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A STABLE CONSTANT CURRENT
POWER SUPPLY WITH REPRODUCIBLE
CURRENT CONTROL

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Date Transmitted: July 1975

PREPARED FOR THE U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
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WITH REPRODUCIBLE CURRENT CONTROL

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ABSTRACT

A highly stable constant current power supply to provide reproducible current control has been developed. Precise reproducibility is highly desirable for measurements such as thermal conductivity and electrical resistivity where it is necessary to provide known currents of varying magnitude and either polarity. A power supply which was built with two independent outputs and with current ranges of 0.1A to 2A and 0.3mA to 63mA has been operated successfully for several months.

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I. THEORY OF OPERATION

A constant current power supply provides through an output load, a d.c. current which is stable and constant independent of load resistance. In this power supply, constant current is maintained with an operational amplifier. The output load resistance is in series with the op. amp. output. In series between the output load and ground is a reference resistor. The input voltage of the op. amp. is held constant by an external power source and the feedback is referenced to the reference resistor. The op. amp. maintains constant voltage across the reference resistor, consequently the current through the reference resistor is constant. The output resistance is in series with the reference resistor, hence constant current will be maintained through the output load independent of the magnitude of the output resistance.

Figure 1 is a schematic of the current regulator. This power supply contains two independent current regulators. One is for the high current supply (0.1A to 2A) and the other is for the low current supply (0.3mA to 63mA). The op. amp. input voltage, V_i , is held constant by the Zener diode D1. The output current of the op. amp. is amplified and passes through the load resistor R_{load} , and through the reference resistors. When the selector switch is in position (j) the op. amp. holds voltage V_j constant. The reference resistance $R_r(j)$ and the feedback resistance $R_f(j)$ are determined by the switch position (j).

Fig. 1. Constant current regulator. The reference resistance and feedback resistance are varied by the selector switch. Note that the switch is in series with the load resistance in order to provide reproducible current control.

$$R_r(j) = \sum_{\ell=j}^n R_{\ell}$$

$$R_f(j) = \sum_{\ell=0}^{j-1} R_{\ell}$$

The current passing through the output resistor R_{load} for switch position (j) is

$$I_j = \frac{V_j}{R_r(j)} + I_o.$$

The feedback current I_o is

$$I_o = \frac{V_j - V_i}{R_f(j)}.$$

The voltage V_j maintained by the op. amp. is approximately

$$V_j = V_i \left[1 + \frac{R_f(j)}{R_i} \right].$$

The op. amp. input voltage V_i depends upon the choice of zener diode D_1 .

The voltage maintained by the Zener diode, V_z , is divided across resistors R'' and R'''

$$V_i = V_z \frac{R'''}{R'' + R'''}$$

Hence the current passing through R_{load} is

$$I_j = V_z \frac{R'''}{R'' + R'''} \left[\frac{1}{R_r(j)} + \frac{R_f(j)}{R_r(j)R_i} + \frac{1}{R_i} \right]$$

which is independent of the load resistance.

The output current will be constant and stable if the op. amp. and the resistors do not drift with time or temperature changes. All resistors in the current regulator stage of the power supply are wire wound with low dR/dT . The low current power supply has an Analog Devices AD260K non-inverting chopper stabilized op. amp. The high current supply has an AD260J. These op. amps. have less than $\pm 0.1 \mu V/^{\circ}C$ (AD260K) and $\pm 0.03 \mu V/^{\circ}C$ (AD260J) output drifts. The op. amps. and input and feedback resistors of both current regulators are mounted in a copper oven which is held at $40^{\circ}C$ by a temperature controller. The oven eliminates day to day temperature variations of the critical components. All solder connections of input, feedback and reference resistors are made with low thermal cadmium solder.

The power supply is designed in such a way that the contact resistance of the rotary switch does not affect the feedback resistance. This feature is important for reproducible current control. If the feedback is designed in series with the rotary switch, it would not be possible to reproduce feedback resistance due to the contact resistance of the rotary switch. In addition any thermal EMF's generated at the switch contacts will not affect the current regulation since the switch is in series with the output resistance.

The Zener diode D1 was chosen to compensate any drifts in the power supply circuitry due to temperature changes.¹ All critical components in the low current supply were mounted in the oven; hence the choice of

¹Kroeger, F. R. and Rhinehart, W. A., Rev. Sci. Inst., 42, 1532 (1971).

diode for this supply was non-critical. Eight 6.2V 1N3496 diodes were placed in an environmental oven and their I-V characteristics were measured as a function of temperature. A diode was chosen for the low current supply which had $(dV/dT)/V = 0$ at $I = 5 \text{ mA}$. This diode was potted in the oven in thermal contact with the resistors of the low current supply. It was necessary however, to compensate the high current power supply for changes in temperature. The currents passing through the reference resistors in the high current supply are large and high power dissipation develops. The power dissipation was reduced by choosing small reference resistances. However the voltage drop across the resistors decreased accordingly. Since, in the non-inverting configuration the op. amp. gain must equal or exceed 1, it was necessary to choose reference resistors near 1Ω in order to keep the op. amp. input voltage reasonably large. The reference resistors were hand wound of manganin wire and were mounted in a copper heat sink which was at room temperature. They were mounted outside the oven because of the large power dissipation (near 1W) that is generated in them when the high current supply is turned on. The temperature coefficient of the resistors, $(dR/dT)/R$ was $50 \text{ ppm}/^{\circ}\text{C}$. The best diode found for temperature compensation was one with $(dV/dT)/V = 39 \text{ ppm}/^{\circ}\text{C}$ at $I = 5 \text{ mA}$. This diode was potted in thermal contact with the high current resistors.

II. CIRCUIT DESCRIPTION

The power supply contains eight circuits which are located on four plug-in boards and one board located in the oven. The circuits are the

high and low current regulators, two circuits which provide over-load protection and current polarity control, an oven temperature controller and three d.c. power supplies. The op. amps. are powered by a ± 15 V power supply, the digital logic is powered by a +5 V power supply, and the oven heater and high and low current outputs are powered by a + 12 V power supply. Figure 2 is a schematic of the circuit board locations in the chasses and Fig. 3 is a block diagram of the power supply.

The ± 15 V power supply was designed by Wayne Rhinehart at Ames Laboratory and has been used successfully for many applications.

The + 5 V and + 12 V power supplies are mounted on board 2, Fig. 4. Voltage regulation is maintained with two 741 op. amps. whose input voltages are fixed with two voltage dividers. The current for this supply is from a transformer separate from the transformer for the ± 15 V supply.

The oven temperature regulator shown in Fig. 5 is also mounted on board 2. It maintains the temperature of the oven at 40°C by comparing the voltage drop across a thermistor mounted in the oven with respect to the voltage drop across the resistor R1. When the bridge is unbalanced, op. amp. 1 amplifies the signal and drives op. amps. 2 and 3. If the oven is too cold the thermistor's resistance is greater than R1 causing op. amp. 1 to go positive. Integrator op. amp. 2 senses the positive voltage of op. amp. 1 and swings negative with a time constant determined by R2 and C1. The negative voltage of op. amp. 2 and the positive voltage of op. amp. 1 drive op. amp. 3 positive. The output current of op. amp. 3 is amplified by transistors Q1 and Q2 to provide

Fig. 2. Constant current power supply chassis.

Fig. 5. Oven temperature controller. Transistor 2N3055 is mounted in a heat sink in the rear of the chassis. The thermistor is potted in the oven in thermal contact with the 40 Ω heater.

current for the oven heater.

Proportional temperature control is achieved in this controller by op. amp. 3. Op. amp. 2 increases or decreases the heater current, with time constant $1/R_2C_1$, depending upon the output polarity of op. amp. 1. Thus op. amp. 2 causes the oven temperature to oscillate about 40°C . Op. amp. 3 damps the oscillations by amplifying the difference between the outputs of op. amps. 1 and 2. Thus as the oven temperature approaches 40°C op. amp. 3 varies the heater current proportional to the difference in resistance between the thermistor and R_1 . When thermal equilibrium has been established, op. amp. 2 maintains the oven at constant temperature.

The high current regulator shown in Fig. 6 is located on board 5; the low current regulator shown in Fig. 7 is located on board 4. Figure 8 is a schematic of the current polarity switching circuit of each regulator. Two such circuits are needed. The switching circuit prevents overload saturation of the op. amps. AD260 and provides a convenient means for reversing the current polarity from a remote station. Since the power supply operates in a constant current mode, the op. amps. would saturate whenever the output is open circuited or if the output load resistance becomes too large. This condition would result in unregulated output current which might not be detected by the operator if overload protection were not present. Also, saturation might cause permanent damage to the op. amps.

The output current of the supply passes through two 24 V relays as shown in Fig. 8. When relay 1 is off, the output is open circuited

Fig. 6. High current regulator. The reference resistors are potted in a heat sink outside the oven. Diode IN3496 is potted in thermal contact with the reference resistors and is chosen to compensate thermal drifts of the reference resistors. Transistor 2N3055 is mounted in a heat sink in the rear of the chasses. Current leads B and C are continued in Fig. 8.

Fig. 8. Current polarity control and overload protection. Two such circuits are needed and are mounted on boards 4 and 5.

and no current passes through the load resistance. Relay 1 can be turned on only if the comparator output (CMP 01C, Figs. 6 and 7) is "0". CMP 01C is "0" only when the output of op. amp. AD260 is less than 14 V. Capacitor C1 and resistor R1 in Fig. 8 delay the switching of relay 1. The delay is necessary since the current polarity switching relay, relay 2, is non-shorting.

III. OPERATION

The panel face contains controls for regulating the magnitude and polarity of the output current. The current controls for each supply consist of a rotary switch for current magnitude selection, a toggle switch for "calibrated" or "uncalibrated" current regulation, a 1 turn potentiometer for current regulation in the "uncalibrated" mode, a ten turn potentiometer op. amp. trim, and three push button switches for current polarity selection: "Forward," "off" and "reverse." When the toggle switch is in the "calibrated" position the rotary switch controls the current magnitude, and reproducible currents are supplied. When the toggle switch is in the "uncalibrated" position the one turn potentiometer is used to adjust the current magnitude.

When the power supply has been turned on for sufficient time to allow the oven to reach thermal equilibrium the supply is ready for use. The output loads are installed in the rear of the chassis. To produce currents of desired polarity one presses either "forward" or "reverse." The "off" switch open circuits the output load. The three LED's on the panel face indicate the current polarity. The current magnitude and polarity may be changed as desired.

The rear of the chassis has five Amphenol plugs as shown in Fig. 9. The three plugs to the left are the current outputs. The two two-pin plugs are wired in parallel with the appropriate leads of the four-pin plugs. The seven pin plug is for remote control of current polarity. The four pin plug to the right is an output of the ± 15 V power supply, + 26 V and ground. This plug may be used to power an additional power supply such as a germanium thermometer supply. Considerable caution should be exercised when using this output since ground loops and overloading of the ± 15 V power supply may develop.

IV. REPRODUCIBILITY

The low current power supply is more stable and reproducible than the high current power supply owing to the better quality of op. amp. AD260K compared to AD260J and to the location of the current reference resistors in the oven. Both supplies are reproducible to better than 0.02%.

The power supply has been used for several months for measurements of electrical resistivity and thermal conductivity. The high current supply provided current for electrical resistivity measurements and the low current supply provided current for gradient heater power in thermal conductivity measurements. The currents were measured with a Leeds and Northrup K-3 potentiometer which measured the voltage drop across a standard resistor in series with the output load. The resistivity and thermal conductivity data were taken in separate runs. Each run lasted an average of one week. During a run the currents were changed many times

Fig. 9. Current output plugs, polarity control plug and power supply output plug.

4 Pin Current	7 Pin Polarity Switching	4 Pin Power Supply
#1 & #2 High Current	A Low Forward	1 + 26 V
#3 & #4 Low Current	B Low Off	2 Ground
	C Low Reverse	3 + 15 V
	D High Reverse	4 - 15 V
	E High Off	
	F High Forward	
	G Ground	

each day, and the currents were measured at random time intervals during the day. Figure 10 is a plot of the average daily relative deviations of the currents from the seven month average for the low current supply and Fig. 11 is a similar plot for the high current supply.

The high current supply drifted slightly during daily use when the currents were left on for several hours. The drift was typically less than 0.02% per day.

The low current supply short term drift was typically not noticeable (to five places) on a daily basis. As seen in Fig. 10, however, this current supply has a long term drift towards higher currents.

Fig. 10. Relative average daily deviations of current from seven month mean of low current supply. The supply shows a long term drift toward higher currents.

Fig. 11. Relative average daily deviation of current from seven month mean of high current supply. This power supply is reproducible to $\pm 0.02\%$.