NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, West Virginia

ELECTRONICS DIVISION INTERNAL REPORT
NO. 300

GBT PRIME FOCUS TEMPERATURE CONTROLLER

S. D. WHITE

November 1995

1.0 General

GBT Temperature Controller

Block Diagram : D35241K014
Wiring Diagram: A35241W005

This report documents the prime focus temperature controller for the 20 meter receiver and the GBT prime focus receiver. The concept for the controller as described in EDIR 81 is basically the same, only the control circuit was modified to take advantage of modern integrated circuits. The closed-loop control is achieved through pulse-width modulation.

With the modified control circuit, a remote control option over the MCB BUSS was implemented as required by the GBT prime focus receiver. Also, the power transformer was replaced with a model which has an increased current specification, and the SCR's were replaced with an SCR bridge to increase the modularity of the unit.

2.0 Control Circuit

20 meter Schematic: D17707S005
GBT Schematic: D35241S004

The control circuit of the temperature controller consists of a thermistor in a Wheatstone bridge, a differential amplifier, a window comparator, a ramp generator and an SCR drive circuit. The resistors in the Wheatstone bridge are selected to linearize the response of the thermistor over a 20 degrees to 30 degrees C temperature range. The voltage differential is then amplified so that 20 degrees C corresponds to 0 volts and 30 degrees C corresponds to 10 volts. A window comparator, consisting of two voltage comparators, detects when the voltage is out of range and enables either the "heating" or "cooling" SCR drive circuit. Another pair of differential amplifiers produce a voltage which is proportional to the difference between the "set" voltage and the detected voltage from the Wheatstone bridge. This voltage and a ramp voltage is input to a circuit producing a pulse width modulation of the SCR bridge. The implementation of the pulse width modulation for the 20 meter controller is built around a Harris zero-crossing detector, Harris 3059, and uses a pulse transformer to drive the SCR bridge. The GBT controller is an improved version which consists of two voltage comparators and a Motorola optical-coupled zero-crossing detector, MOC3031, to drive the SCR bridge.

2.1 Temperature Detection and Conversion

A fenwal thermistor, GB34P2, is mounted in the front-end box, where a twisted pair of wires connect the thermistor to the control circuit box located in the controller chassis. The resistor values for the Wheatstone bridge are calculated using the resistance of the thermistor at 20, 25 and 30 degrees C. The equation for the two resistors in the "bottom" half of the Wheatstone bridge is

$$(R_{T1}R_{T2} + R_{T2}R_{T2} - 2R_{T1}R_{T3})/(R_{T1} + R_{T3} - R_{T2})$$

where R_{T1}, R_{T2} and R_{T3} are the thermistors resistance at the low end, midpoint, and high end of the temperature range, respectively.[2] The value of the resistance in the "upper" leg is equal to the thermistors resistance at 20 degrees C to give a 0 voltage differential at this temperature. The Wheatstone bridge is biased by a 10 volt precision regulator. With these values, a differential amplifier circuit with a gain of 10.7 gives the desired sensitivity of 1V/degree C. Table 1 shows the theoretical error resulting from the nonlinear behavior of the thermistor for different beta values. The errors were calculated using Wheatstone bridge resistances, calculated with the average thermistor beta of 3442.

Note: A version similar to the 20 meter controller regulates the temperature for a USNO receiver located in Richmond, Florida. This version uses a 10K thermistor with different temperature coefficient.

2.2 Window Comparator and Error Sensing Circuit

The voltage from the bridge circuit is input to a window comparator. The window circuit detects when the voltage is outside a certain range and turns on the appropriate SCR drive. When the voltage is higher than the window, indicating the box temperature is high, a comparator enables the cooling SCR drive circuit while the heating drive circuit remains disabled. For the 20 meter controller, a voltage greater than 1.2V applied to the "External inhibit" input disables the drive to the pulse transformers. For the GBT controller, a positive voltage is applied to the base of a 2N2222 transistor, which draws current from the strobe input, thus disabling the output current to the MOC 3031. When the voltage is inside the window, indicating no temperature error, both heating and cooling drive circuits are disabled. The heating drive circuit is enabled when the voltage is lower than the window. One AD converter located on the digital card sets the upper voltage of the window, and one AD converter sets the lower voltage. The setting of the window is described in section 3.0.

The error-sensing circuit consists of two differential amplifiers: one which amplifies the difference between the bridge voltage and the upper window voltage, and one which amplifies the difference between the lower window voltage and the bridge voltage. The gain of the differential amplifier is such that a temperature error greater than 0.1 degree C causes the amplifier to saturate to the positive voltage rail. The error voltage is then input to a comparator, so that when the error voltage is greater than the ramp voltage, a pulse is produced which turns on the SCR's.

2.3 Pulse Modulation and Zero Crossing Circuit

Two Harris zero-crossing IC's in the 20 meter temperature controller generate a pulse to turn on the appropriate SCR pair. One IC turns on a pair of the SCR's in the bridge for positive voltage by a pulse input to a pulse transformer; the other IC turns on a pair of SCR's for the negative voltage.

For the GBT controller and any subsequent controllers, the Harris IC and the pulse transformer are eliminated in favor of a Motorola optical zero-crossing IC, MC3031. The 3059 has cumbersome interface requirements, while the MC3031 was TTL compatible and could be connected directly to the SCR bridge. A simple voltage comparator is now used to generate the pulse-width modulation, and the Motorola IC provides the zero crossing to reduce the RFI from the SCR's.

The ramp voltage is generated by two operational amplifiers, with three potentiometers to adjust the frequency, amplitude and offset. The frequency is adjusted to approximately one-tenth the line frequency, or about 0.6 Hz. The maximum amplitude is adjusted to 11 volts with zero offset. For the RCA 3059, the ramp offset must be greater than 1.2 volts, with the maximum voltage less than 11.0 volts.

3.0 Digital Control Circuit

20 Meter Schematic: D17707S005
GBT Schematic: D35241S001

The digital control circuit for the manual temperature controller provides the high window comparator voltage and low window comparator voltage. An EPROM is programmed to produce appropriate digital input to the AD for a given temperature setting. The EPROM and the ADC's effectively map the 20.0 to 29.9 front-panel digit-switch range to a 0.0 to 9.9 voltage range, respectively. The output of the EPROM is input to the "high" voltage AD and also input to an ALU IC. An 8-bit digit switch, located on the card, is input as the subtrahend. The output of the ALU is input to the "low" voltage AD. Therefore, the width of the comparator window is adjusted by the 8-digit switch. The resolution of the ADC is 39 millivolts; thus, the window comparator width can be adjusted in 0.039 degree C steps. The circuit provides a safeguard so that a window width greater than the EPROM output will not produce a "low" voltage which is greater than the "high" voltage. If this condition occurs, the output of the ALU is 00h and the "low" ADC is 0.0V.

In the remote version of the digital card, a 34-ribbon cable inputs the monitor and control signals from the MCB interface box. The monitor signals input to the MCB interface are the EPROM input, remote/manual, DC switch ON/OFF, DC current and front panel temperature reading. The control signals are the remote mode, DC switch ON/OFF and temperature setting. A multiplexer IC switches the input of the EPROM between the front panel digit switch and the MCB interface. A multivibrator produces a clock pulse to a D flipflop which sets the temperature controller in remote mode. A front panel switch resets the controller to manual mode.

A current monitor circuit amplifies the voltage difference across the DC front panel meter. The meter has a series resistance of approximately 0.01 Ohms; therefore, a 29 millivolt potential appears across the meter with a load of 1 Ohm. However, the potential on each side of the meter is approximately 29 volts relative to ground. With the given offset voltages and currents, and maximum input of most operational amplifiers, this proved difficult to measure with a single operational amplifier. The board was modified so that a voltage divider is proceeded by a voltage follower and is input to the differential amplifier. This circuit, however, is only moderately successful at monitoring the current. The typical values are given in Table 3.

4.0 Test Results

The measured voltage across a one Ohm load for the GBT temperature controller is 26.6 Vrms. The measured voltage across a one Ohm load for the 20 meter controller is 28.0 Vrms. The difference in voltage is due to the drop across the MOSFET relay and diode bridge network for remote control of the DC current. The diode bridge is needed because the relay is a unidirectional device.

A typical rectified waveform is shown in Figure 1, with a typical voltage waveform across the thermoelectric units given in Figure 2.

The 20 meter unit was tested with the 20 meter receiver front-end box in the lab. A power resistor was placed inside the box for the thermal load. With the outside ambient temperature being 25 degrees C, the unit could keep the temperature at 20.0 degrees C within 0.1 degree for a 200W load. With more load, the unit could not regulate the temperature. With the addition of a fan forcing air across the load, the controller could handle up to a 625W load. The theoretical capability, with I = 22A and Vrms = 2.8 V, each unit should have a capacity of 60W. With a total of 20 units, the cooling capability should be 1200W. Thus, the air flow needs to be improved inside the box for greater efficiency. Currently, the controller can withstand a higher load if the load is distributed throughout the box.

5.0 Program Information

A program written by D. Varney to program an EPROM using the ALLPRO software was modified to program the temperature controller EPROM. The document number for the source code is A35241D010.

A program was written to monitor and control the temperature controller over the MCB BUSS. This program contains routines to set and monitor all controller functions as well as initialize the MCB BUSS. The document number for the source code is A34241D010.

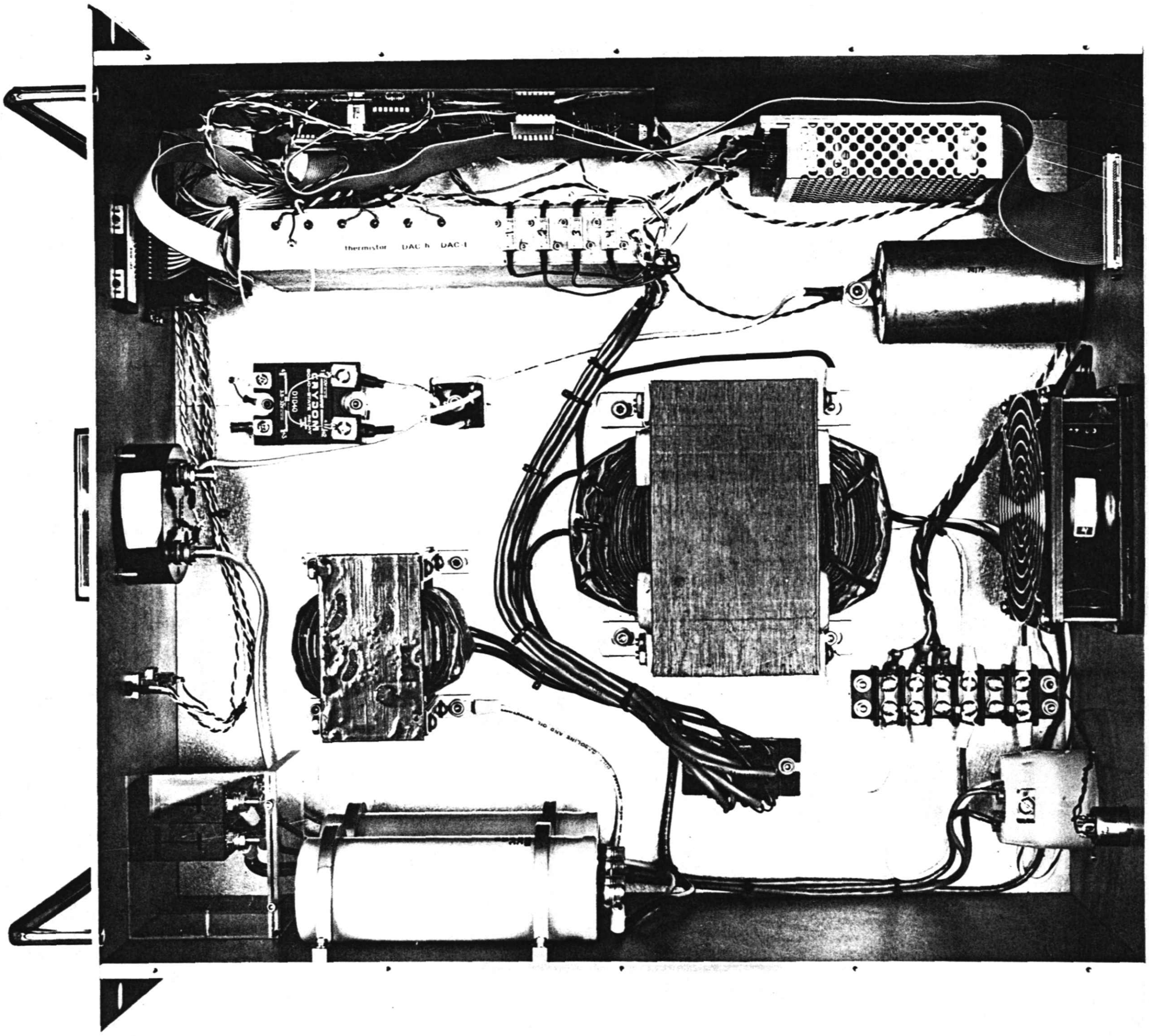
6.0 Acknowledgments

The Green Bank machine shop manufactured all the chassis and associated hardware. Jim Oliver did the mechanical layout and constructed all the temperature controllers.

7.0 References

1. EDIR NO. 81, "Front-End Temperature Controller", J. Payne (October 1968).

2. Trietley, Harry L. "Electronic Temperature Measurement", Radio-Electronics, April 1992. pp 40-46.



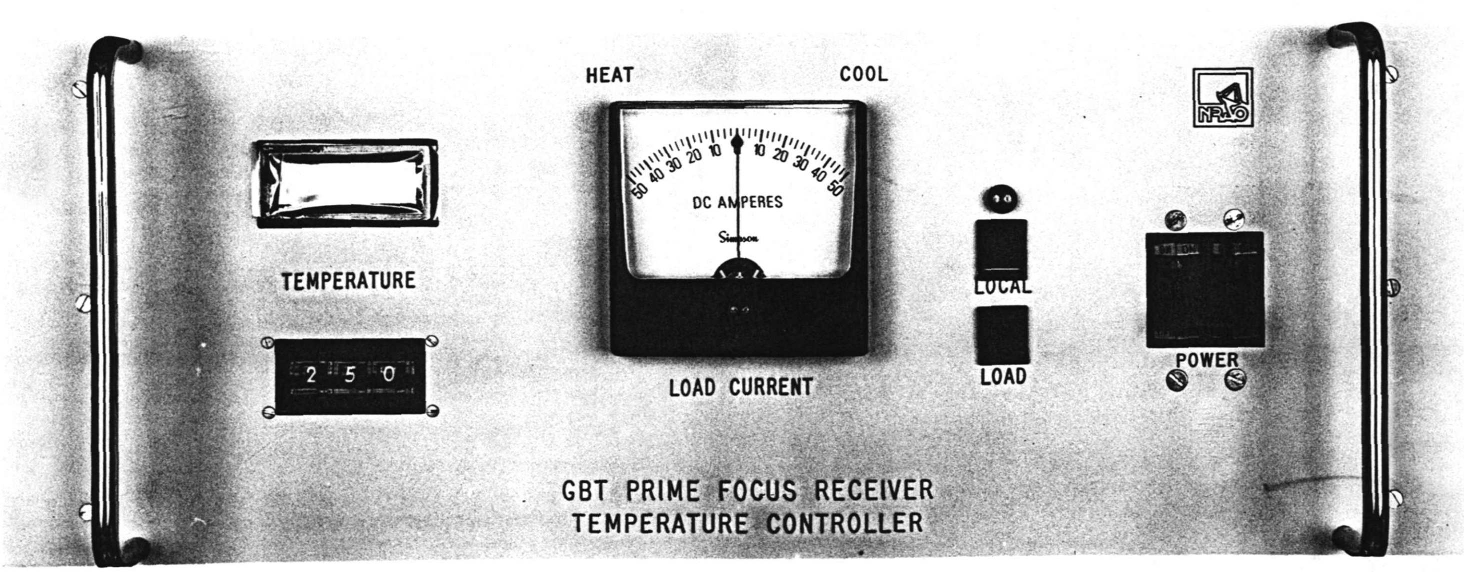

HEAT
COOL
DC AMPERES
Simpson
TEMPERATURE
2 5 0
LOCAL
LOAD
LOAD CURRENT
POWER
NRAO
GBT PRIME FOCUS RECEIVER
TEMPERATURE CONTROLLER

TABLE 1

Theoretical Error Table for the Range of Thermistor Beta Values with R_{T1} = 4871, R_{T2} = 4000, R_{T3} = 3305 : B = 3442 and R1 calculated to be 2822.

Temp [C]	Error [C]	
	B = 3352	B = 3532
20	-0.128	0.128
21	-0.101	0.105
22	-0.077	0.078
23	-0.055	0.049
24	-0.034	0.018
25	-0.014	0.014
26	0.007	-0.046
27	0.028	-0.078
28	0.051	-0.108
29	0.076	-0.136
30	0.105	-0.160

TABLE 2

Monitor and Control Addresses

RA	Name	Comments
32	DC Current	AD Input
33	Analog Temperature	AD Input
50	Temperature Reading	EPROM Input
51	ID|Parity|Remote|DC	FEXX DCR OFF REMOTE ON FFXX DCR OFF REMOTE OFF FDXX DCR ON REMOTE OFF FCXX DCR ON REMOTE ON
48	Set REMOTE	00 then 01 DCR OFF 00 the 03 DCR ON
4A	Set Temperature	EPROM Input

TABLE 3
DC Current Monitor Values

Reading [V]	Indication
-7.0 - -10	Negative Voltage to Thermoelectric Unit DC Relay may be ON or OFF
0 +/- 1.0	SCR not firing no current
7.0 - 10.0	Positive Voltage to Thermoelectric Unit DC Relay may be ON or OFF

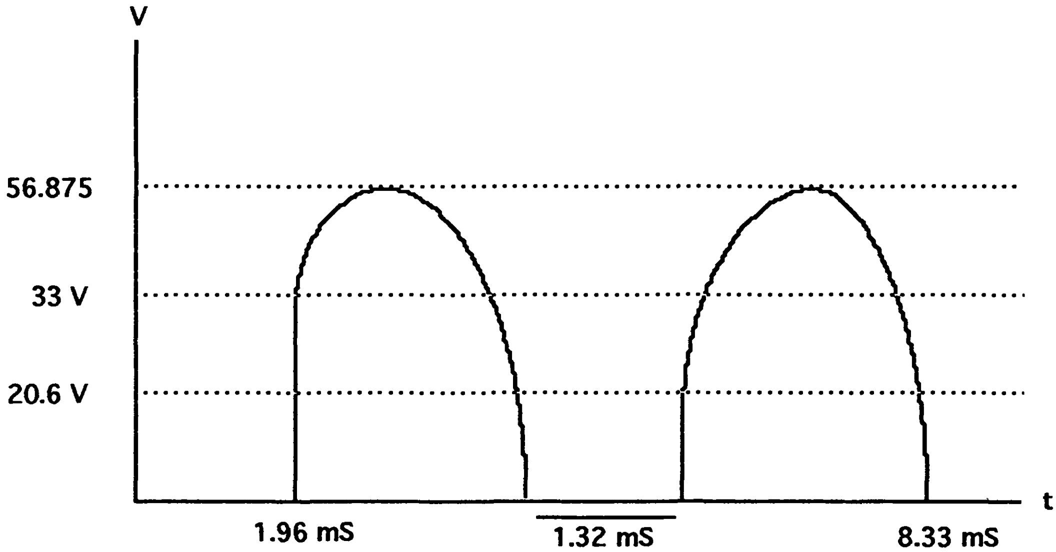


Figure 1. Rectified Voltage Waveform

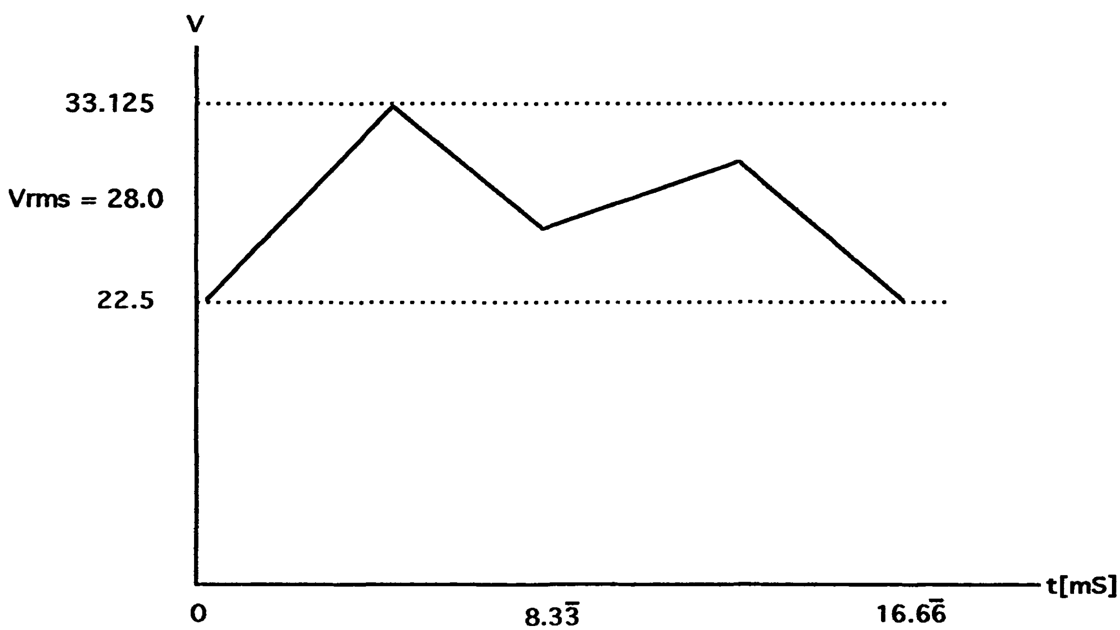
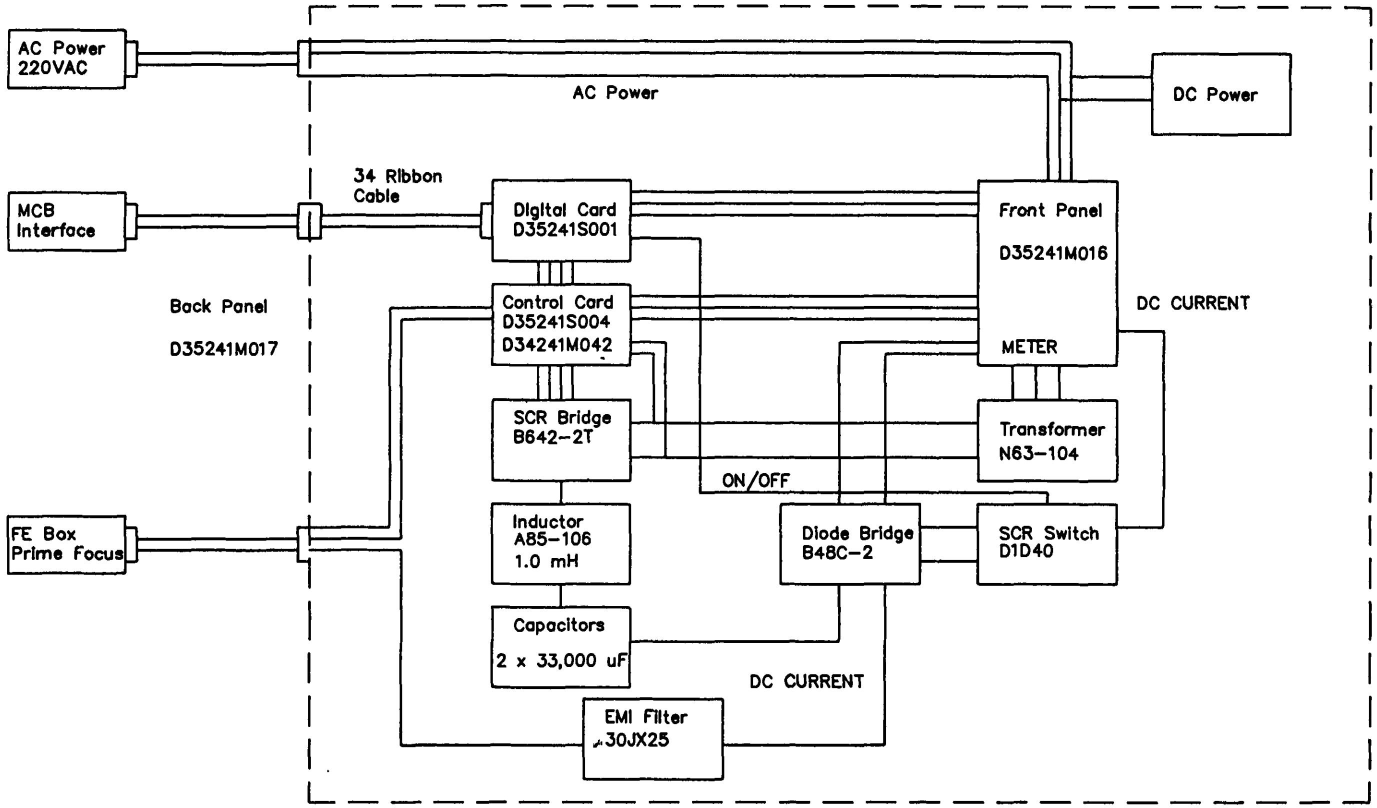


Figure 2. Voltage Waveform across 20 Peltier Units.



Temperature Controller

PARTS LIST

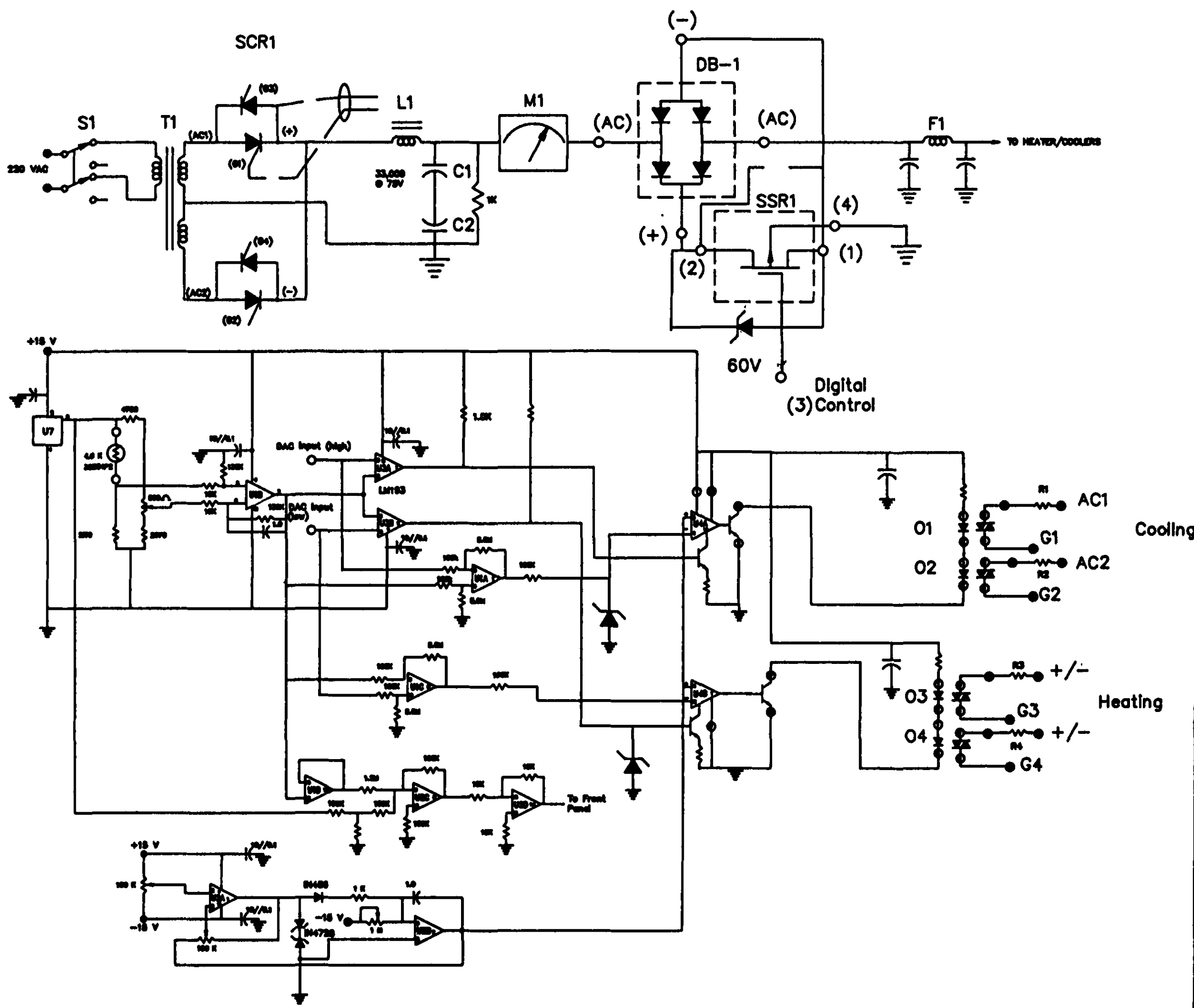
NATIONAL RADIO ASTRONOMY OBSERVATORY

N/A N/A N/A

1 OF 1

D35241K014

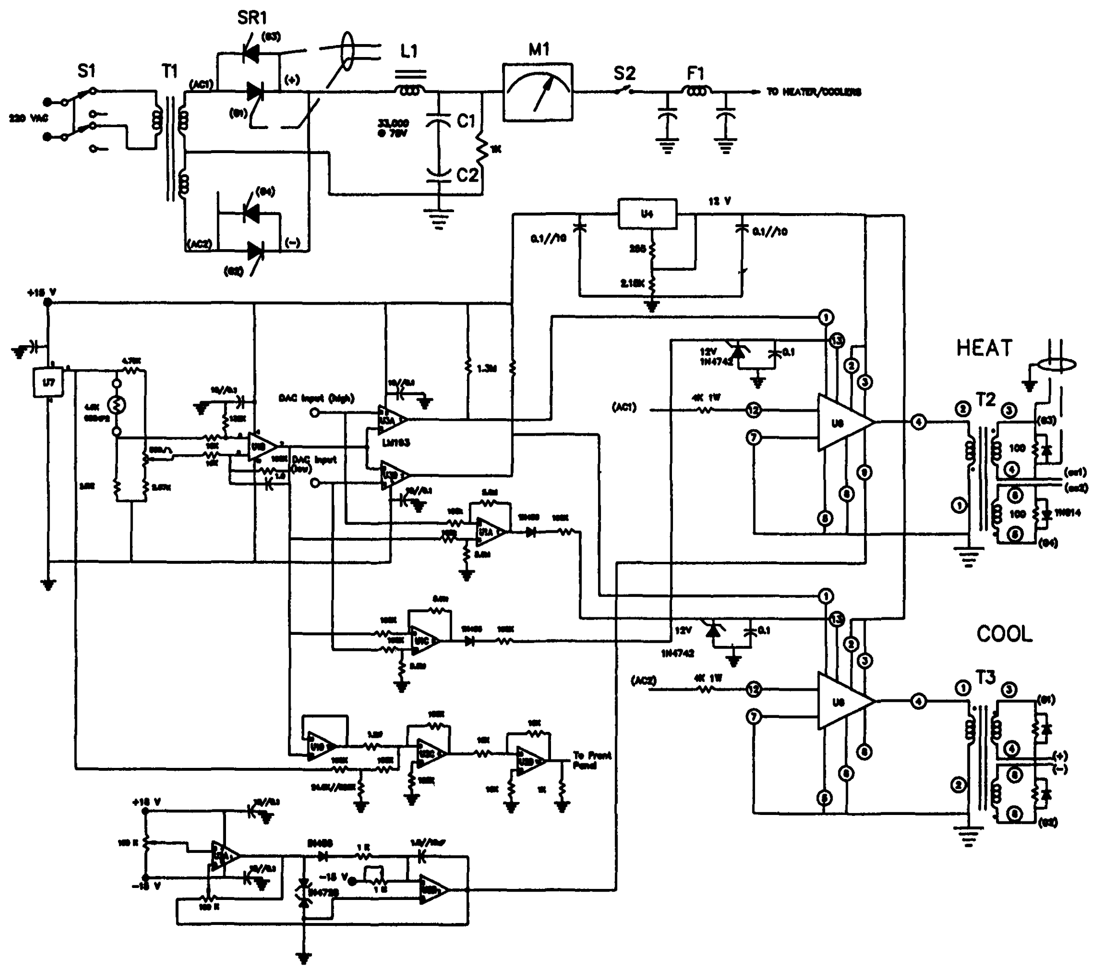
A35241W005						
Pin	Name	RA	PCB Pin	Name	Chasis Con	Date
P11-1	AIN 3G	32	JP1-10	DC Current	P1-24	10/4/95
P11-2	AIN 4G	33	N/A	Meter	P1-37	
P12-1	RA50-DM0	50	JP1-26	TEM0	P1-32	
P12-2	RA50-DM1	50	JP1-25	TEM1	P1-13	
P12-3	RA50-DM2	50	JP1-24	TEM2	P1-31	
P12-4	RA50-DM3	50	JP1-23	TEM3	P1-12	
P12-5	RA50-DM4	50	JP1-22	TEM4	P1-30	
P12-6	RA50-DM5	50	JP1-21	TEM5	P1-11	
P12-7	RA50-DM6	50	JP1-20	TEM6	P1-29	
P12-8	RA50-DM7	50	JP1-19	TEM7	P1-10	
P12-9	RA51-DM0	51		ID0	NC	
P12-10	RA51-DM1	51		ID1	NC	
P12-11	RA51-DM2	51		ID2	NC	
P12-12	RA51-DM3	51		ID3	NC	
P12-13	RA51-DM4	51		ID4	NC	
P12-14	RA51-DM5	51		ID5	NC	
P12-15	RA51-DM6	51		ID6	NC	
P12-16	RA51-DM7	51		Parity	NC	
P12-17	RA51-DM8	51	JP1-9	Remote/Loc	P1-5	
P12-18	RA51-DM9	51	JP1-11	DCR Switch	P1-6	
P13-1	RA48-DC0	48	JP1-28	Remote	P1-33	
P13-2	RA48-DC1	48	JP1-27	RemoteDC	P1-14	
P13-3						
P13-4						
P13-5						
P13-6						
P13-7						
P13-8						
P13-9						
P13-10						
P13-11						
P13-12						
P13-13	RA4A-DC0	4A	JP1-1	COM0	P1-1	
P13-14	RA4A-DC1	4A	JP1-2	COM1	P1-20	
P13-15	RA4A-DC2	4A	JP1-3	COM2	P1-2	
P13-16	RA4A-DC3	4A	JP1-4	COM3	P1-21	
P13-17	RA4A-DC4	4A	JP1-5	COM4	P1-3	
P13-18	RA4A-DC5	4A	JP1-6	COM5	P1-22	
P13-19	RA4A-DC6	4A	JP1-7	COM6	P1-4	
P13-20	RA4A-DC7	4A	JP1-8	COM7	P1-23	
P13-21						
P13-22						



R4	[illegible]	1	[illegible]	
R3	[illegible]	1	[illegible]	
R2	[illegible]	1	[illegible]	
R1	[illegible]	1	[illegible]	
O4	[illegible]	1	OPTICAL TRIAC DRIVER	
O3	[illegible]	1	OPTICAL TRIAC DRIVER	
O2	[illegible]	1	OPTICAL TRIAC DRIVER	
O1	[illegible]	1	OPTICAL TRIAC DRIVER	
U4	LM311	1	DUAL VOLTAGE COMPARATOR	
U3	[illegible]	1	OP AMP	
U2	[illegible]	1	OP AMP	
U1	[illegible]	1	OP AMP	
SSR1	[illegible]	1	MOSFET AC RELAY	
DB-1	[illegible]	1	[illegible]	
T1	[illegible]	1	TRANSFORMER	
SCR1	[illegible]	1	[illegible]	
S2	[illegible]	1	SWITCH	
S1	[illegible]	1	SWITCH	
M1	[illegible]	1	METER	
L1	[illegible]	1	INDUCTOR	
F1	[illegible]	1	FILTER	
C2	[illegible]	1	CAPACITOR	
C1	[illegible]	1	CAPACITOR	
ITEM	PART NO.	QTY	DESCRIPTION	MATL.

PARTS LIST

NATIONAL RADIO ASTRONOMY OBSERVATORY



U7	AD [illegible]	1	VOLTAGE REFERENCE	
U6	[illegible]	1	OP AMP	
U5	[illegible]	1	OP AMP	
U4	NS LM317	1	VOLTAGE REGULATOR	
U3	NS [illegible]	1	OP AMP	
U2	NS LM124	1	OP AMP	
U1	NS LM124	1	OP AMP	
T3	DALE [illegible]	1	TRANSFORMER	
T2	DALE [illegible]	1	TRANSFORMER	
T1	[illegible] LAKE [illegible]	1	TRANSFORMER	
SR1	[illegible]	1	RECTIFIER	
S2	[illegible]	1	SWITCH	
S1	[illegible]	1	SWITCH	
M1	[illegible]	1	METER	
L1	[illegible] LAKE [illegible]	1	INDUCTOR	
F1	[illegible]	1	FILTER	
C2	SPRAGUE [illegible]	1	CAPACITOR	
C1	SPRAGUE [illegible]	1	CAPACITOR	
ITEM	PART NO.	QTY	DESCRIPTION	MATL.

PARTS LIST

NATIONAL RADIO ASTRONOMY OBSERVATORY

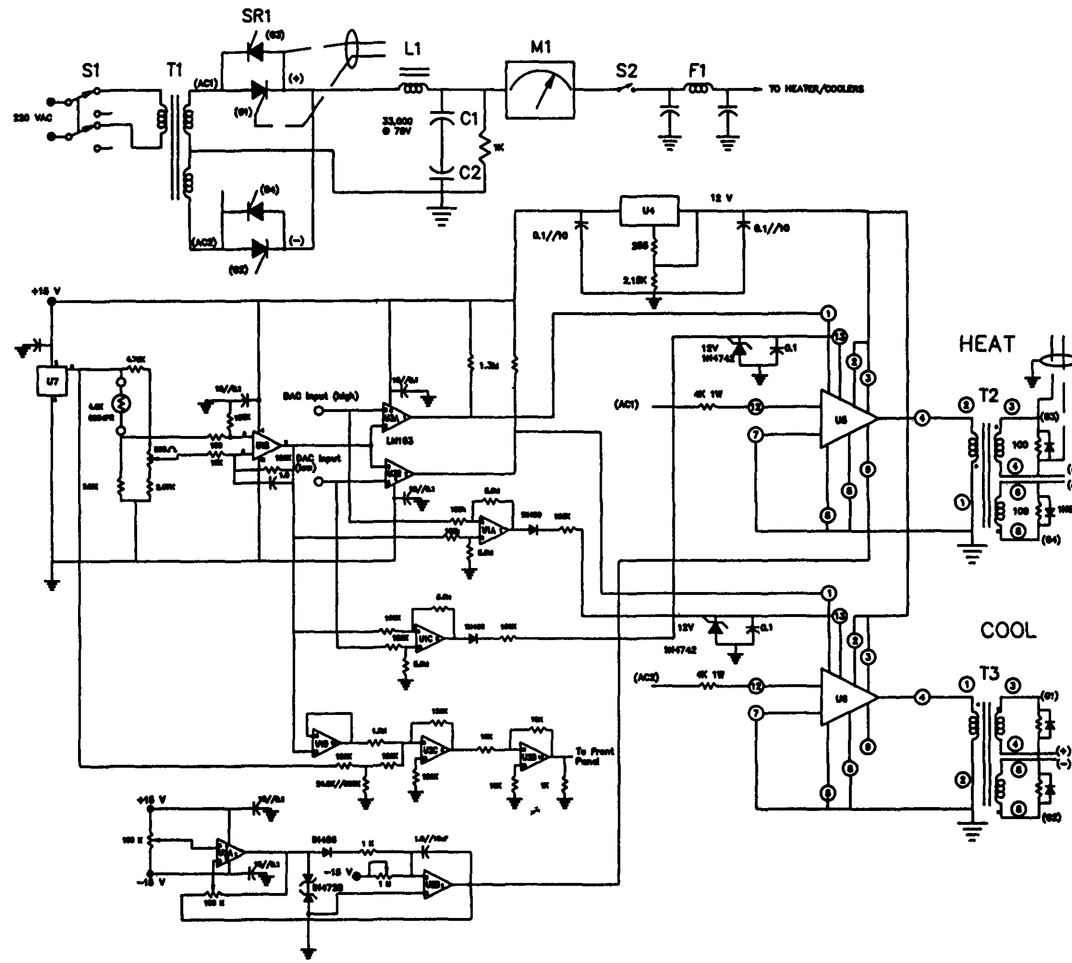
[illegible]

TEMPERATURE CONTROL SCHEMATIC

N/A | N/A | N/A

1 OF 1

017707S004



ITEM	PART NO.	QTY	DESCRIPTION	MATL.
U7	[illegible]	1	VOLTAGE REFERENCE	
U6	[illegible]	1	OP AMP	
U5	[illegible]	1	OP AMP	
U4	[illegible]	1	VOLTAGE REGULATOR	
U3	[illegible]	1	OP AMP	
U2	[illegible]	1	OP AMP	
U1	[illegible]	1	OP AMP	
T3	[illegible]	1	TRANSFORMER	
T2	[illegible]	1	TRANSFORMER	
T1	[illegible]	1	TRANSFORMER	
SR1	[illegible]	1	RECTIFIER	
S2	[illegible]	1	SWITCH	
S1	[illegible]	1	SWITCH	
M1	[illegible]	1	METER	
L1	[illegible]	1	INDUCTOR	
F1	[illegible]	1	FILTER	
C2	[illegible]	1	CAPACITOR	
C1	[illegible]	1	CAPACITOR	

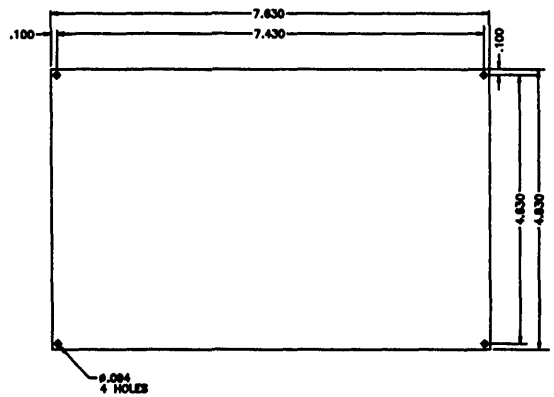
PARTS LIST

NATIONAL RADIO ASTRONOMY OBSERVATORY

N/A | N/A | N/A

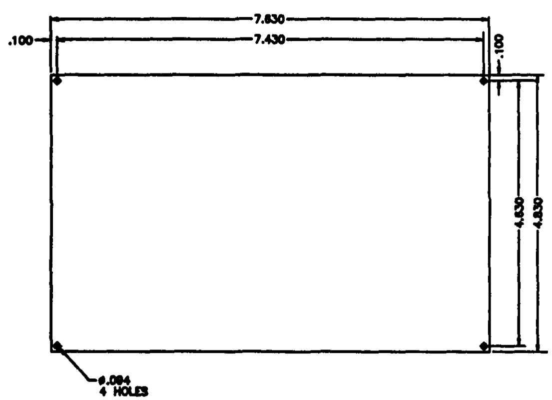
1 OF 1

D17707S004



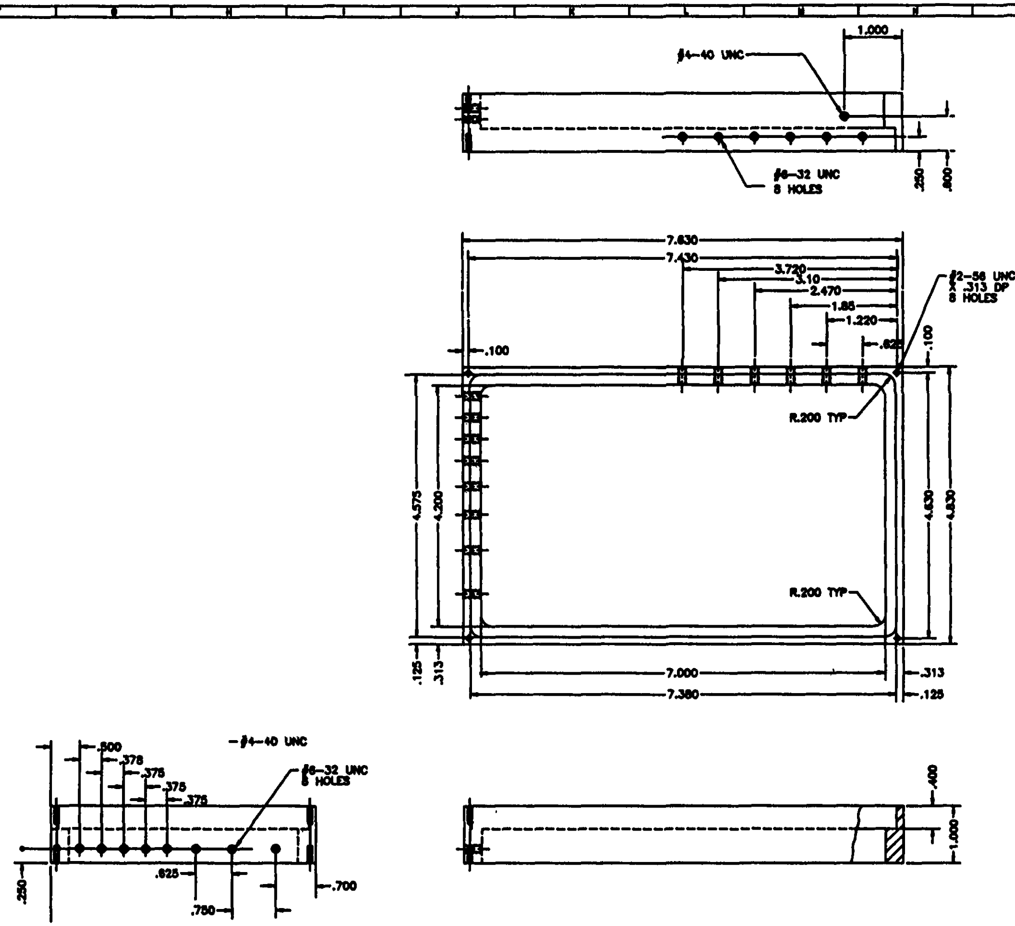
PART NO. -1 COVER PLATE

SCALE: FULL
MATERIAL: .062 THK ALUMINUM
FINISH: CHROMATE
REMOVE ALL BURRS & SHARP EDGES



PART NO. -2 BASE PLATE

SCALE: FULL
MATERIAL: .062 THK ALUMINUM
FINISH: CHROMATE
REMOVE ALL BURRS & SHARP EDGES



PART NO. -3 BOX BODY

SCALE: FULL
MATERIAL: ALUMINUM
FINISH: CHROMATE
REMOVE ALL BURRS & SHARP EDGES

NATIONAL RADIO ASTRONOMY OBSERVATORY

D35241M042