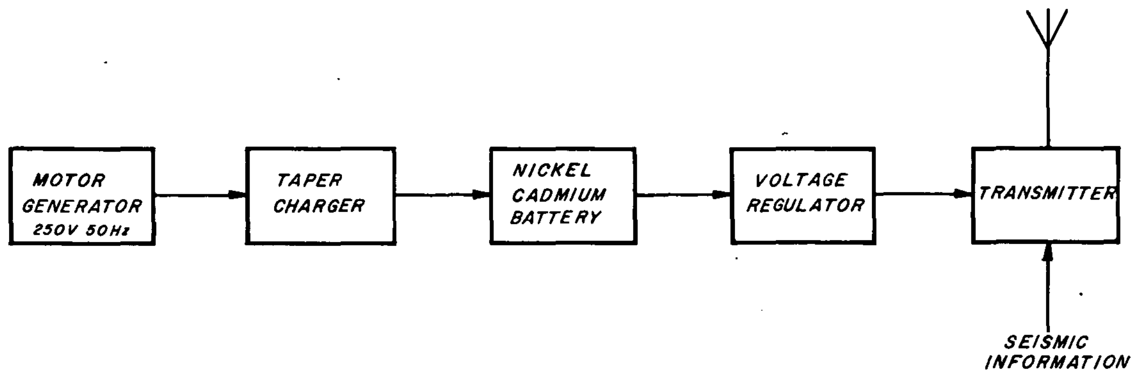
The only control is the switch/circuit breaker. To turn the regulator on, pull the control rod upwards; to turn off, push downwards.

If the breaker trips, the control rod may stay in the "ON" (up) position because of friction in the O-ring seal. To reset, push the rod downwards to re-engage the switch mechanism, then pull upwards.

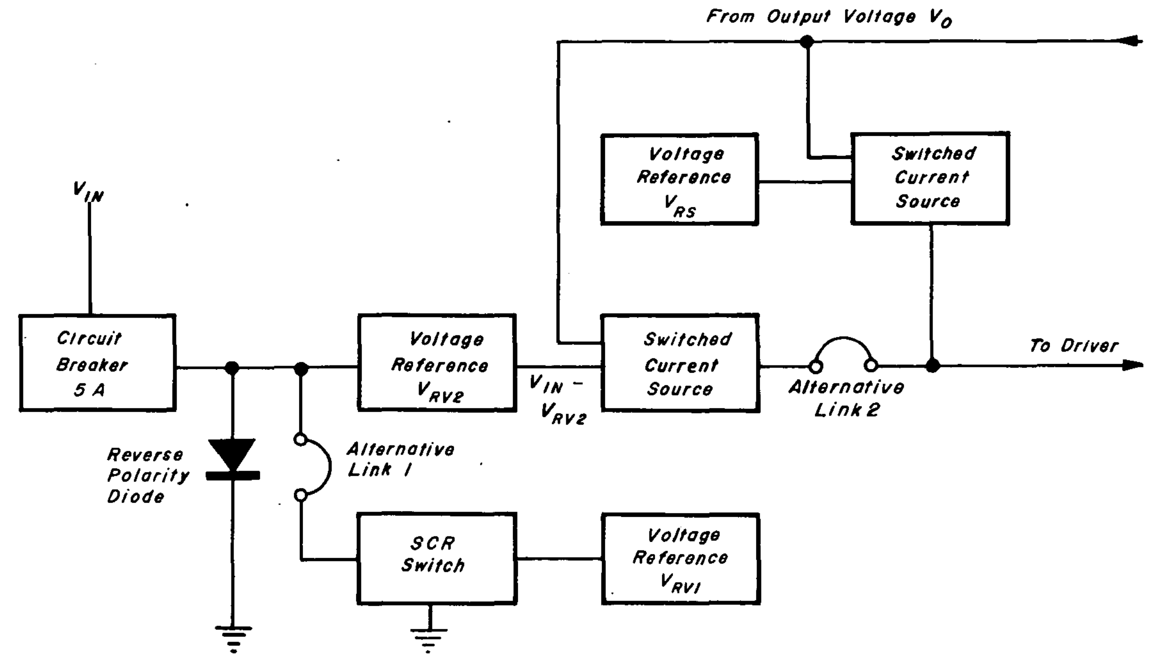
In the units sent to Rabaul, both links used for overvoltage protection (section 3.2) have purposely been left in circuit because protection given by Link 1 occurs at a slightly lower voltage than protection given by Link 2, and therefore predominates. The inclusion of Link 2 increases the speed of short-circuit protection.

However, for possible future applications, when the operator may need to select the type of overvoltage protection, the location of Link 1 is shown on the internal heatsink layout diagram (Plate 4), and that of Link 2 on the fibreglass card layout diagram (Plate 2).

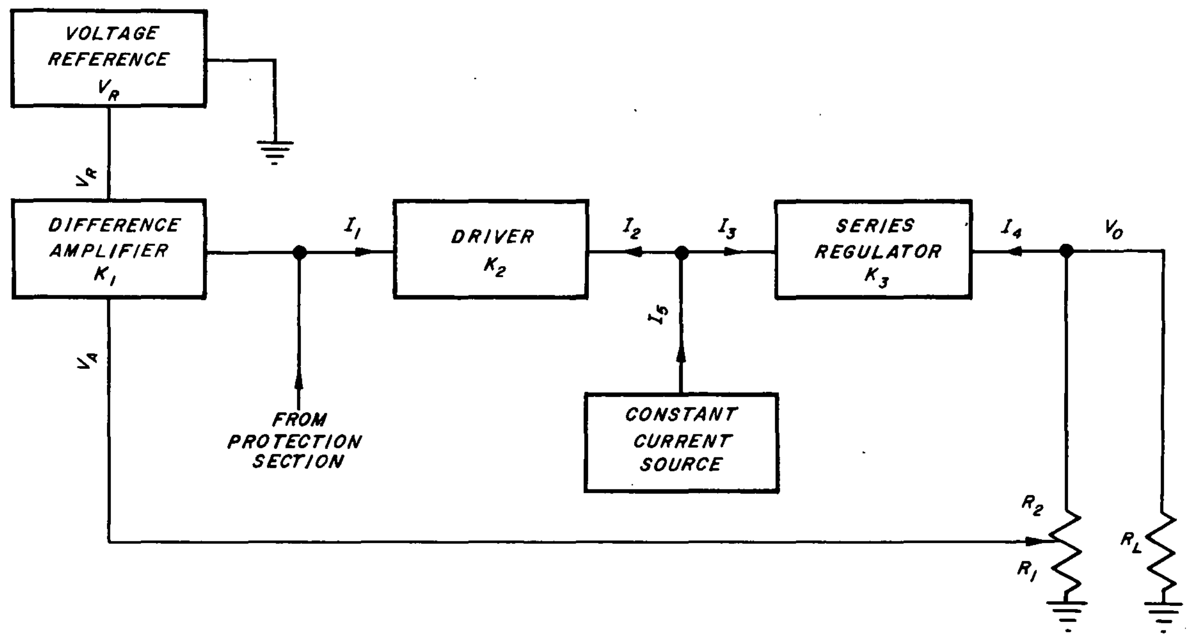
If remote sensing is required, refer to section 9 for connection details.



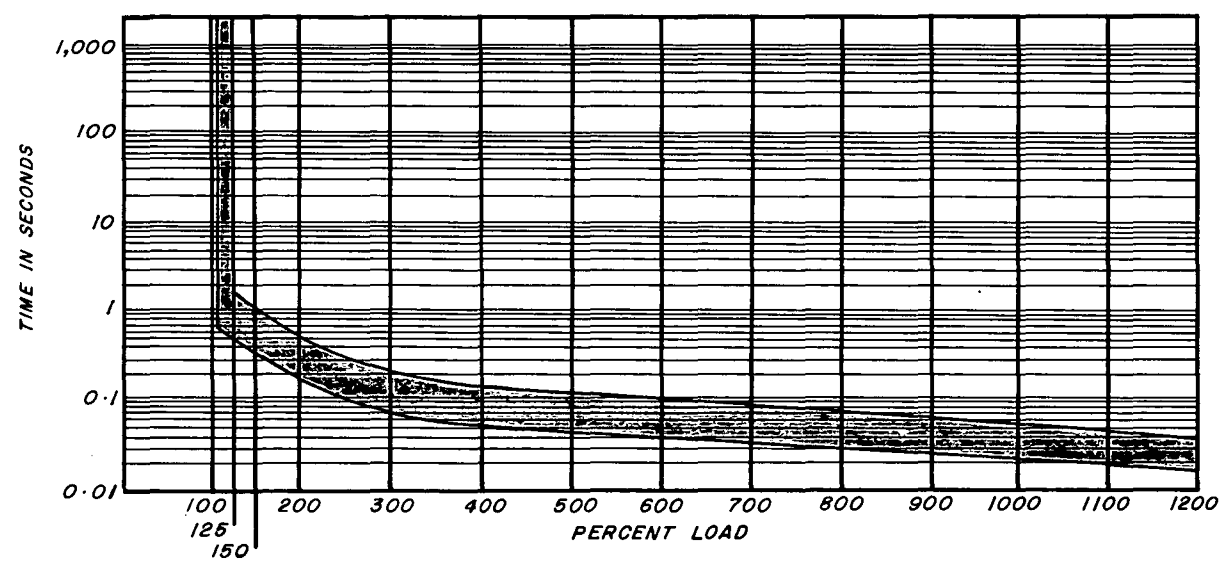
a. INSTALLATION BLOCK DIAGRAM



c. PROTECTION CIRCUIT BLOCK DIAGRAM



b. REGULATING SECTION BLOCK DIAGRAM



d. CIRCUIT BREAKER RESPONSE

VOLTAGE REGULATOR PVR1

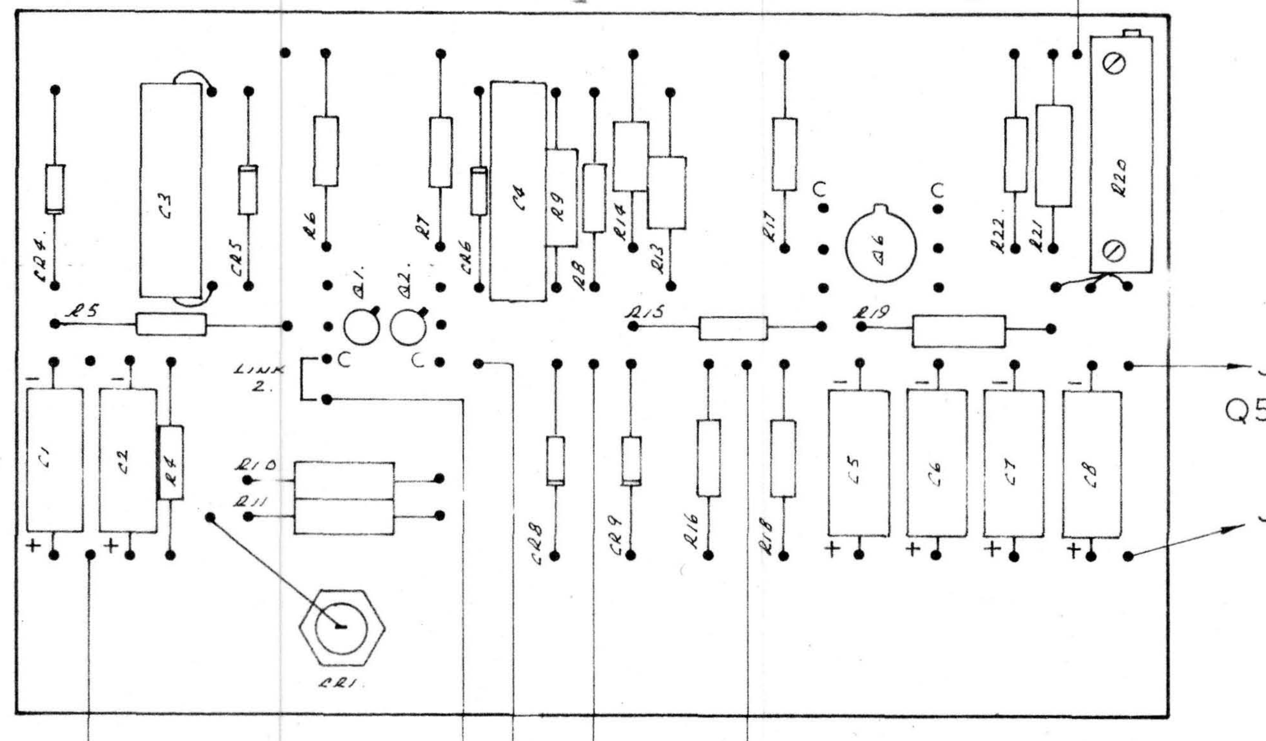
BLOCK DIAGRAMS & CIRCUIT BREAKER RESPONSE CURVE

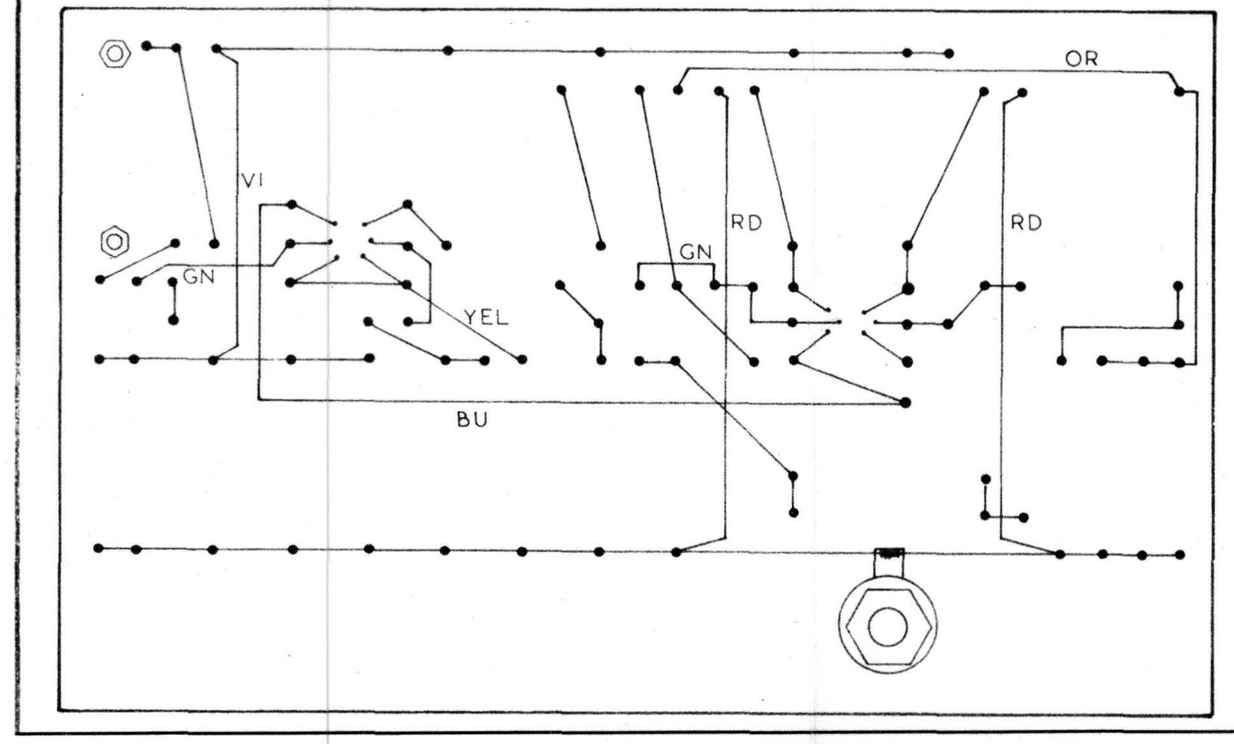
G82/3-96

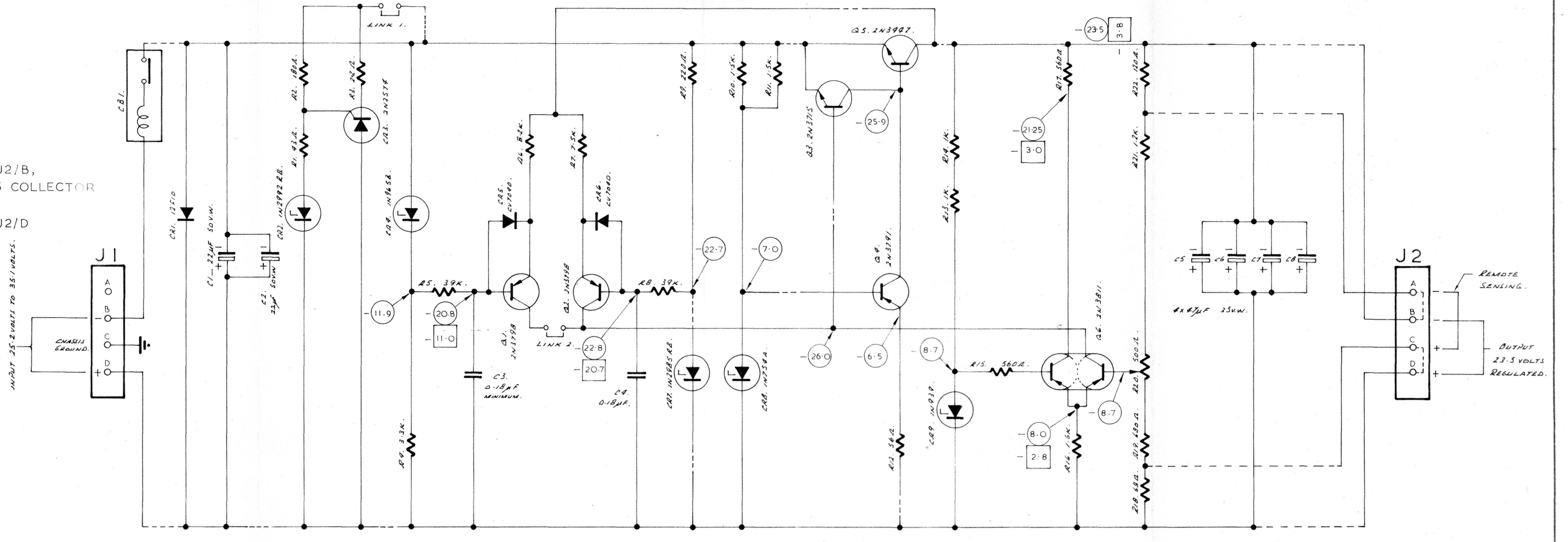
TO ACCOMPANY RECORD No. 1967/132

NAME	DATE	AMENDMENTS	ISSUE
R.L.	12.9.67		1

PLATE 2







– – – – COMPONENTS LOCATED EXTERNAL TO CARD SHOWN ON THIS DRAWING. SEE NOTES.

NOTES.

(i) — J1 J2 CB1 MOUNTED ON FRONT PANEL.

(ii) — Q5 MOUNTED ON HEATSINK AT REAR.

(iii) — COMPONENTS MARKED THUS * MOUNTED ON INTERNAL HEATSINK.

(iv) — VOLTAGES INDICATED THUS -23.5 ARE TYPICAL VALUES MEASURED ON NO LOAD WITH RESPECT TO THE POSITIVE RAIL; AND WITH INPUT AT 27 VOLTS.

(v) — VOLTAGES INDICATED THUS $\boxed{-22}$ ARE AS ABOVE BUT WITH SHORT CIRCUIT PROTECTION OPERATING.

(vi) — CR2, CR3, CR7, Q3, Q4, Q5 TO BE INSULATED FROM HEATSINK WITH 0·002" MICA WASHERS SMEARED EACH SIDE WITH DOW CORNING DC4 SILICONE COMPOUND.

(vii) — WHEN MOUNTING CR2 & CR7 TORQUE ON NUT NOT TO EXCEED 12 INCH-POUNDS.

VOLTAGE REGULATOR PVRI
CIRCUIT DIAGRAM AND LAYOUT

(BASED ON DRAWING Nº PVRI SHEET I) TO ACCOMPANY RECORD Nº 1967/132 G82/3-97

COMPONENT LIST.

CAPACITORS.

C1,C2.......Capacitors Electrolytic Solid Tantalum $22\mu F$ 50v.w. Sprague Type CS13BG226K
C3..........Capacitor Polyester $0.18\mu F$ (minimum) 125v. Philips Type C296
C4.......... " " " " " " "
C5,6,7,8.... " Electrolytic Solid Tantalum $47\mu F$ 35v.w. Sprague Type CS13BF476K

CIRCUIT BREAKER.

CB1.......5 amp. D.C. Heineman Type CF1. Curve 3

DIODES.

CR1...............Silicon Rectifier 12 amp. International Rectifier Type 12F10
CR2*..............Zener Diode 39v. 10 watt. Type 1N2992RB. Motorola Series ML2
CR3*..............Silicon Controlled Rectifier Type 2N2574. Motorola.
CR4...............Zener Diode 15v., 0.4 watt. Type 1N965B, Motorola Series ML2
CR5,CR6...........Silicon Diode Type CV7040. Mullard.
CR7*..............Zener Diode 22v. 10 watt. Type 1N2985RB, Motorola Series ML2
CR8............... " " 6.8v. 0.4 " " 1N754A " " "
CR9............... " " Temperature Compensated, 9v., Type 1N939, Motorola.

CONNECTORS.

J1.......4 pin male Cannon Type MS3102E-20-24P
J2......." " female " " MS3102E-20-24S

TRANSISTORS.

Q1,Q2.......2N3798.........Motorola.
Q3*.........Power Transistor Type 2N3715......Motorola.
Q5*......... " " " 2N3447...... "
Q4*......... " " " 2N3791...... "
Q6..........Dual Transistor " 2N3811...... "

RESISTORS.

R2.........180ohms. Metal Oxide $\frac{1}{2}$w. 5% Welwyn Type F20
R1.........43 ohms. " " " " " " "
R3.........2.2 ohms Wire Wound 4.5w. 10% I.R.C. Type RWV4K
R4.........3.3K. Metal Oxide $\frac{1}{2}$w. 5%. Welwyn Type F20
R5,R8......39K. " " " " " " "
R6.........8.2K. " " " " " " "
R7.........7.5K. " " " " " " "
R9.........220 ohms. Wire Wound 3w. 5% I.R.C. Type RWV4J
R10,R11....1.5K. " " 1.5w." " " RWV3J
R12........56 ohms " " " " " " "
R13,R14....1K. " " " " " " "
R15,R17....560 ohms. Metal Oxide $\frac{1}{2}$w." Welwyn Type F20
R16........1.6K. " " " " " " "
R22........120 ohms " " " " " " "
R21........1.2K. Wire Wound 1.5w. " I.R.C. " RWV3J
R20........500 ohms. 22 turns wire wound potentiometer Bourns Type 224L-1-501
R19........680 ohms. Wire Wound 1.5w. I.R.C. Type RWV3J
R18........68 ohms. Metal Oxide $\frac{1}{2}$w. 5% Welwyn Type F20
Heatsink for Series regulator....Delco Type 7281366
Feed through terminals....Oxley P.T.F.E. Barb Lead Through Type 156
Hook-up wire....22 s.w.g. 7x30 P.T.F.E. Insulated Belden.
Potting Compound.....Silicone Resin Dow Corning 'SYLGARD' 184

* Mounting Kit required.

(BASED ON DRAWING No PVRI SHEET 5)

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS

DRAWING No. G82/3-99

SHEET

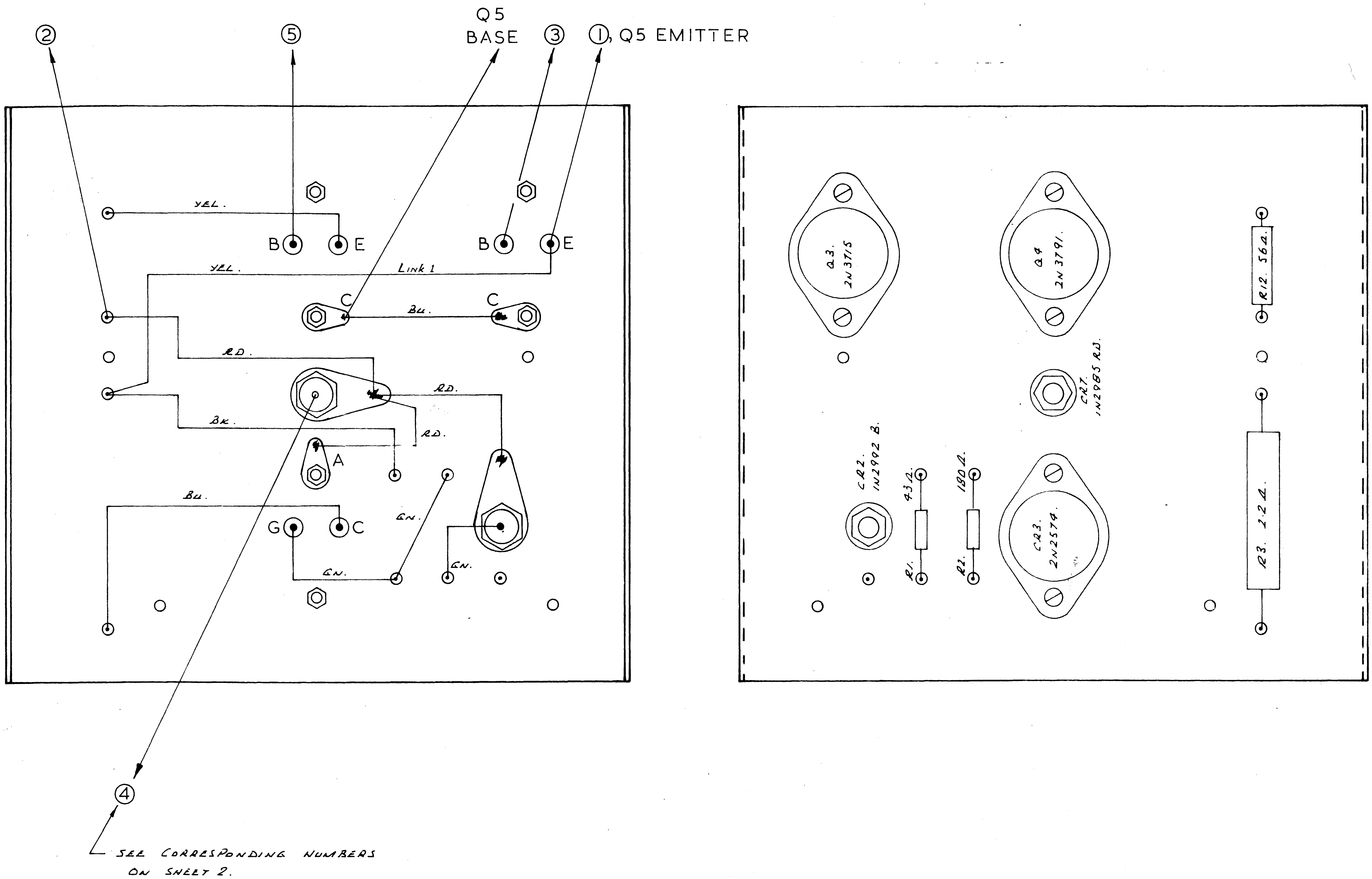
INSTRUMENT VOLTAGE REGULATOR PVRI

LIST OF COMPONENTS

TO ACCOMPANY RECORD No 1967/132

PLATE 3

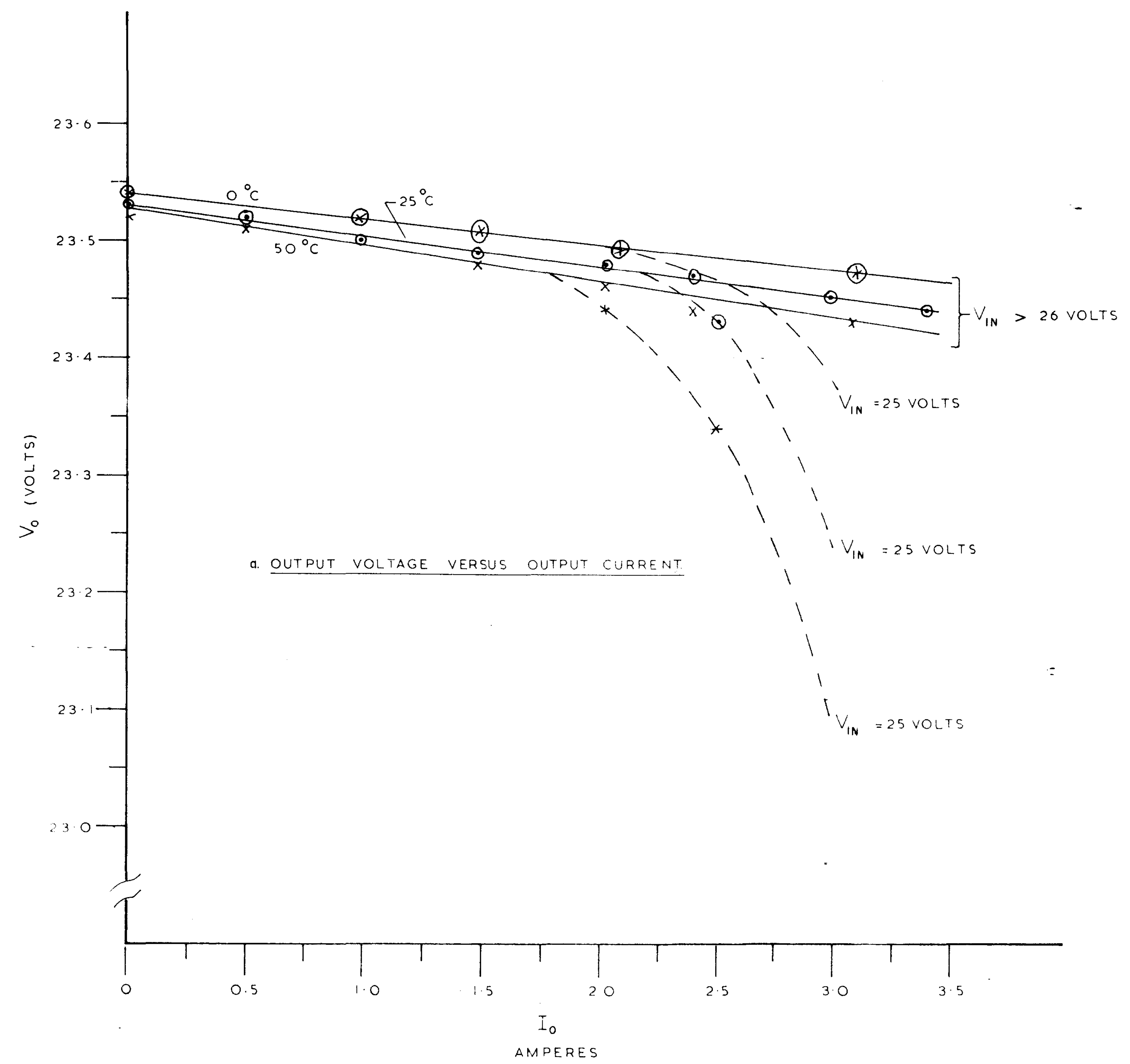
PLATE 4



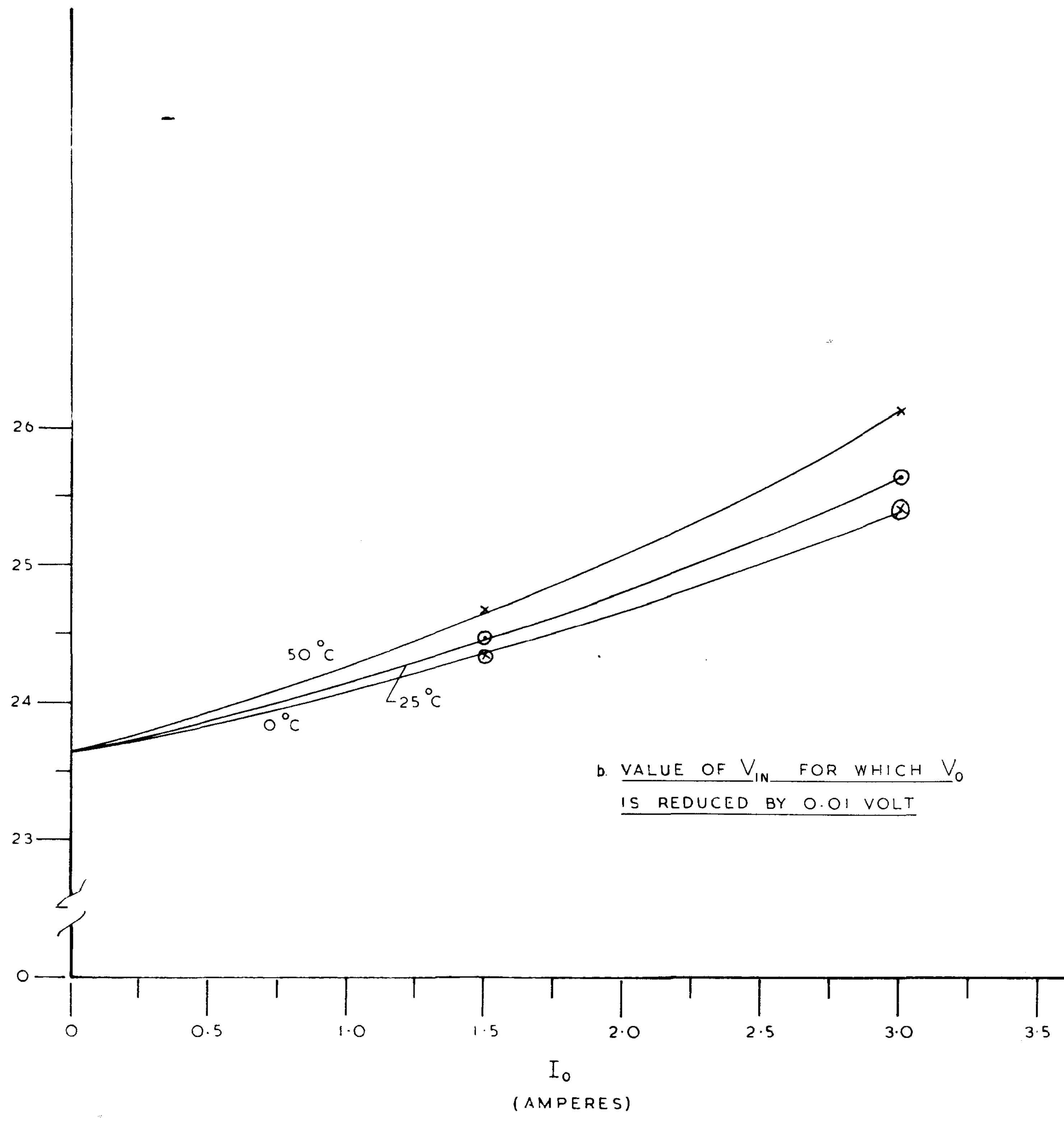
(BASED ON DRAWING Nº PVRI SHEET 2)

TO ACCOMPANY RECORD Nº 1967/132

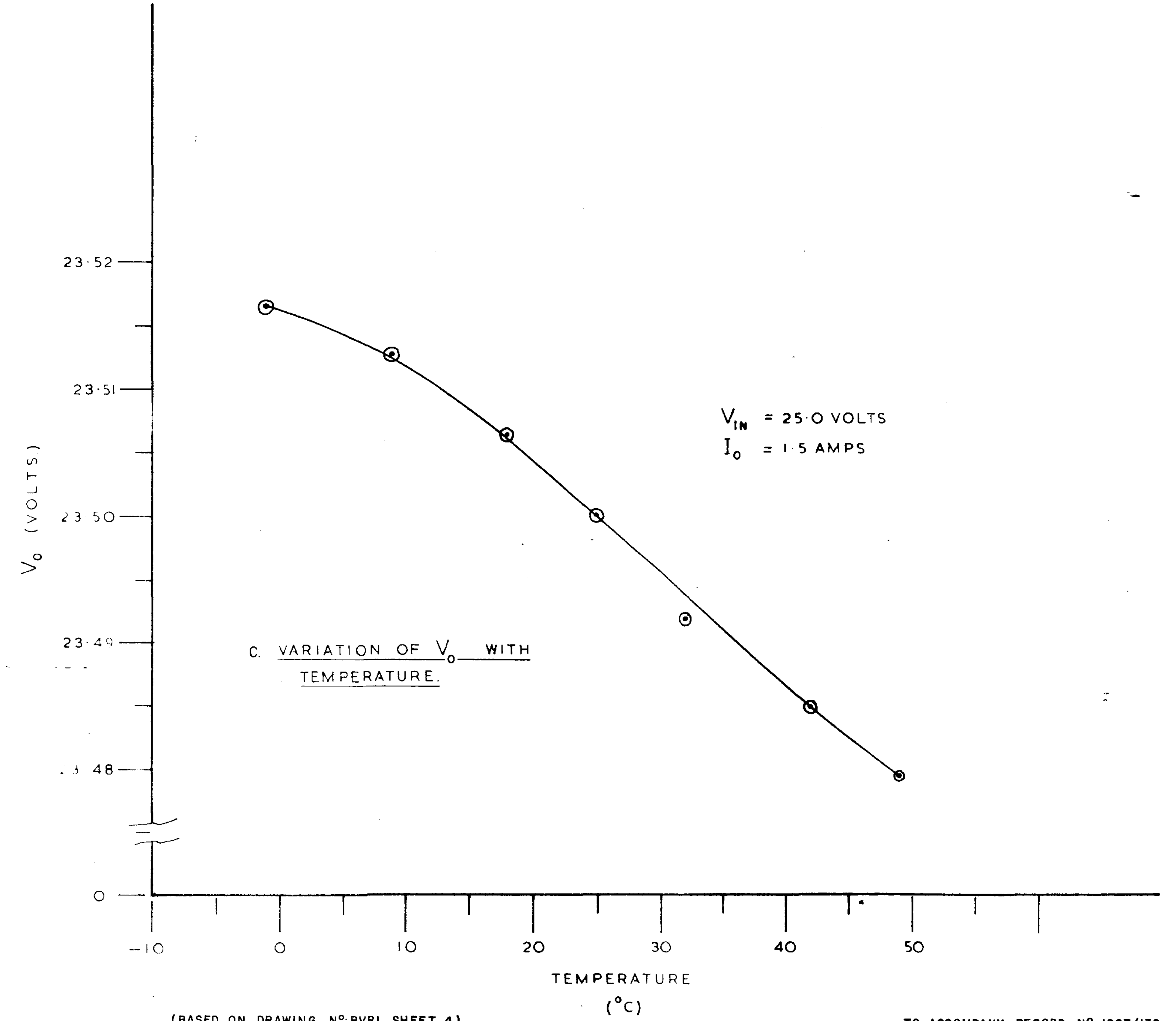
BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS	DRAWING No. G82/3-98	SHEET	INSTRUMENT VOLTAGE REGULATOR PVRI HEATSINK LAYOUT



a. OUTPUT VOLTAGE VERSUS OUTPUT CURRENT



b. VALUE OF V_{IN} FOR WHICH V_0 IS REDUCED BY 0·01 VOLT



c. VARIATION OF V_0 WITH TEMPERATURE.

(BASED ON DRAWING Nº PVRI SHEET 4)

TO ACCOMPANY RECORD Nº 1967/132

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS	DRAWING No. G82/3-100	SHEET	INSTRUMENT VOLTAGE REGULATOR PVRI PERFORMANCE CURVES