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Green Bank, West Virginia

Electronics Division Internal Report No. 81

FRONT-END BOX TEMPERATURE CONTROLLER

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1.0 Summary

This report describes a temperature control system for the standard front-end boxes in use at the Observatory. The system will maintain the front-end box to within ± 0.2 °C of a preset temperature regardless of outside temperature variations. Full constructional and alignment details are given.

2.0 Introduction

The system described uses thermo-electric heat pumps (for specifications see Figure 1) which heat or cool the interior of the box in order to keep it at a constant temperature. A thermistor inside the box is used to generate an error signal to a power amplifier supplying the control current to the thermo-electric heat pumps.

There are many alternatives to be considered in the realization of this essentially simple system. Nearly all of them concern the power amplifier. The resistance of the heat pumps, together with telescope cabling, is about 1 ohm. The current required is about 30 amps maximum. Three alternatives were considered:

1) A linear transistor amplifier.
2) A zero switching SCR amplifier.
3) A conventional SCR amplifier.

A controller using a linear transistor amplifier was built and worked well, but because of the power dissipation and the necessity of operating transistors in parallel it was decided that a neater design would be possible using SCR's.

The main objection against using SCR's is the risk of generating radio interference. Zero switching is one possible technique but in this design would prove rather a limitation. The other technique is the obvious one of careful screening and filtering. This proved a practical method and, in spite of many dire predictions, radio interference has not proved a problem.

3.0 Principles of Operation

3.1 General Principle

The general principle of operation is made clear in Figure 2. A thermistor bridge circuit senses the box temperature and generates an error signal centered around the desired box temperature. The sign of the error signal determines the direction of the control current output of the power amplifier and hence whether the heat pumps heat or cool the box.

At first sight the system has the appearance of a simple linear servo loop. In actual fact this is not so: the rather peculiar properties of the heat pumps when considered in conjunction with usual problems of heat flow result in a system that is not readily amenable to mathematical analysis. Practical work showed that it was possible to use a system gain sufficient to give a maximum error of ± 0.1 °C and still maintain a reasonable transient response. This being the case, it was decided to dispense with elegant mathematics and concentrate on building a practical system.

3.2 Circuit Details

3.2.1 Thermistor Bridge

The complete circuit diagram is shown in Figure 3. The temperature sensing circuit is a standard type of bridge circuit. VR1 is a front panel mounted ten turn potentiometer calibrated from 20 °C - 30 °C. When used with the thermistor GB34P122 (Fenwall Electronics), the calibration will be accurate to within ± 1/2 °C with any thermistor and any temperature increment will be accurate to within ± 5%. VR2 is used for the initial setting up of the thermistor bridge. M2 reads the temperature error (the difference between the temperature set on VR1 and the thermistor temperature) with either 1 °C full scale or 10 °C full scale.

Sixty Hz pick-up proved a problem on the prototype unit and C7 and C8 provide low pass filtering to alleviate this problem. The parallel T filter following amplifier A1 provides additional rejection at 60 Hz. The phase shift introduced by the low pass filter and the parallel T filter are not important at the very low frequencies that are significant in the overall servo system.

The sensitivity of the output of amplifier A1 is approximately 0.8 V/°C of error. Amplifier A3 provides additional amplification, R33 providing a convenient point for changing the gain of the system.

3.2.2 SCR Firing Circuitry

The power amplifier uses a full wave center tapped configuration. For positive voltages on the load, SCR-1 and SCR-3 fire — for negative voltages SCR-2 and SCR-4. Transformer T3 is associated with SCR's 1 and 3 and transformer T2 with SCR's 2 and 4. For no error signal the following conditions apply. Q13 and Q14 turn on for a short time at the beginning of each line half cycle, thus discharging capacitors C15 and C16. Considering just capacitor C15 for a moment: after being discharged by Q14 it starts to charge with a current consisting of the difference between that supplied by Q2 and that drained away by Q4. For zero error the capacitor does not reach the firing point of Q1 before the next discharge pulse arrives from Q14. A similar argument applies to C16 so neither T2 or T3 supply firing pulses to the SCR's.

Now consider the case of a positive error signal. Q6, Q8, and Q9 turn on thereby diverting more current from C16 so Q11 still does not fire. However, less current is diverted from C15 due to differential amplifier action so Q1 will fire, the firing point depending on the size of the error signal. It will be noted that C15 and Q1 form a relaxation oscillator so that for significant errors more than one pulse will be produced in one half cycle. The first pulse turns the SCR on; the others are of no significance. A similar argument applies to the negative error signal case which results in SCR's 1 and 3 firing. The waveforms in Figure 4 should make the circuit operation clear.

A highly undesirable condition is that spurious pulses may turn on, say, SCR's 1 and 4 together, thereby shorting the transformer.

The prototype unit included low-value resistors in the transformer leads to minimize the magnitude of this disaster. Subsequent tests, however, have shown that this problem does not exist, so these resistors have been omitted from the design.

3.2.3 Current Limiter

When the unit is initially switched on, large error signals may give rise to excess current, particularly when the controller is being used with short leads in the laboratory. To limit the current by switching the unit off, via a circuit breaker, is not a good solution as all heating (or cooling) action is lost. In view of this it was decided to incorporate a current limiter in the design. The current is sensed as a voltage developed across the 30-0-30 amp meter, smoothed and amplified by amplifier A4. When the current reaches a certain value, the threshold detector (A4 and associated components) gives an output. This output is fed into the summing junction of A3, the polarity being such as to oppose the error signal causing the current. This secondary servo loop has a high gain and effectively limits the current to positive and negative limits that may be set by VR-3 and VR-4. A fast loop is not needed, and to make the loop stable a large lag in the form of C12 and C13 was added. A contact breaker insures against damage in the event of an accidental short circuit.

4.0 Mechanical Construction

The mechanical construction of the unit is clear from the photographs in Figure 5. A fairly robust construction has been used, particular care being taken to make the box "RF tight". Every lead into the box is RF filtered.

The size of the unit is 19" x 19" x 5 1/4" and the weight is 40 pounds.

The two items requiring cooling are the SCR's and the transformer. The SCR's are mounted in front of the rear mounted extraction fan, the air inlet being directly over the transformer. Printed circuit details are shown in Figure 6.

5.0 Operation of Unit

The unit has been designed to be fully protected under all operating conditions but the following procedure has been found to be the best when connecting up the controller.

Assuming the thermistor and heat pumps to be connected, the "Power" breaker should be turned on and the "Temperature Error" meter zeroed using the "Temperature Set" control. The "Load" breaker should then be closed and a slight error introduced, sufficient to give 20 amps control current. If the error falls after a short time, the heat pumps are correctly connected; if it increases, the heat pumps should be reversed. After this initial check the "Temperature Set" control may be set to the desired box temperature and the unit left.

6.0 System Tests

The prototype unit has been subjected to extensive tests. RFI tests were carried out using an HRO communications receiver. As expected, with the lid removed, RFI was observed; with the lid closed, no interference was detectable.

Operational tests have included many weeks of continuous operation at the Little Big Horn and one week at the 140-foot.

Temperature error was monitored and the day-to-night variations did not exceed ± 0.1 °C.

7.0 Alignment Instructions

7.1 General

Before switching the unit on, the following steps should be made:

a) Remove printed circuit from main frame.

b) Disconnect SCR gates by removing lugs 9-16 on terminal strip. (Make sure the loose leads cannot short during the tests.)

c) Remove one end of resistor R32. This disables the current limiter.

d) Connect the thermistor input to a decade resistance box.

e) Supply the line to the unit via a variac equipped with a current meter.

7.2 Adjustment of Temperature Sensing Circuits

a) Set decade resistance box to 3.65 K ohm and "Temperature Set" control to 25 °C.

b) Turn on the unit, leaving the "Load" breaker open.

c) Zero the "Temperature Error" meter by adjusting VR-2.

d) Check that when the "Temperature Set" control is moved to 26 °C the "Temperature Error" meter reads 1 degree "cold".

7.3 Adjustment of Firing Circuits

For these tests use a dual beam scope with triggering set to "Line". Before starting the adjustments make sure that VR-5 is set to approximately mid-range and VR-6 is turned fully clockwise.

a) Connect scope probes to the primary of T2 and T3 with scope ground connected to chassis.

b) With the "Temperature Error" meter reading zero, adjust VR-6 until a pulse is observed on either beam. (A suitable scope sensitivity is 1 V/cm and 2 ms/cm.) Now change the "Temperature Error" meter either side of zero by using the "Temperature Set" control. The pulse train should appear on one beam or the other in accordance with the sign of the error signal. Figure 7 should make this clear. VR-5 and VR-6 should be adjusted so that a "dead zone" of about 0.1 °C (± 0.05 °C) is established symmetrically about zero temperature error.

c) Connect the SCR gates by reconnecting lugs 9-16 on the terminal strip.

d) Connect a 1 ohm, 1 KW load to the output terminals, turn unit on, adjust "Temperature Error" to zero, and close "Load" breaker.

e) Check that when the "Temperature Error" reads "hot" the "Control Current" reads "cooling".

f) Check that the voltage across the load is about 30 volts for 25 amps control current.

g) Check that the line current never exceeds 10 amps.

7.4 Adjustment of the Current Limiting Circuits

a) Turn pots VR-3 and VR-4 fully clockwise.

b) Connect the scope to the output of amplifier A4. A suitable scale is 0.5 V DC/cm.

c) Connect the output of the unit to a 0.5 ohm, 1 KW resistor and set the current to 28 amps heating.

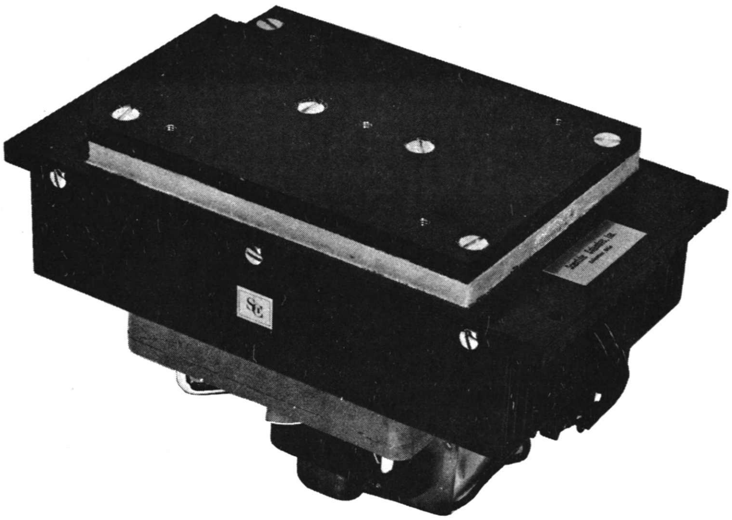
d) Adjust VR-4 until the output of the amplifier just starts to go positive.

e) Change to 28 amps cooling and adjust VR-3 until the amplifier output just starts to go negative.

f) Reconnect resistor R32.

THERMOELECTRIC COOLING PACKAGES ○○○○

SELF CONTAINED REFRIGERATION SYSTEMS FOR COMMERCIAL, INDUSTRIAL AND AREO-SPACE APPLICATIONS



* COMPACT
* RUGGED
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* MANY PERFORMANCE LEVELS IN ONE PACKAGE
* EASY INSTALLATION

FEATURES

The TCP-6 series incorporates three performance and operating levels into the same physical package in order to provide flexibility for the original equipment manufacturer. The design utilizes the latest technology in engineering and production of thermoelectric devices. These compact, rugged, self-contained refrigeration systems exhibit reliability unheard of in mechanical refrigeration systems. The package may be mounted in any position and is virtually unaffected by physical shock and vibration.

A FEW APPLICATIONS TO PRODUCTS

* Marine Refrigeration
* Water Coolers for Railway locomotives
* Process Instrumentation
* Home Beverage Dispensers
* Parametric Amplifier temperature control
* Constant Temperature baths
* Instrument and component cooling
* Portable water coolers
* Laboratory instruments (such as osmometers, freeze dryers, etc.)
* Constant temperature chambers

SPECIFICATIONS

MODEL	NOMINAL DC INPUT CURRENT	TERMINAL VOLTAGE	MAXIMUM AMBIENT TEMPERATURE	MAXIMUM HEAT PUMPED ($\Delta T=0; T_a=30°C$)
TCP-6-25F	20 A	6.0 v	100°C	75 watts
TCP-6-30F	30 A	4.8 v	100°C	100 watts
TCP-6-40F	40 A	6.0 v	100°C	150 watts

Heat Exchanger fan power (all models) 115 v, 60 cps, 15 watts

Finish (all models) - black anodized aluminum - cold plate insulated from package to 500 volts

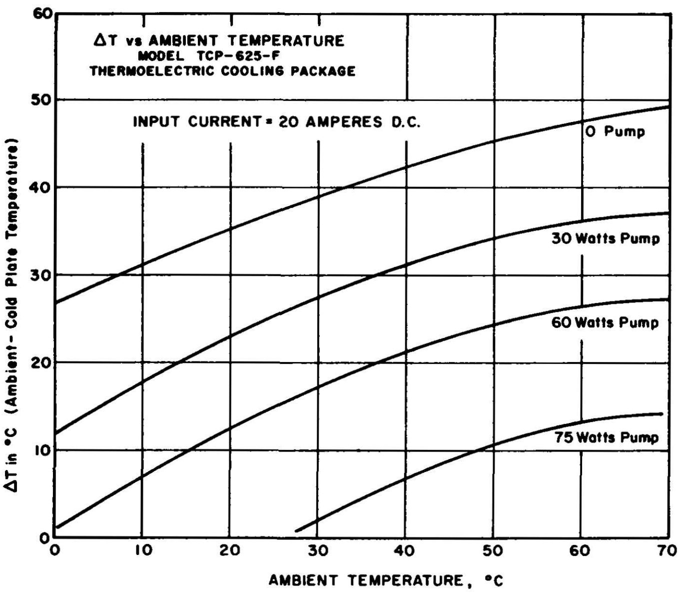
DC power source (not supplied) must have less than 10% ripple for maximum performance.

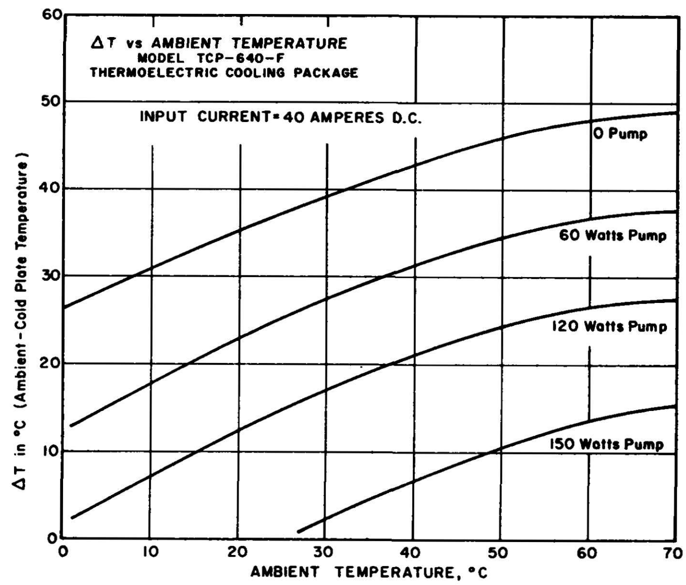
HEAT PUMP SPECIFICATIONS

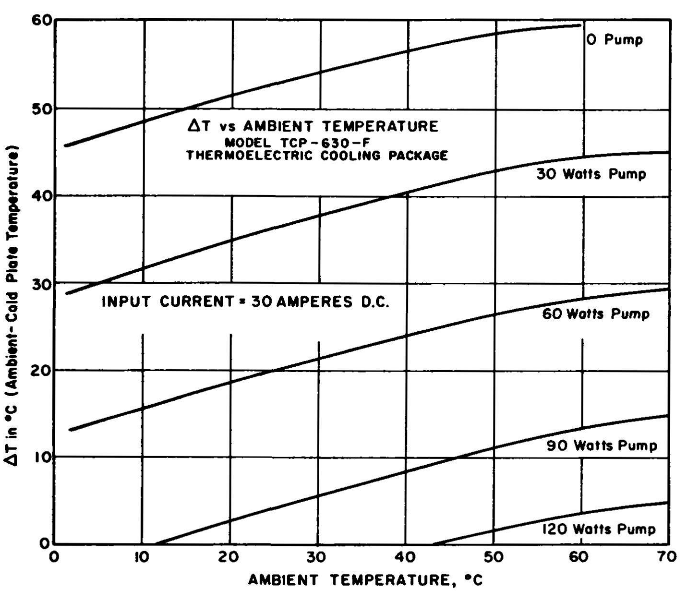
FIGURE 1

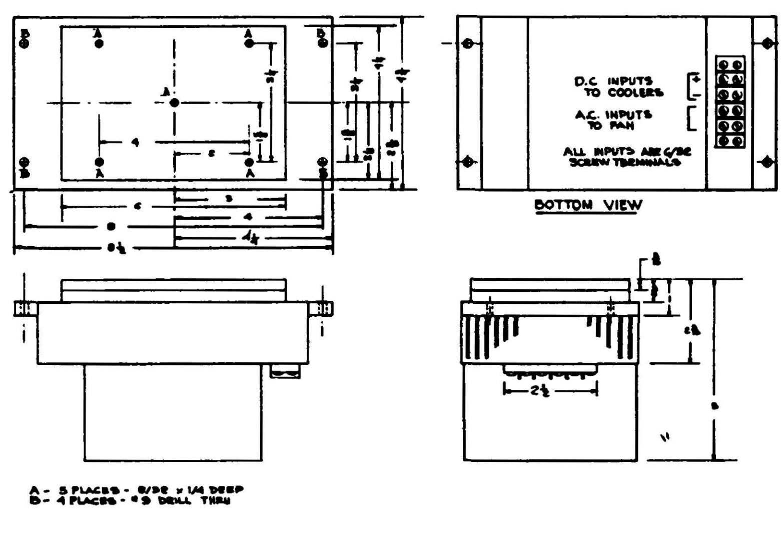
PERFORMANCE CURVES

A performance curve is presented for each model cooling package. These curves can be used in the following manner to establish the model and the number of units needed to accomplish a specific application. Select the maximum ambient temperature in which the unit will be required to operate. Find that temperature on the horizontal coordinate of the graph and draw a vertical line from that point. Determine the "cold" temperature desired and algebraically subtract from the ambient temperature selected. The result is the temperature difference (▲T) which the cooling package must attain for your application. Find this ▲T on the vertical coordinate of the graph and draw a horizontal line from this point. The two lines drawn will intersect at some point. The quantity of heat which can be pumped while maintaining the ▲T selected will be indicated by the point of intersection. Several load curves (heat pumped) are shown on each graph for easy interpolation. Fit the conditions selected to each of the three curves. Now determine the heat quantity which you must remove from the object to be cooled in order to lower its temperature to the "cold" temperature selected. Select the model which will at least meet or exceed this quantity. If none of the curves indicate the heat pumping capacity which you have selected then more than one package will be required. Divide the heat quantity selected by the heat pumping capability indicated on the curve. The result is the number of units needed for your application.







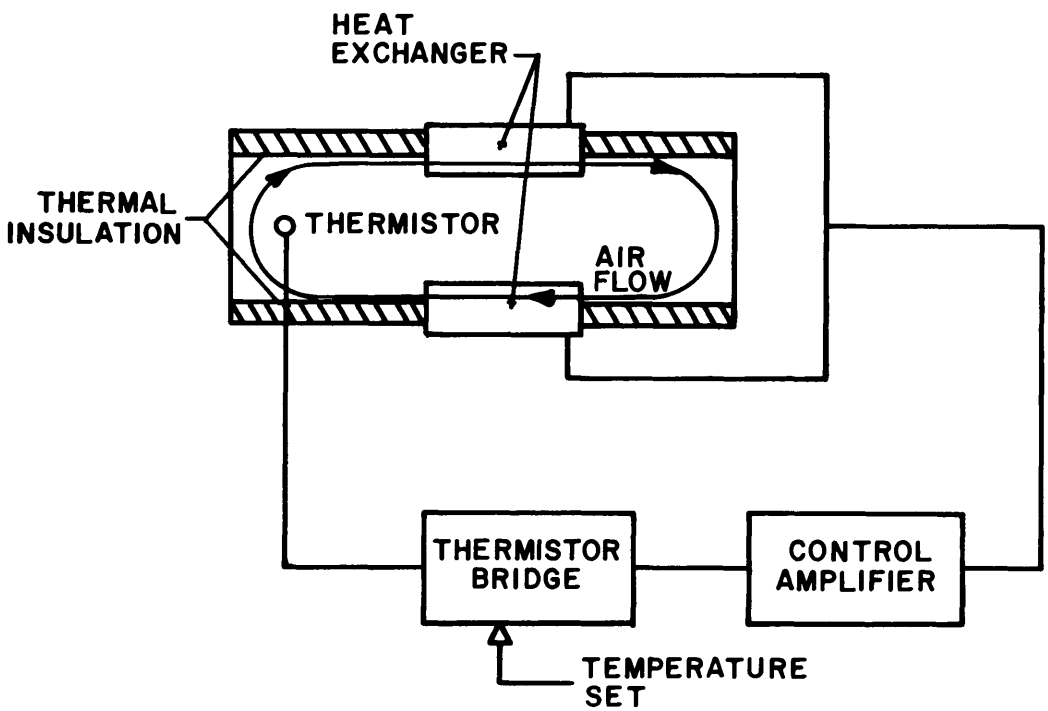


ORDERING INFORMATION

When ordering specify the complete model number (Example: TCP-625-F). Special design available—if the models listed do not satisfy your requirements – send complete specifications.

SCIENTIFIC COLUMBUS, INC.
1035 WEST THIRD AVENUE, COLUMBUS, OHIO 43212
TELEPHONE: 614-291-4681

FIGURE 1A



BLOCK DIAGRAM OF TEMPERATURE CONTROLLER

FIG. 2

SOLID STATE TEMPERATURE CONTROL
PARTS LIST

TRANSISTORS

1. Q-13 - 2N1613
2. Q-14 - "
3. Q-4 - 2N3904
4. Q-5 - "
5. Q-6 - "
6. Q-7 - "
7. Q-9 - "
8. Q-12 - "
9. Q-2 - 2N3906
10. Q-3 - "
11. Q-8 - "
12. Q-10 - "
13. Q-1 - 2N491
14. Q-11 - "

CONTROLLED RECTIFIERS

1. SCR-1 - MCR 2935-4
2. SCR-2 - "
3. SCR-3 - "
4. SCR-4 - "

DIODES

1. D-1 - 1N914
2. D-2 - "
3. D-3 - "
4. D-4 - "
5. D-5 - 1N4731 Zener
6. D-6 - " "
7. D-7 - 1N4734 "
8. D-8 - 1N914
9. D-9 - "
10. D-10 - 5A6TR
11. D-11 "
12. D-12 - 1N914
13. D-13 - "

CAPACITORS

1. C-1 - 6,000 mfd, 50 V DC Elec.
2. C-2 - " " " "
3. C-3 - " " " "
4. C-4 - " " " "
5. C-5 - " " " "
6. C-6 - " " " "
7. C-7 - 0.1 mfd, 100 V
8. C-8 - " " "
9. C-9 - 1 mfd, 200 V
10. C-10 - " "
11. C-11 - 2 mfd, "
12. C-12 - 50 mfd, 10 V DC Elec.
13. C-13 - " " "
14. C-14 - .05 mfd, 50 V
15. C-15 - .47 mfd, 25 V
16. C-16 - " "
17. C-17 - .01 mfd, "

OPERATIONAL AMPLIFIERS

1. A-1 - Burr Brown, 105A
2. A-2 - " " "
3. A-3 - " " "
4. A-4 - " " "

RESISTORS

1. R-1 - 47 ohm, 1/4 watt, 5%
2. R-2 - " " "
3. R-3 - " " "
4. R-4 - " " "
5. R-5 - 15 K " "
6. R-6 - 3651 ohm, 1%
7. R-7 - 4020 ohm, 1%
8. R-8 - 15 K, 1/4 watt, 5%
9. R-9 - 2740 ohm, 1%
10. R-10 - 43 K, 1/4 watt, 5%
11. R-11 - 22.1 K, 1%
12. R-12 - " "
13. R-13 - 475 K "
14. R-14 - 27 K, 1/4 watt, 5%
15. R-15 - 475 K, 1%

RESISTORS (CONTINUED)

16. R-16 - 43 K, 1/4 watt, 5%
17. R-17 - 1 meg, 1/4 watt, 5%
18. R-18 - 27 K " "
19. R-19 - 8.25 K, 1%
20. R-20 - 75 K, 1%
21. R-21 - 10 K 1/4 watt, 5%
22. R-22 - " " "
23. R-23 - 30 K " "
24. R-24 - 15 K " "
25. R-25 - 30 K " "
26. R-26 - 100 ohm " "
27. R-27 - 10 K " "
28. R-28 - 470 ohm " "
29. R-29 - 470 ohm " "
30. R-30 - 100 K " "
31. R-31 - 27 K " "
32. R-32 - 47 K " "
33. R-33 - 150 K " "
34. R-34 - 27 K " "
35. R-35 - 1 K " "
36. R-36 - 1 K " "
37. R-37 - 2.2 K " "
38. R-38 - 1 K " "
39. R-39 - 5.6 K " "
40. R-40 - 2.2 K " "
41. R-41 - 2.2 K " "
42. R-42 - 5.6 K " "
43. R-43 - 2.2 K " "
44. R-44 - 1 K " "
45. R-45 - 2.2 K " "
46. R-46 - 10 K " "
47. R-47 - 47 K " "
48. R-48 - 1 K " "
49. R-49 - 6.8 K " "
50. R-50 - 470 ohm " "
51. R-51 - 470 ohm " "
52. R-52 - 6.8 K " "
53. R-53 - 6.8 K " "
54. R-54 - 100 ohm " "
55. R-55 - 1 K, 1 watt

POTENTIOMETERS

1. VR-1 - 2 K, 10 turn, Bourns 3500S-2-202
2. VR-2 - 500 ohm, Helitrim 62PA R500
3. VR-3 - 5 K, Bourns E-Z Trim 3007P-1-502-5K
4. VR-4 - " " " " "
5. VR-5 - " " " " "
6. VR-6 - " " " " "

KNOBS

1. 1 ea. - Beckman Digidial Model 210 (for VR-1)

SWITCHES

1. 1 ea. - Alco MST 115D SPDT (for 1-10° meter range)

METERS

1. 1 ea. - Simpson Model 1327, Cat. No. 4440, 100-0-100 μA
2. 1 ea. - Simpson Model 1327, Cat. No. 2800, 30-0-30 amp

CIRCUIT BREAKERS

1. 1 ea. - Wood Elec. Co. P/N 130-210-101, 15 amp, 250 V AC
2. 1 ea. - Wood Elec. Co. P/N 130-230-101, 40 amp, 50 V DC

PILOT LAMPS

1. 1 ea. - Eldema RMA 64D5 LH74/I - holder

INDUCTORS

1. L-1-1 mH, 25A, Central Transformer Co. (modified)

POWER SUPPLY

1. PS-1 - Burr Brown 501 Dual Supply

TRANSFORMERS

1. T-1 - Power, Central Transformer Co., SK-1030, 040568
2. T-2 - Pulse Transformer 1:1:1, Sprague 11213 6747
3. T-3 - Pulse Transformer 1:1:1, Sprague 11213 6747

LAMPS

1. 1 ea. - NE-2D neon lamp.

HANDLES

1. 1 pr. - Cambion P/N 1252-1 - handles.

TERMINAL STRIPS

1. 1 ea. - Cinch Jones 20-140 - terminal strip
2. 1 ea. - " " 7-142 " "
3. 1 ea. - " " 20-140 - marker strip
4. 1 ea. - " " 7-142 " "

FILTERS

1. F-1 - Sprague 10JX33, 10 amp, 100 V DC
2. F-2 - " " " "
3. F-3 - " 30JX25, 30 amp, 250 V AC, 60 c, 600 V DC
4. F-4 - Erie 1200-028, 50 V DC, D753
5. F-5 - " " " "

CONNECTORS

1. J-1 - Amphenol Mfg. Type 160-11
   " " " 61-61
2. J-2 - Switchcraft Mfg. Type D-3F

FANS

1. 1 ea. - Boxer Model B.S. 2107F

FIG. 3A

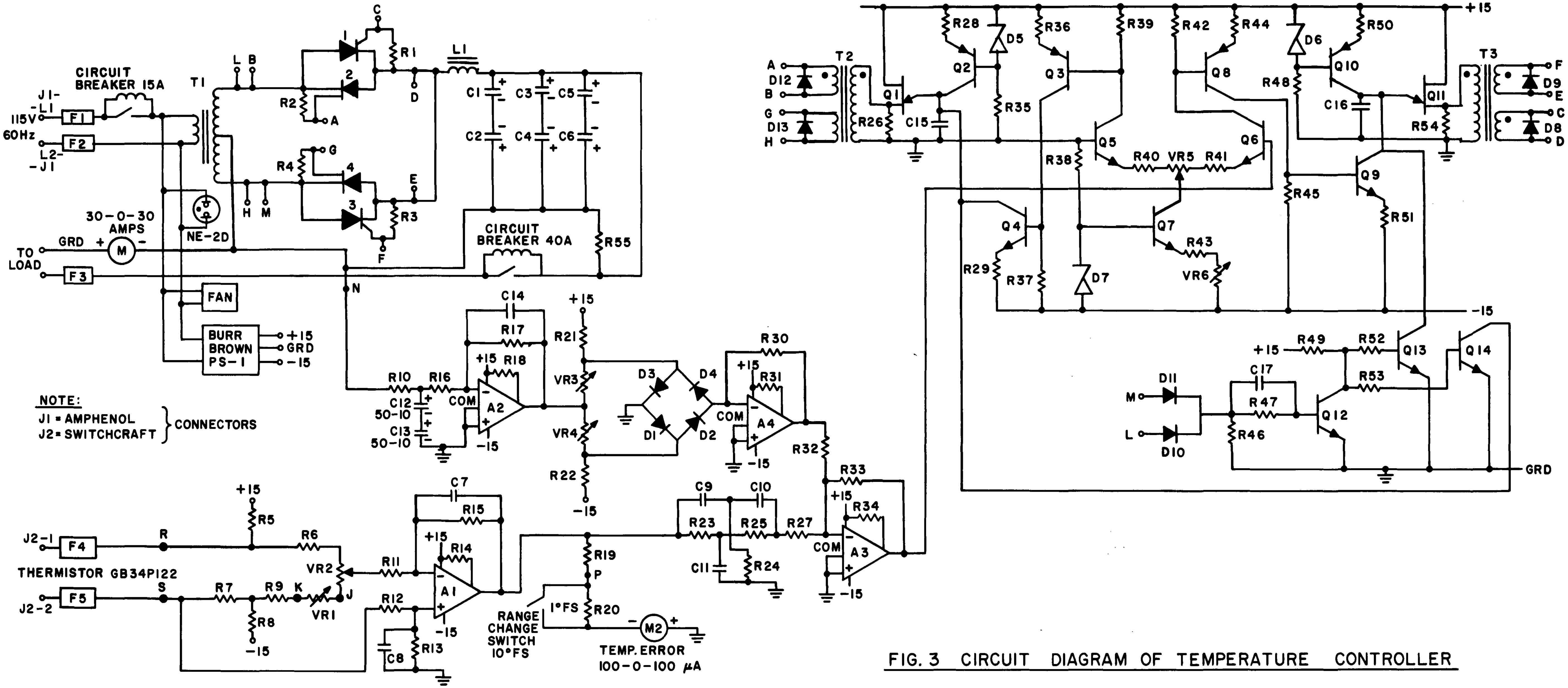


FIG. 3 CIRCUIT DIAGRAM OF TEMPERATURE CONTROLLER

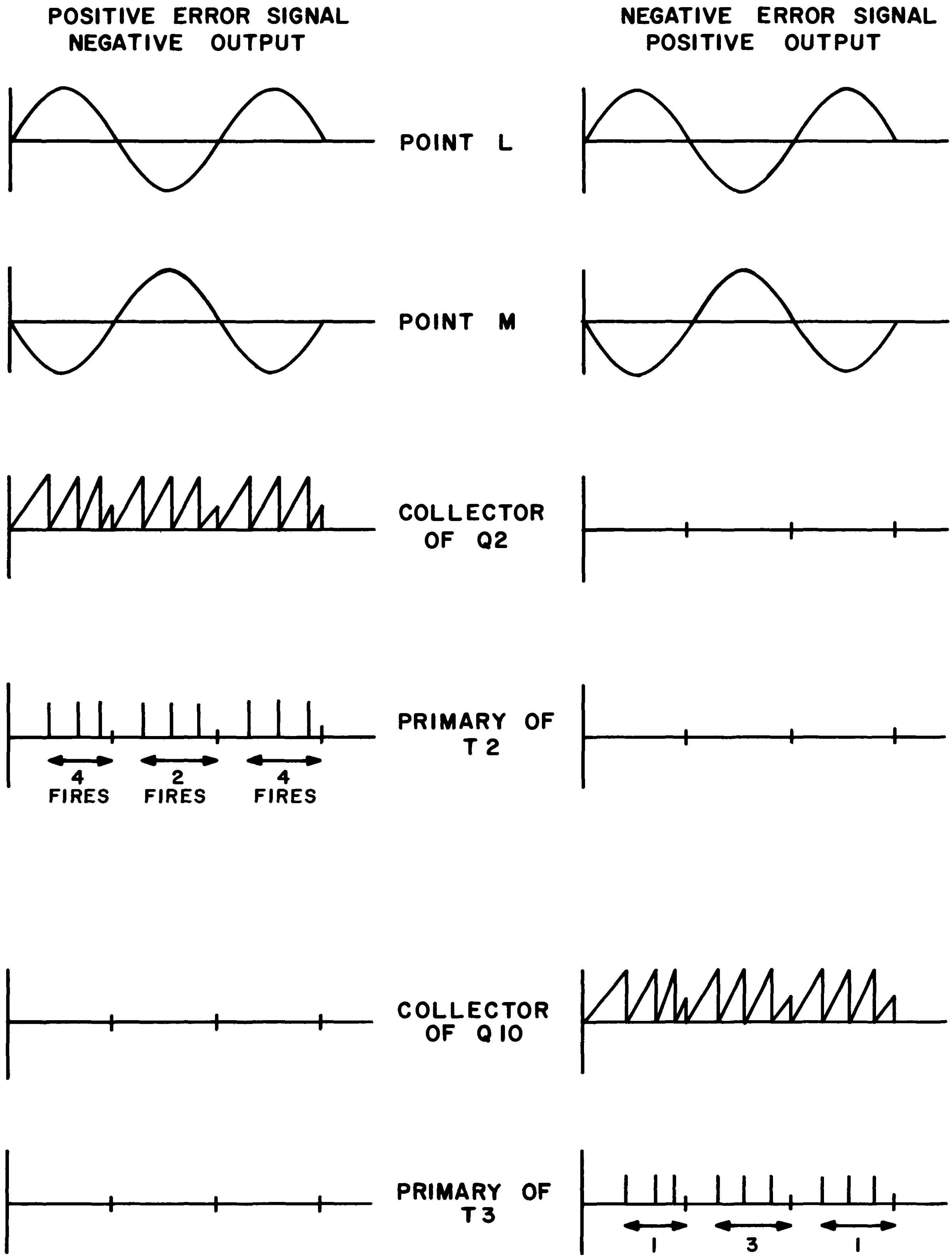

POSITIVE ERROR SIGNAL
NEGATIVE OUTPUT
NEGATIVE ERROR SIGNAL
POSITIVE OUTPUT
POINT L
POINT M
COLLECTOR OF Q2
PRIMARY OF T2
4 FIRES
2 FIRES
4 FIRES
COLLECTOR OF Q10
PRIMARY OF T3
1
3
1

FIG. 4

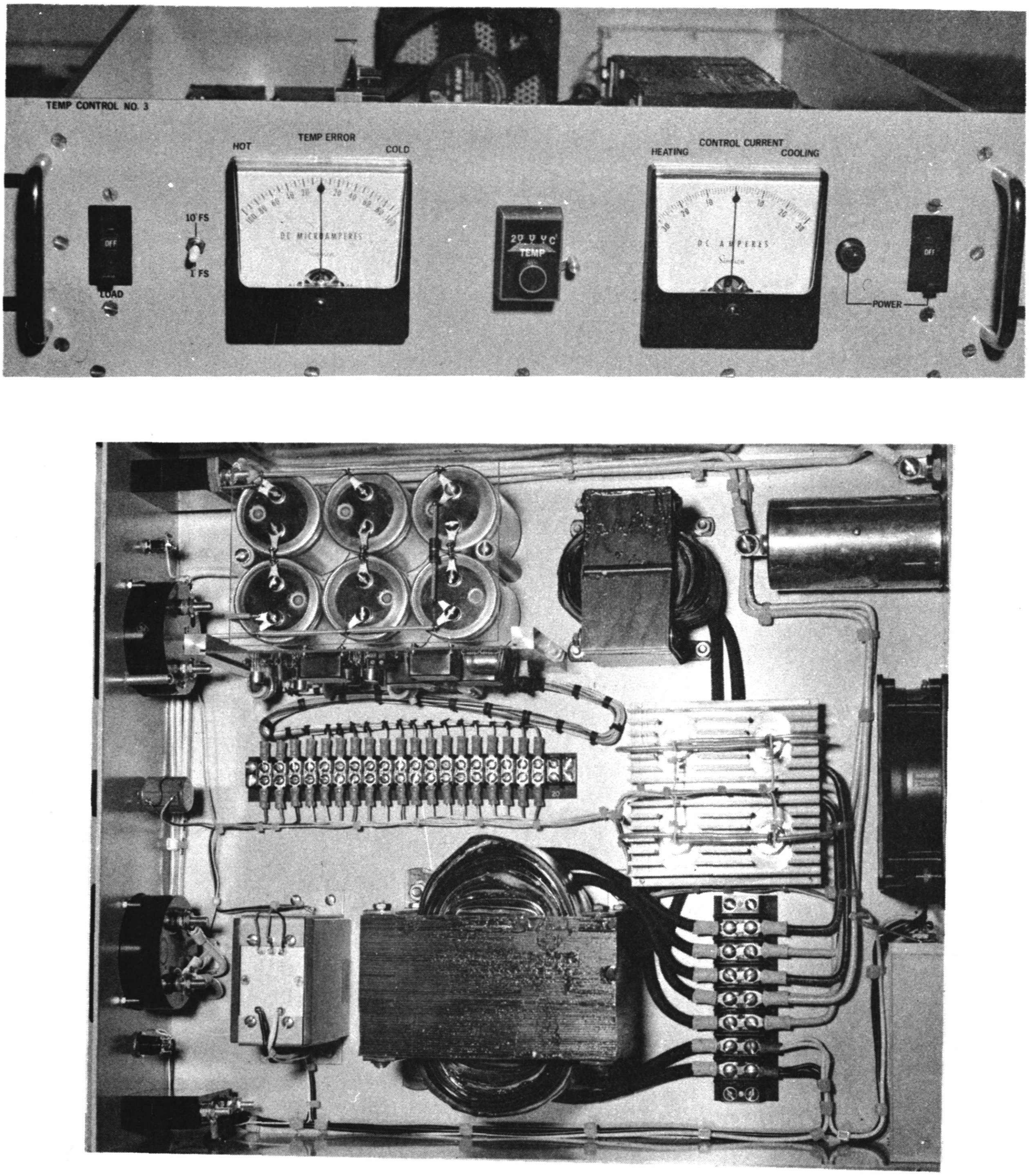
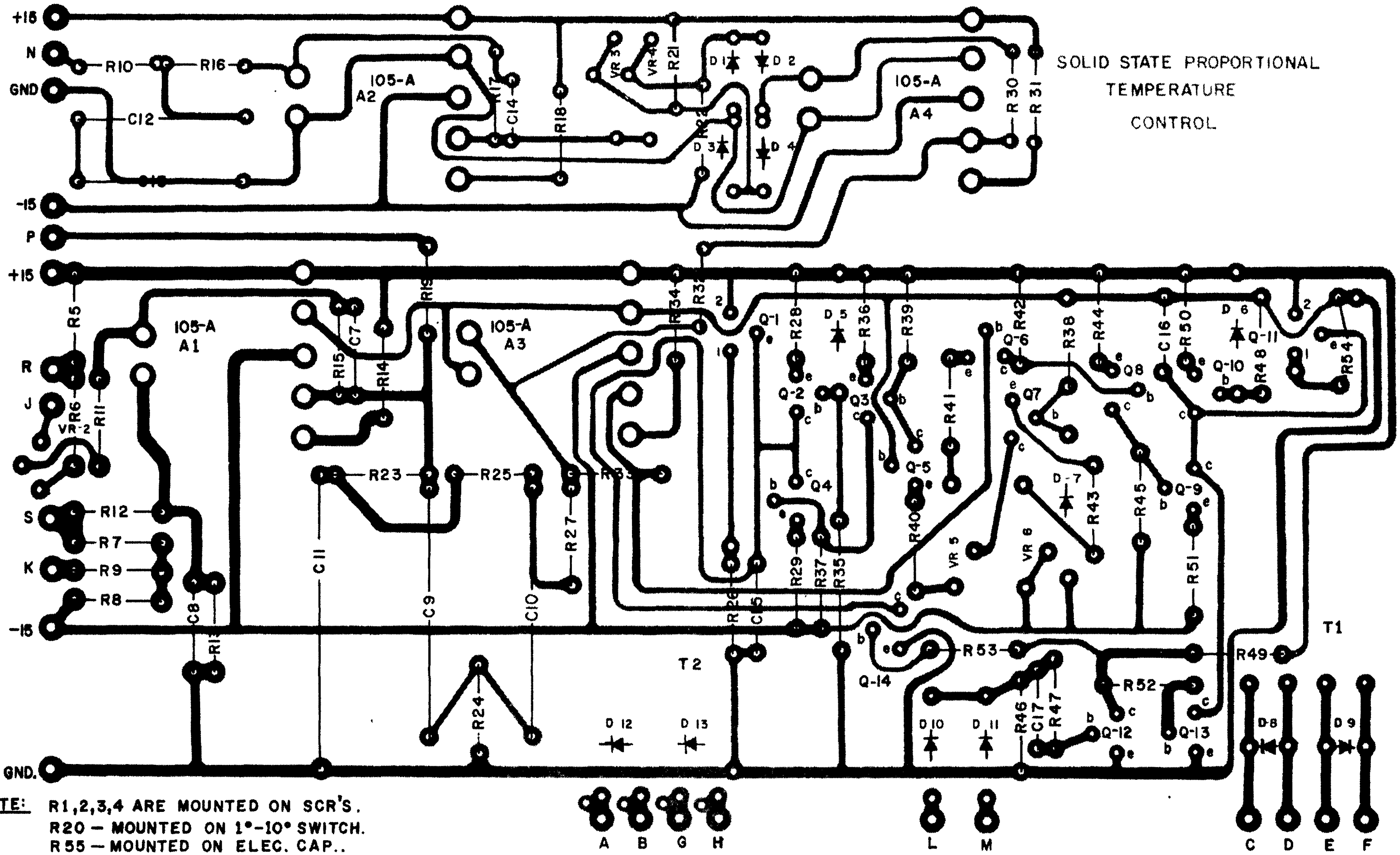

TEMP CONTROL NO. 3
TEMP ERROR
HOT
COLD
CONTROL CURRENT
HEATING
COOLING
10 FS
1 FS
LOAD
OFF
D.C. MICROAMPERES
TEMP
D.C. AMPERES
POWER

FIGURE 5

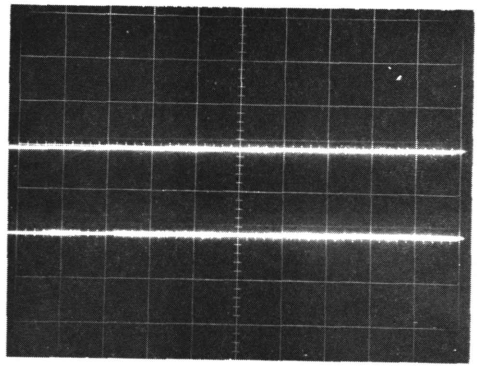


NOTE: R1,2,3,4 ARE MOUNTED ON SCR'S.
R20 — MOUNTED ON 1°-10° SWITCH.
R55 — MOUNTED ON ELEC. CAP..
C1,2,3,4,5,6 ELEC. — MOUNTED ON CHASSIS.

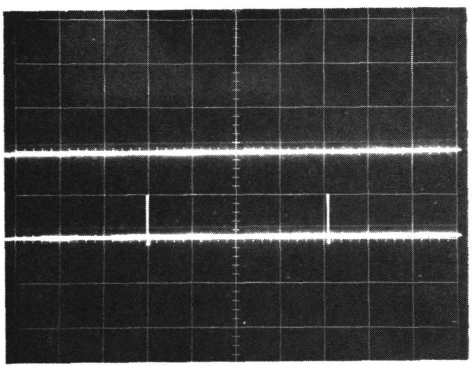
PRINTED CIRCUIT
FIG. 6

S.C.R. TRIGGERING WAVE FORMS

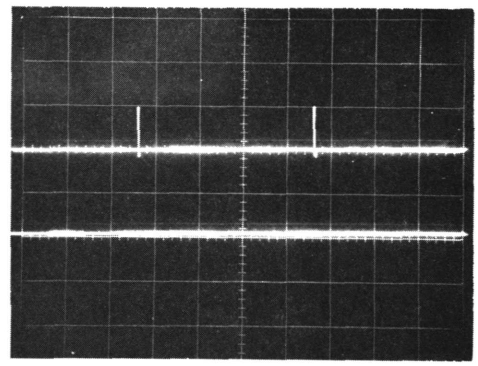
Top Beam — T2 Primary.
Bottom Beam — T3 Primary.
Temperature set to 25 °C.



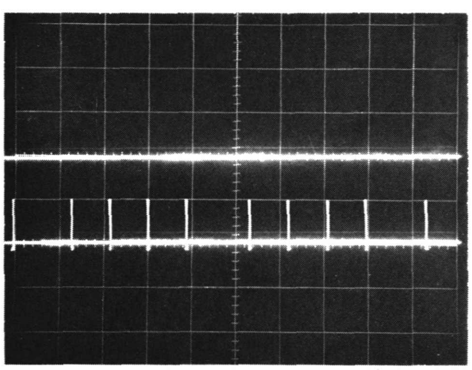
Zero Error



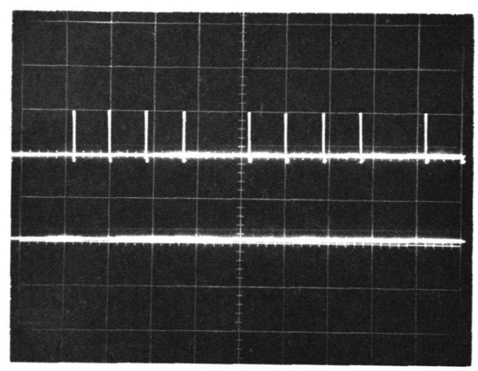
0.1 °C cold



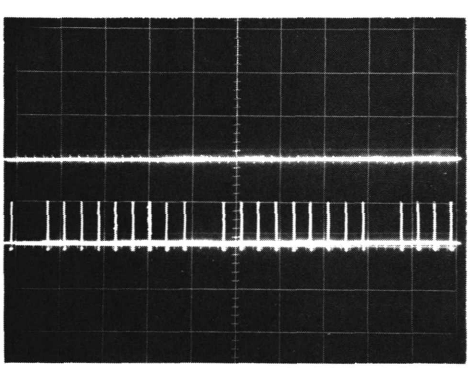
0.1 °C hot



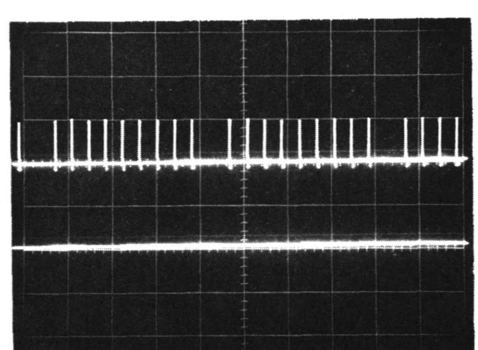
0.4 °C cold



0.4 °C hot



1.0 °C cold



1.0 °C hot

FIGURE 7