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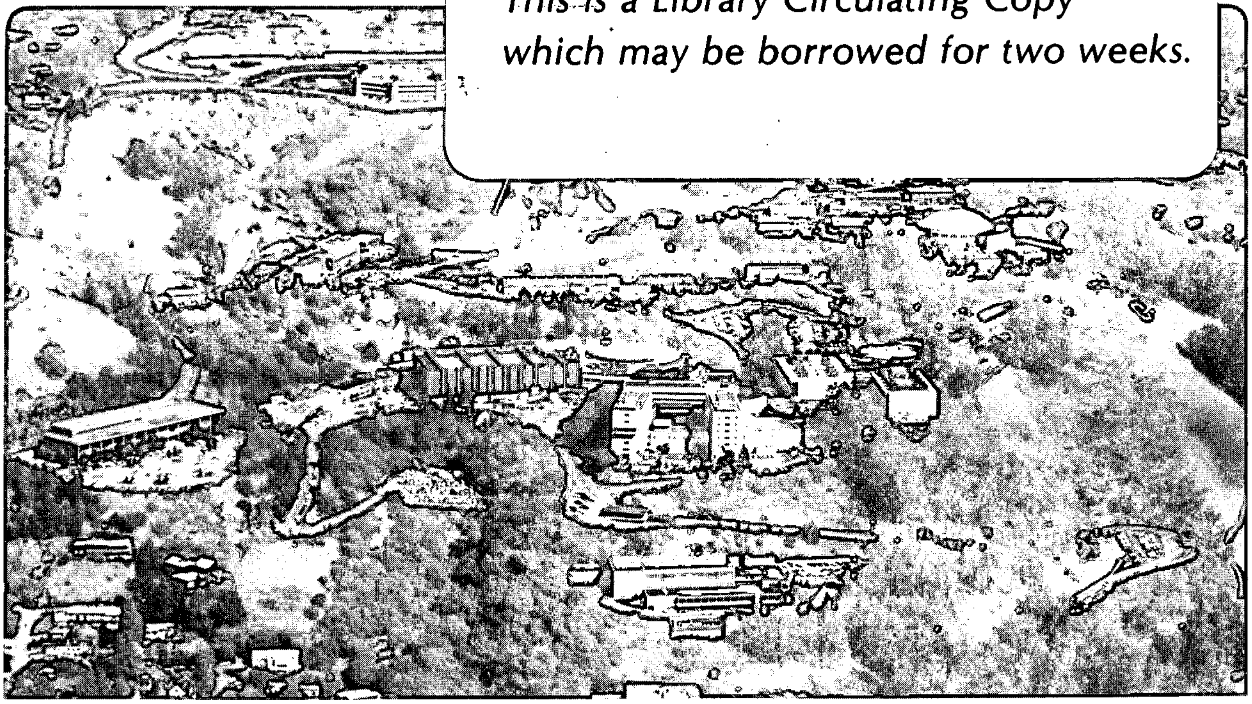
November 1988



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A VARIABLE TEMPERATURE CRYOSTAT THAT PRODUCES IN SITU CLEAN-UP OF GERMANIUM DETECTOR SURFACES

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ABSTRACT

Variable temperature cryostats that can maintain germanium detectors at temperatures from 82 K to about 400 K while the thermal shield surrounding the detectors remains much colder when the detectors are warmed have been developed. Cryostats such as these offer the possibility of cryopumping material from the surface of detectors to the colder thermal shield. The diode characteristics of several detectors have shown very significant improvement following thermal cycles up to about 150 K in these cryostats. Important applications for cryostats having this attribute are many.

CRYOSTAT DESIGN

This paper describes some important benefits of a design of the variable temperature cryostat design that we developed for an extensive study of radiation damage of germanium detectors. These cryostats had to satisfy the twin thermal requirements of being able to maintain detectors at a temperature only slightly warmer than the liquid nitrogen coolant, while also providing sufficient thermal impedance between the cold finger and the detectors to allow the detectors to be warmed over a wide temperature range by a reasonably small power input to a heater element attached to the detector mount.

In modern high resolution X- and gamma-ray spectrometers, germanium detectors are normally enclosed within metallic containers whose temperature is maintained at essentially the same temperature as the detectors. This thermal shield prevents the infrared radiation emitted by the inner wall of the vacuum enclosure, which is at room temperature, from impinging on the germanium detectors and thereby increasing their leakage current.

In our variable temperature cryostats, the thermal shield is attached to the cold finger side of the thermal impedance, as shown in Fig. 1. The twin thermal requirements were satisfied by this design; in fact, the temperature range far exceeded the original goal. These cryostats can maintain detector temperatures anywhere from 82 K to about 400 K (detectors have actually been operated at temperatures as low as 73 K by pumping on the liquid nitrogen) while the cold finger is still in liquid nitrogen. This is achieved by varying the power in either one or two stud-mounted 10 W Zener diodes attached to the detector mount as shown in Fig. 1. The thermometry employed is described in Appendix I; the controller used to power the Zener diodes and regulate the temperature of the detectors is described in Appendix II.

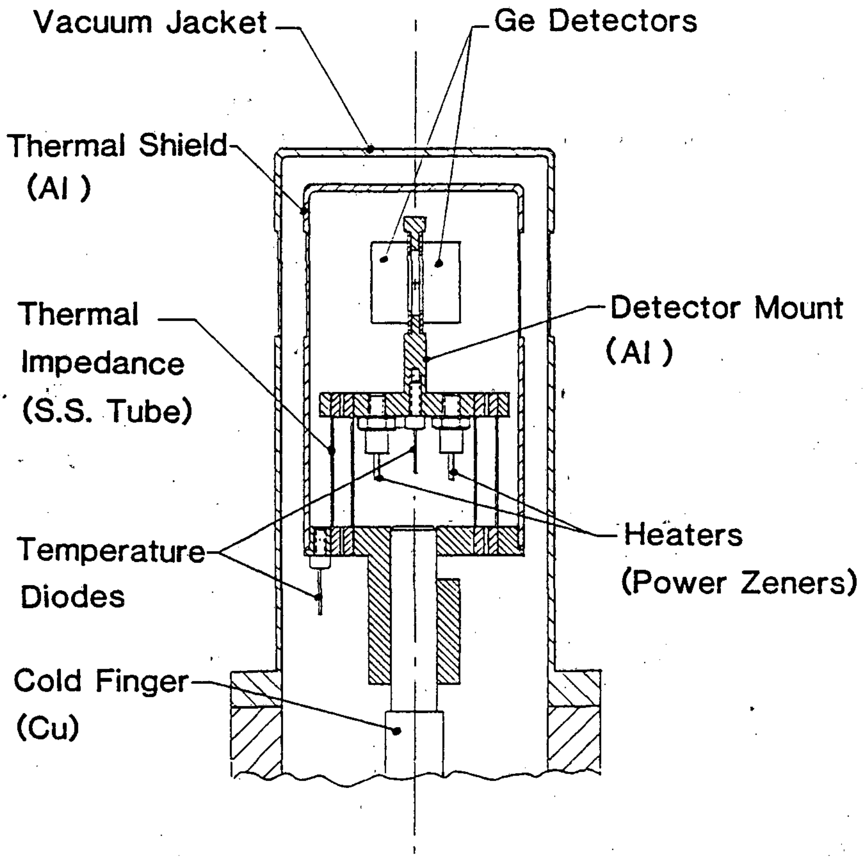

FIG. 1

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Fig. 1 Cross-sectional view of the variable temperature cryostat.

These particular 100 V (at room temperature) Zener diodes were chosen as the heating elements for several reasons. A high voltage, low current heating element is desirable because it is important to be able to minimize the conductive heat load of the wire. We used small diameter (0.011") stainless steel wires. Zener diodes, in the 10 W stud package, have the silicon chip eutecticly bonded to a copper stud which provides good thermal coupling of the heating element to the detector mount. In addition, when operated in the forward-biased mode, a Zener diode can be used to measure temperature, providing what has proven to be a very important back-up temperature sensor.

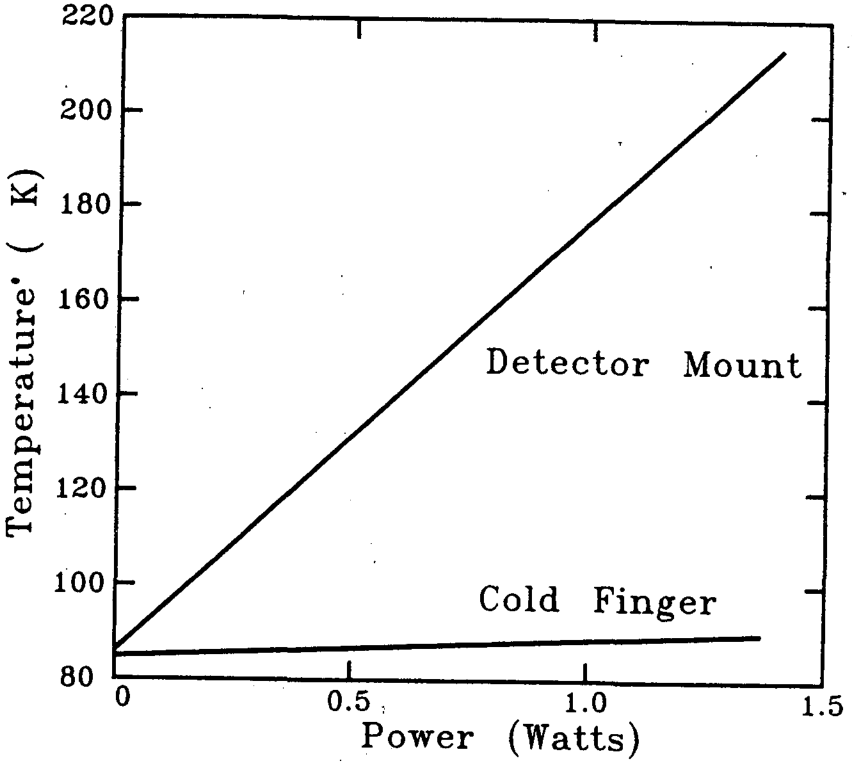

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Fig. 2 Temperatures of the detector mount and cold finger measured as a function of power dissipated in the Zener diodes. At equilibrium, the detectors are at essentially the same temperature as the detector mount while we assume the thermal shield is only marginally warmer that the cold finger.

ADDITIONAL BENEFITS OF THIS DESIGN

Since there is a large thermal impedance between the thermal shield and the Zener diodes the thermal shield remains relatively unaffected by the power dissipated in the Zener diodes when the detectors are warmed. Consequently, when the detectors are warmed they are surrounded by a surface that is significantly colder than they are. This results in the possibility of cryopumping material from the surface of the detector to the colder thermal shield. The temperatures of the detector mount and cold finger measured as a function of power in the Zener diodes are presented in Fig. 2. Essentially identical temperature relationships exist in all four cryostats used in this study. At equilibrium, the detectors are at the same temperature as the detector mount while we assume the thermal shield is only marginally warmer than the cold finger.

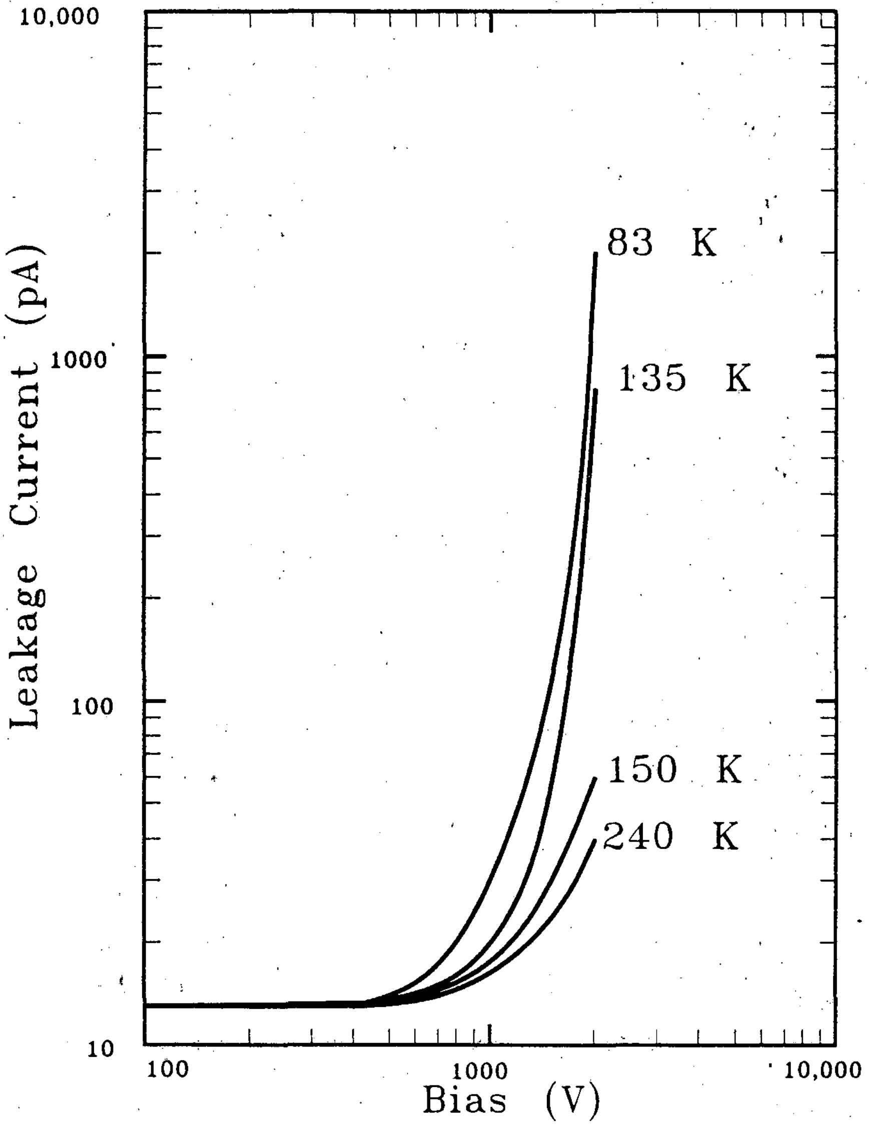

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Fig. 3 Leakage current as a function of reverse bias following a series of thermal cycles to ever increasing temperature. All measurements made when the detector is at 83 K.

The diode characteristics of several detectors have shown significant improvement following thermal cycles up to about 150 K and marginal additional improvement following thermal cycles up to about 240 K. An example of these improvements in the diode characteristics is shown in Fig. 3. These improvements were sufficient to change detectors that were essentially non-operational into quite acceptable devices. Furthermore, all these detectors continued to exhibit their improved diode characteristics following additional thermal cycles of widely varying periods at various temperatures up to 400 K.

These observations were made during the course of an extensive ongoing study of radiation damage of germanium detectors; there has been no systematic study devoted to using these variable temperature cryostats for in situ cleanup of germanium detector surfaces. However, it is very likely that the same benefit would accrue in all systems.

Important applications for cryostats that can maintain detectors at a warmer temperature than the surface surrounding them are many. For example, germanium spectrometers that have been radiation damaged could be annealed in place instead of being removed from their overall system and attached to an auxiliary vacuum pump. This scheme would also allow higher annealing temperatures than many cryostats allow because the plastic components that often limit the annealing temperature would not be warmed significantly. The only cost is a relatively minor additional use of liquid nitrogen.

In a similar vein, to diminish the chance of surface contamination during the cool-down part of any thermal cycle the detector can always be maintained at a significantly higher temperature than its surroundings. Likewise, but more importantly, during the warm-up part of any thermal cycle the detector can be maintained at a higher temperature than its surroundings; in normal germanium detector cryostats, unfortunately, the detector is the last component to warm.

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At LBL, Paul Luke fabricated the germanium detectors; Martin Pollard assisted with the thermal measurements; Fred Goulding provided continuing support. At IUCF, Kevin Komisarcik maintained the germanium detector systems.

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APPENDIX I

Thermometry

Since 1978, the LBL Semiconductor Spectrometer Group has used the fact that the voltage drop of forward-biased silicon diodes is dependent on temperature (at constant current) to monitor temperatures within cryostats. The voltage-temperature relationship of about 2.2 mV/deg is nearly linear over the temperature range of interest from 70 K to 425 K. The sensitivity of copper-constantan thermocouples, commonly used for low temperature thermometry, is about 130 times less around 80 K, i.e., about 0.016 mV/deg. We have used "temperature diodes" in two forms, switching diodes such as 1N4447 and the emitter base diode of metal canned transistors. Thermal coupling is accomplished more easily with the metal can transistors but they have the drawback of requiring more space.

All temperature diodes are calibrated before installation. Calibration is a relatively simple procedure. While operated with a constant current of 300 μA the voltage drop of each diode is measured when sequentially immersed in liquid nitrogen, water at the ice point and boiling water. Diodes carefully calibrated in this manner can achieve an accuracy of about ± 1 K from 70 K to 425 K. The major source of error in using temperature diodes is heat flowing into the diode via conduction. To diminish this problem small cross sectional area wires of low thermal conductivity metals such as stainless steel and manganin are used.

Although a few of our temperature diodes have failed, others continue to function after several hundred thermal cycles. Recognition that temperature diodes occasionally fail has prompted us to employ the power Zener diodes (used as heaters) as back-up temperature sensors. The Zener diodes are calibrated in the same manner as the other temperature diodes.

APPENDIX II

Detector Temperature Controller

Figure 4 shows a block diagram of the temperature controller unit. It consists of five main circuits:

1) temperature sensing
2) metering
3) demand temperature
4) heater controller
5) protection circuits

1) The temperature is sensed by measuring the voltage drop of a forward-biased diode operated with constant current (300 μA). The block diagram shows two temperature sensing diodes. Diode D2 is on the cold finger and diode D1 is on the detector mount.

2) The meter circuit contains an LCD display digital voltmeter (DVM) that can be switched to read the different diode voltages. Two 300 μA current sources are used. One is permanently connected to diode D1 as this diode is used in the temperature control circuit. The other current source is switched by the meter switch to other diodes being measured. A buffered recorder output of the diode voltage is also provided.

3) The demand temperature is set by a multiturn dial accurately calibrated so that the dial setting of 300 to 1300 equals 300 to 1300 mV. This voltage is subtracted from the voltage of diode D1 and is used in the heater control circuit.

4) The heater control is a proportional controller that controls the power in Zener diode Z1 on the detector mount. A second Zener diode Z2 can be manually switched on if additional power is required. The current to the 100 V (at room temperature) Zener diodes is limited to ≈30 mA to protect the small wires in the cryostat. A portion of the current flows through front mounted LEDs as an indicator of current flow.

5) The protection circuit turns off the heater voltage supply if the detector mount temperature exceeds a maximum value set by the operator, or if diode D1 should open or short. The control setting of the maximum temperature uses a front panel-mounted trimpot adjustable from 300 to 1300 mV. This voltage can be read at one position of the meter switch. Comparator A senses excess temperature or a shorted diode while Comparator B senses an open circuit diode. The comparators trigger a bistable circuit that drives a relay which turns off the heater power and lights a trouble lamp. The operator must turn the power supply off and on again to reset the bistable circuit.

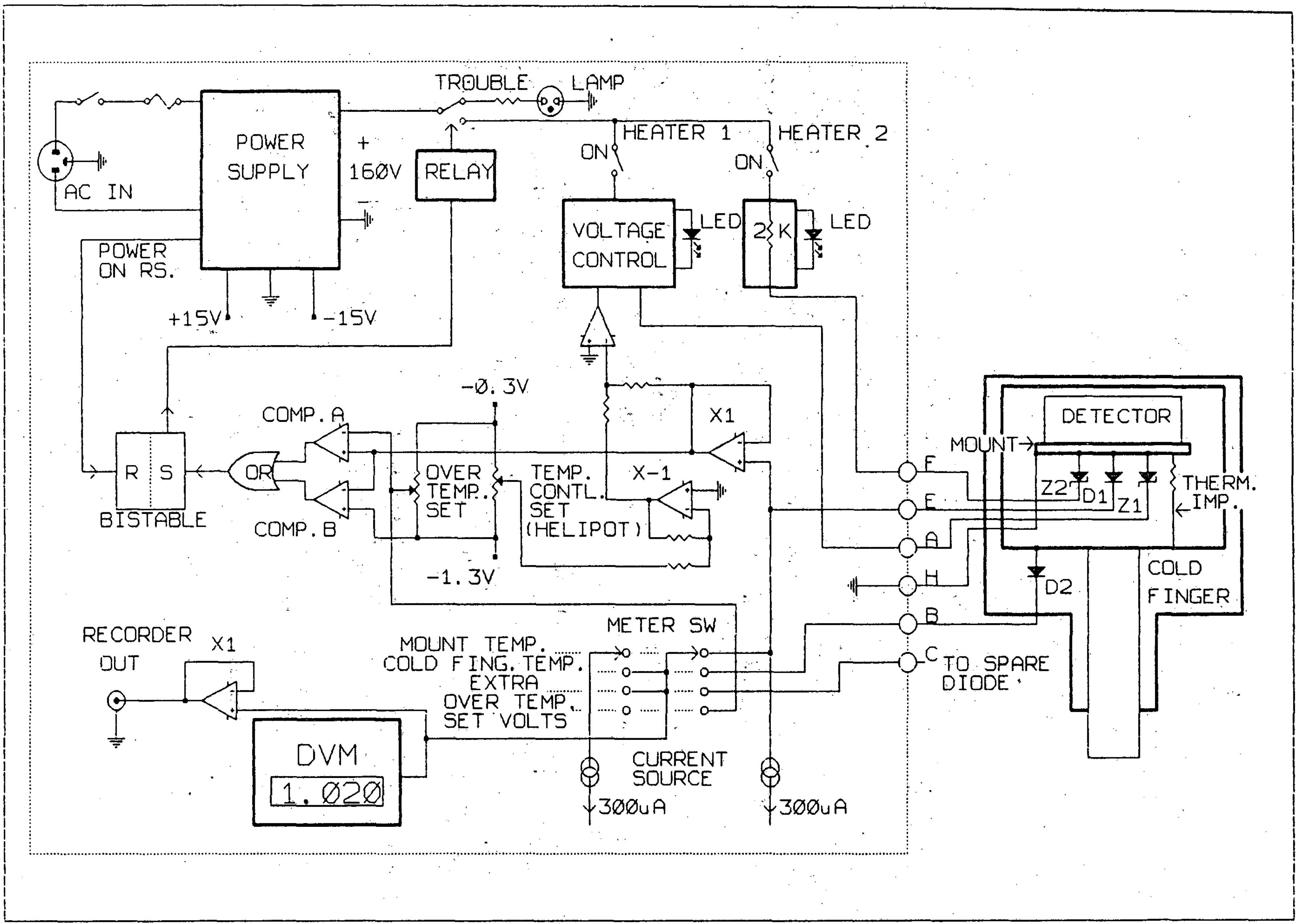

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Fig. 4 Block diagram of the detector temperature controller.