NATIONAL RADIO ASTRONOMY OBSERVATORY
SOCORRO, NEW MEXICO
VERY LARGE ARRAY PROGRAM

VLA ELECTRONICS MEMORANDUM NO. 184

VERTEX ROOM TEMPERATURE CONTROL

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1.0 HISTORY AND PRESENT STATUS

The temperature control equipment for the vertex rooms has had a long history of difficulties. As originally specified to E-Systems, the temperature was to be held at 23±1°C over a reasonable range of outside air conditions of temperature and wind, and with an internal load of 0 to 3 kW.[1] In the course of negotiations it was agreed that this temperature need only be held at the outlet duct of the temperature control equipment; NRAO would accept responsibility for delivering the controlled air to its electronic equipment.

Tests on early antennas showed that even this loose specification was not being met, and E-Systems agreed to make modifications.[2] At NRAO's request, they also agreed to supply a high air flow rate to facilitate distribution to the electronics and to minimize the temperature drop across the room. Their modified system contains a 36,000 btu/hr closed-cycle freon refrigerator and a 10 kW (38,000 btu/hr) proportionally-controlled heater, the latter connected to a room thermostat. The refrigerator was set to turn off at outside air temperatures below 55°F. The arrangement met our specification over periods of a few days in winter (refrigerator off) and summer (refrigerator fully on). But there were two major problems: when the refrigerator turned on or off, the change in load on the heater normally took the latter out of its control range; and, even when in range, the gain of the heater control loop was too low to hold the temperature within the ±1°C specification for large variations in outside air temperature. Thus, our specification was still not being met; nevertheless, NRAO has been accepting this equipment from E-Systems.

To improve the performance, modifications to the refrigeration loop have been made by the NRAO.[3] The refrigerator is now left on continuously, but its cooling rate is modulated by automatic valves according to the cooling demand, as estimated by pressure and temperature sensors within the freon loop.

Presently, the NRAO-modified equipment provides excellent performance on some antennas, with peak-to-peak variations of <0.3°C over several days (although good records of the performance over a full year of seasonal variations have not yet been obtained). However, other antennas show much worse performance, around 2°C peak-to-peak (diurnal).

In parallel with these developments, measurements have been made of the temperature stability of numerous components of the vertex room electronics[4] and much circuitry has been redesigned to reduce its temperature coefficient[5]. Specifications for critical components, especially filters[6] have required unusually small temperature coefficients, and this has caused considerable, but necessary, extra cost. We thus believe that the temperature stability of the electronics now approaches the state of the art, and that further improvements in performance must come from tighter temperature control.

To reduce temperature variations connected with antenna movement in elevation, temperature-controlled air has been ducted directly through B-Rack before being discharged into the room. The forced flow rate has been made much greater than that due to thermal convection in any orientation. Similar ducting is planned for A-Rack.

2.0 PERFORMANCE REQUIREMENTS

The basic requirement that the synthesis telescope imposes on the antenna electronics is that the (complex) transfer function from the antenna feed to the correlator be as stable as possible. However, variations in the magnitude of the transfer function are minimized by ALC loops, and residual variations are continuously monitored and can be corrected (at least for continuum operation) in a post-correlation computer. Thus we are concerned primarily with the stability of the phase of the transfer function.

Table I gives a breakdown of the electronic subsystems which affect phase stability, along with their measured or estimated phase coefficients of vertex room temperature. The coefficients are given for an observing frequency of 1.4 GHz, at the low end of the VLA's frequency range, because the required stability is greatest there; this is because tropospheric inhomogeneities cause phase fluctuations which increase with frequency, and we desire the stability of the electronics to be always better than that of the troposphere. The measured values in the table are derived from results given by Bagri.[4] The estimate for the front end is based on assuming that most of the temperature coefficient is due to filters in modules F7 and F8; their coefficients have been tightly specified[6][1]. The table also gives an estimate of the amount of phase variation not related to vertex room temperature; this includes the

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[1] A measurement by Bagri[3] gives a coefficient for the front end ten times worse than that used here. It is thought that there may have been a failure of some front end component during this measurement; it should be repeated.

TABLE I: PHASE ERRORS AT f_{obs} = 1.4 GHz, BY SUBSYSTEM

Subsystem	$\Delta\phi_{1.4}/\Delta T_{VR}$	$\Delta\phi_{1.4}$, Other[1]	$\Delta\phi_{1.4}$ Total	
			ΔT_{VR}=1°C	ΔT_{VR}=0.5°C
Front End	0.3°/C [1]	0.1°	0.4°	0.25°
LO Transmission (T1/T2)	.05 [2]	0.0	.05	.03
Antenna LO				
600 MHz Recovery	0.1 [2]	0.05	0.15	0.1
3.4 GHz Synthesis[3]	0.7 [2]	.05	0.75	0.4
3.2 GHz Synthesis	0.1 [1]	.0	0.1	.05
IF Transmission (T2/T1)	0.4 [2]	.0	0.4	0.2
Waveguide Effects[4]	0.0	0.2	0.2	0.2
Central LO				
600 MHz Recovery	0.0	0.1	0.1	0.1
RT & Detector Error	0.0	0.3	0.3	0.3
		0.8	2.45	1.63

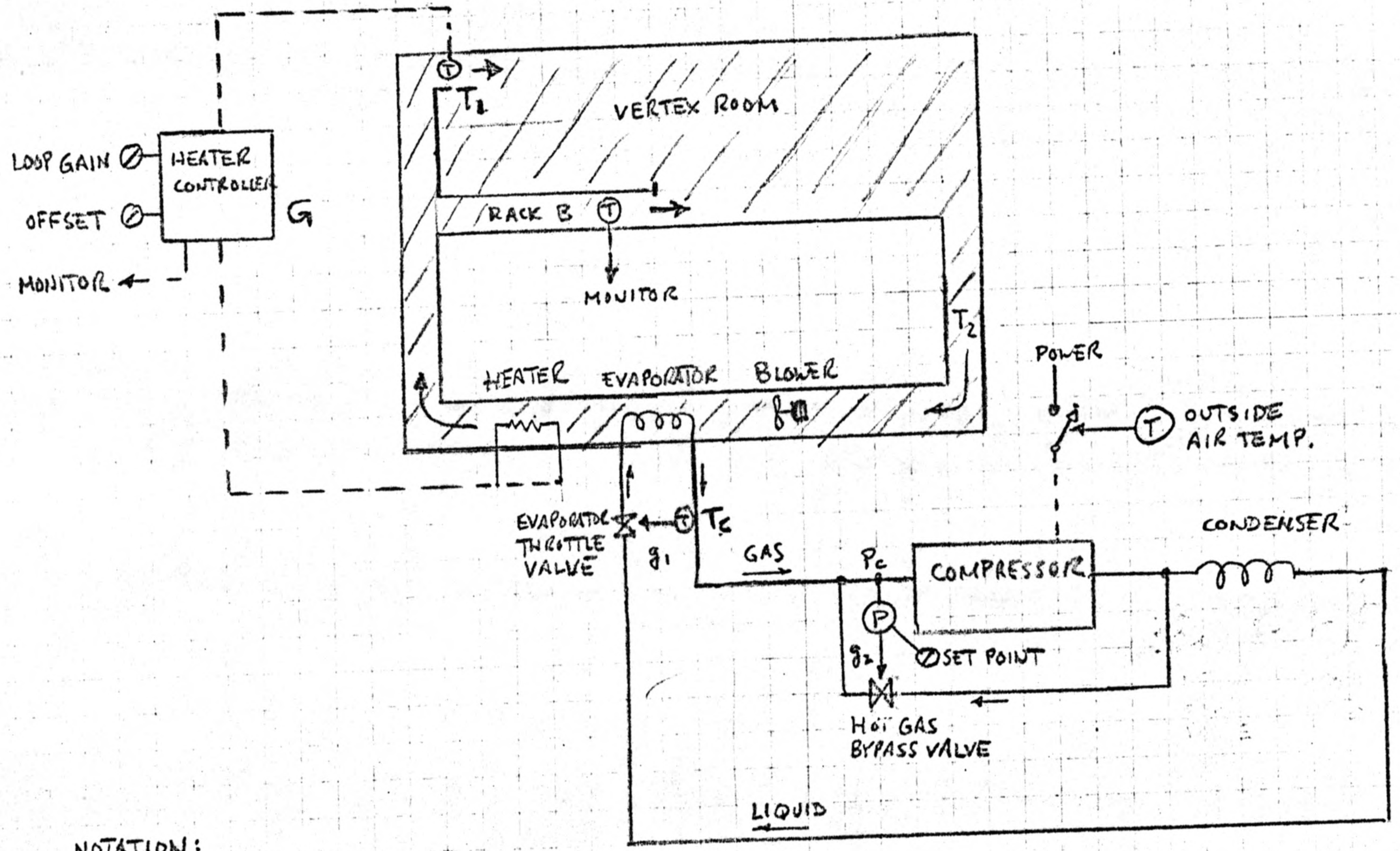
NOTES:
1. Estimated.
2. Bagri, D., VLA Electronics Memorandum No. 168, March, 1978.
3. Most of the phase shift in the 3-4 GHz synthesis occurs in the L7 (fringe rotator) module.
4. The main waveguide effect considered is nonreciprocity of the outgoing and return paths.

effects of variations in signal levels, uncorrected waveguide length changes, and central electronics room equipment. Unfortunately, the sign of the temperature coefficients given in Table I is in most cases not known. Thus, only a worst-case estimate of the net coefficient is possible. The final columns of the table give estimates of the total phase variation for two different temperature variations, adding all subsystems with the same sign.

A goal of the electronics design effort has been to achieve a phase stability of $1.0° \times (f_{obs}/\mathrm{GHz})$, where f_{obs} is the observing frequency, or 1.4° in the case considered here. This figure is somewhat arbitrary, but was based on a rough guess of minimum tropospheric instability. There is some confusion over whether this goal should be regarded as a maximum rms, peak, or peak-to-peak deviation. Specifying only the allowed rms deviation, without further specifying the temporal autocorrelation function, places only a weak constraint on the system because it allows poor performance some of the time if good performance is achieved at other times. I consider this undesirable, and therefore will take the stability goal as a maximum peak deviation. Table I was constructed with this in mind. Apparently, then, our design goal can be achieved, within the errors of estimation in the table, if the peak temperature variation of the vertex room electronics is held to $\lesssim 0.5$°C (1.0°C peak-to-peak). Slightly better performance than predicted may occur because some (but not most) of the temperature coefficients will cancel.

3.0 PRESENT TEMPERATURE CONTROL EQUIPMENT: THEORY OF OPERATION

Consider the schematic diagram of Figure 1. Air taken from the vertex room outlet at temperature T_2 is forced by a blower to exchange heat with an evaporator (cooler) and a



NOTATION:

Ⓣ TEMPERATURE SENSOR
Ⓟ PRESSURE SENSOR
⋈ VALVE
– – – ELECTRICAL SIGNAL
⊘ SCREWDRIVER ADJUSTMENT

VERTEX ROOM TEMP. CONTROL
SCHEMATIC DIAGRAM

LRD 790508

FIGURE 1

heater. It is then returned to the room at temperature T_1. The latter temperature is monitored by a sensor, which then controls the heater. The system can be modeled by the following equations in the steady state:

$$T_1 = T_2 + \frac{C_v}{f}(q_c + q_H) \tag{1}$$

$$q_H = G(T_1 - T_0) + q_{H0} \tag{2}$$

where C_v is the specific heat of air at constant volume; f is the volume flow rate produced by the blower; q_c, q_H are the rates of heat addition (power dissipation) due to the cooler and heater, respectively; G is the gain of the heater controller; and T_0 is the controller's set point. Equation (2) assumes that the controller produces a zero-order loop.[2] We also have

$$T_2 = T_1 + \frac{C_v}{f}(q_{elec} + q_{ext}) \tag{3}$$

where q_{elec} is the power dissipated in the room by electronic equipment and q_{ext} is the heat inflow from external sources (through the walls).

Combining (1) and (3) we find

$$q_H = -(q_c + q_{elec} + q_{ext}), \tag{4}$$

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[2] The controller manufacturer is reluctant to discuss its design, but experimental evidence shows that the assumption is valid. See also Appendix B.

and using this in (2) gives

$$T_1 - T_0 = \frac{1}{G}(q_{H0} - q_c - q_{elec} - q_{ext}). \tag{5}$$

Also, using (4) in (1) gives

$$T_1 - T_2 = \frac{C_v}{f} (q_{elec} + q_{ext}). \tag{6}$$

Equation (6) shows that the temperature drop across the room varies directly with the internal and external heat load, and can only be reduced by increasing the air flow rate f. In equation (5), we can assume that the first and third terms on the right are constants; if the cooling rate q_c remains constant, then variations in the external load q_{ext} induce variations in the control point temperature T_1 proportional to G^{-1}. (Actually, q_c does not quite remain constant, because the control valves in the cooling circuit tend to compensate for variations in q_{ext}, as discussed below). But when power to the compressor is switched on or off, a step charge occurs in q_c, and (5) shows that a similar step must occur in T_1 (unless G is infinite).

The cooling circuit functions approximately as follows. Liquid freon is supplied to the evaporator, where it gains sufficient heat from the airstream to become a gas; the gas is compressed, and then loses sufficient heat to the ambient air at the condenser to become a liquid again. The compressor provides a fixed flow rate of freon, but the flow through the evaporator and condenser are modulated by control valves according to the cooling demand. Suppose, for example, that G is large so that T_1 is held relatively constant. Then (6) shows that a decrease in q_{ext} will cause a decrease in T_2.

This will tend to cause a decrease in the evaporator outlet gas temperature; the latter is sensed and causes the evaporator throttle valve to close, decreasing the freon flow rate and increasing q_c (making q_c less negative). In (5), this tends to compensate the decrease in q_{ext}, keeping T_1 constant even if G is not extremely large. However, for practical reasons the range of control available with the throttle valve is limited; when it is closed as far as possible (approximately 70 to 80% of fully open), a further decrease in q_{ext} and T_2 causes a drop in temperature throughout the freon circuit. At the compressor inlet, this causes a decrease in pressure; the pressure change is sensed and causes the hot gas bypass valve[3] to open, thereby reducing the freon flow rate through the condenser and evaporator, thus once again increasing q_c.

The cooling loop thus operates so as to force q_c to be a monotonically decreasing function of T_2. Quantitative analysis of the system faulters at this point, because the function $q_c(T_2)$ is not known. In practice, components have been sized and adjusted empirically.

4.0 EXPERIMENTAL RESULTS

4.1 Effect of Hot Gas Bypass Modification

Figure 2 and 3 show the behavior of the temperature control systems at antennas 1 and 10 just before and just after the installation of the NRAO hot gas bypass modification. It should be apparent that the major effect of the modification is to reduce the capacity of the cooling circuit by a constant amount, since the heater power required for similar outside air temperatures has been reduced. This is more evident in Figures 4a and 4b where the heater

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[3] The hot gas bypass is an NRAO-designed modification [3], whereas the evaporator throttle valve was part of the original equipment.

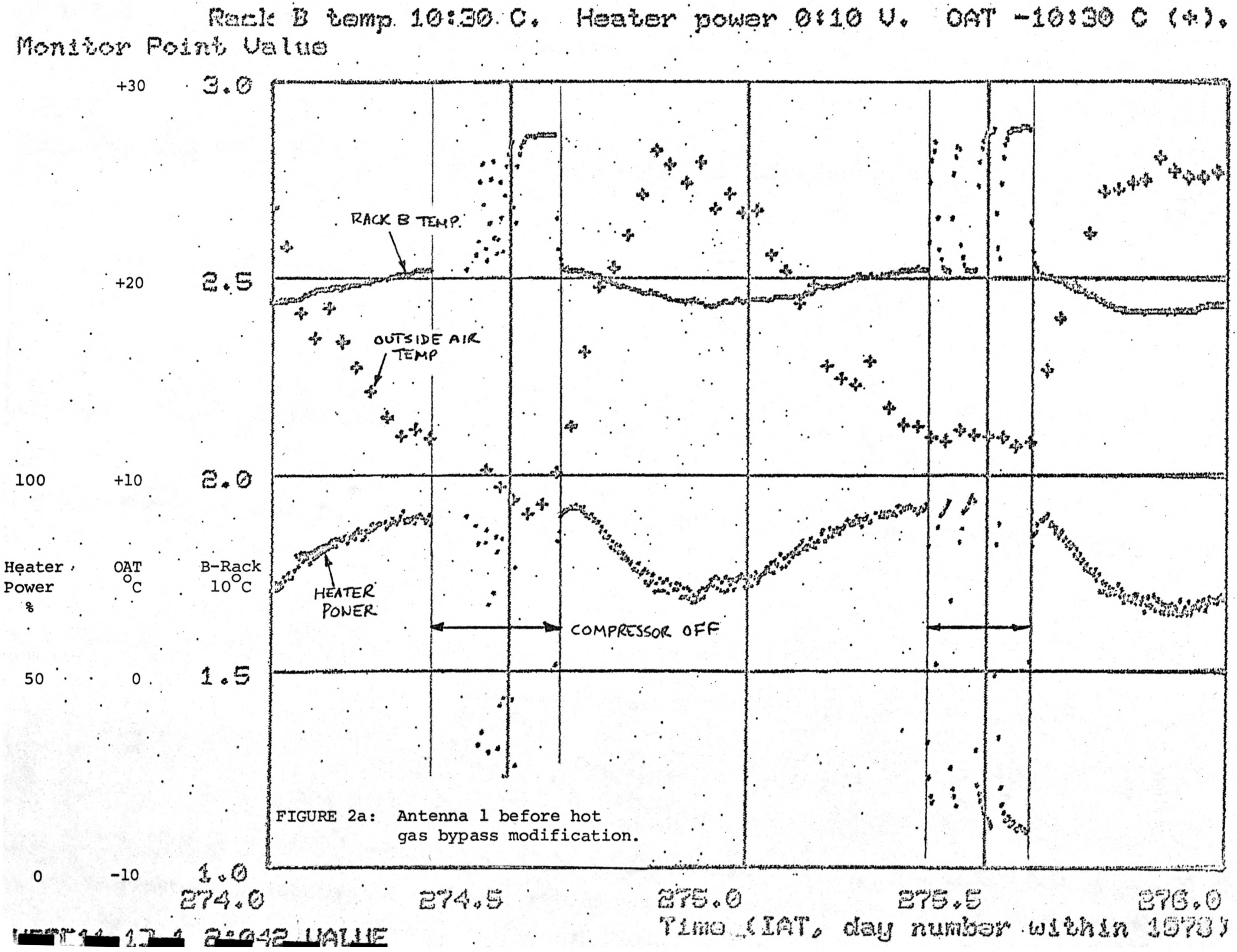


FIGURE 2a: Antenna 1 before hot gas bypass modification.

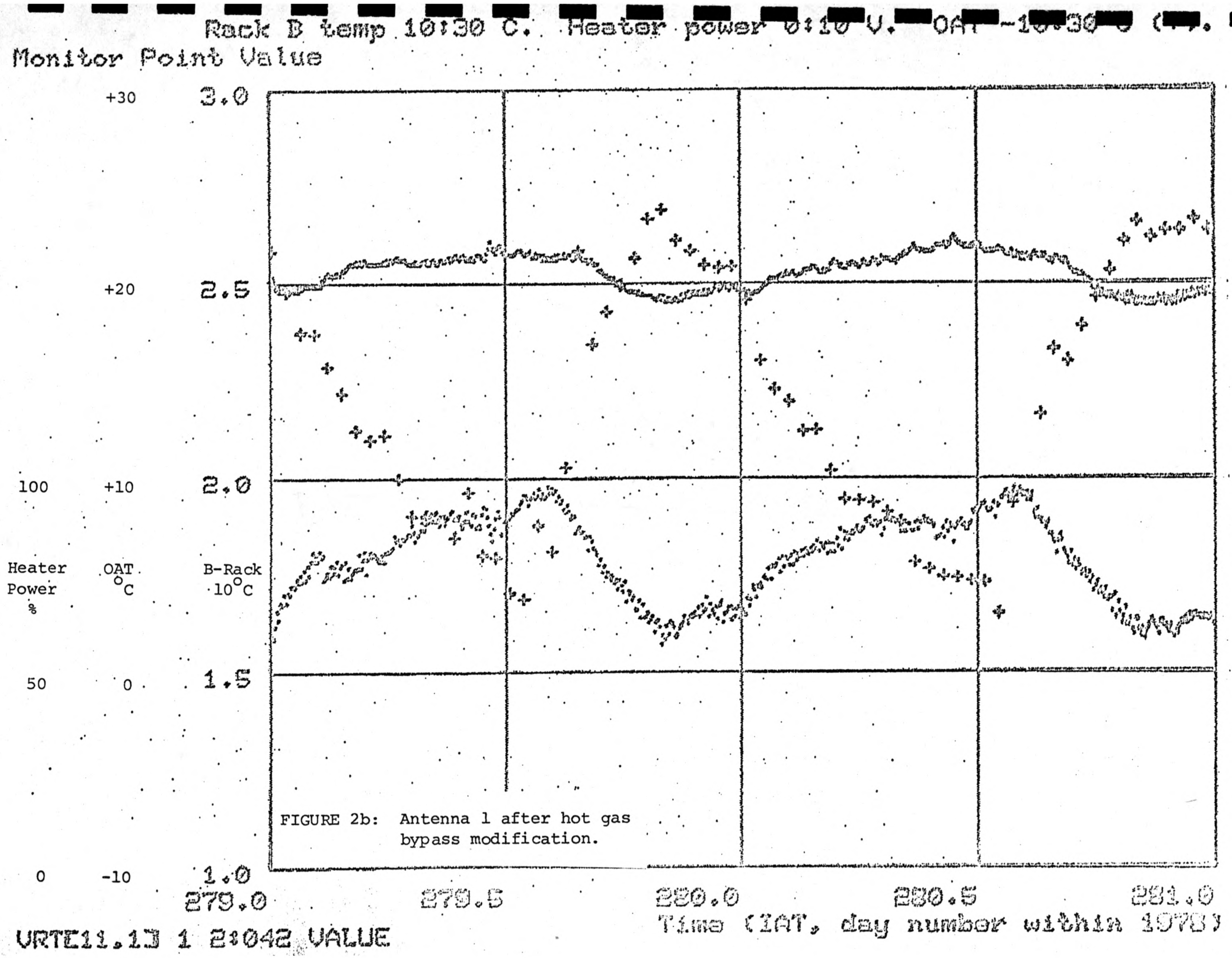


FIGURE 2b: Antenna 1 after hot gas bypass modification.

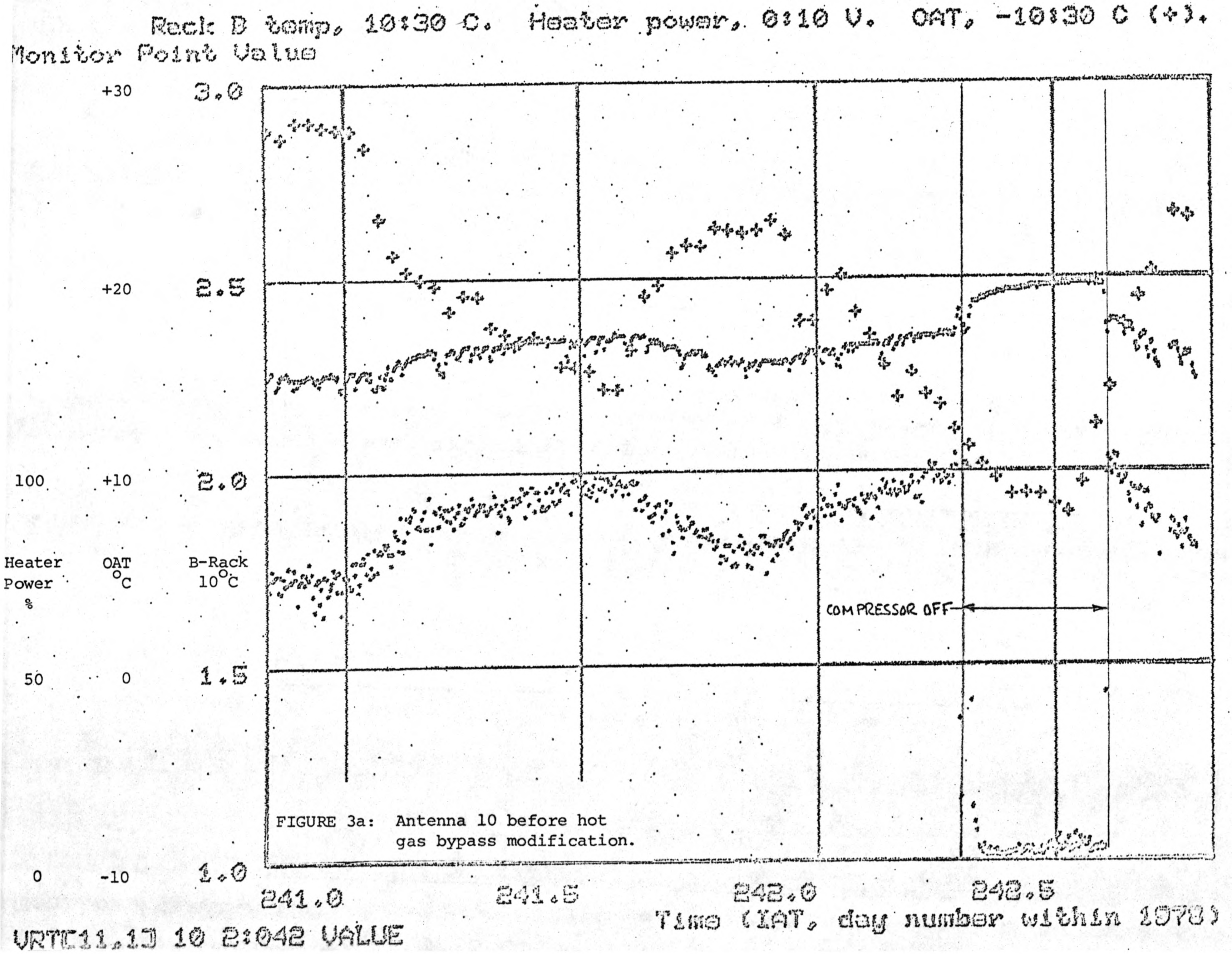


FIGURE 3a: Antenna 10 before hot gas bypass modification.

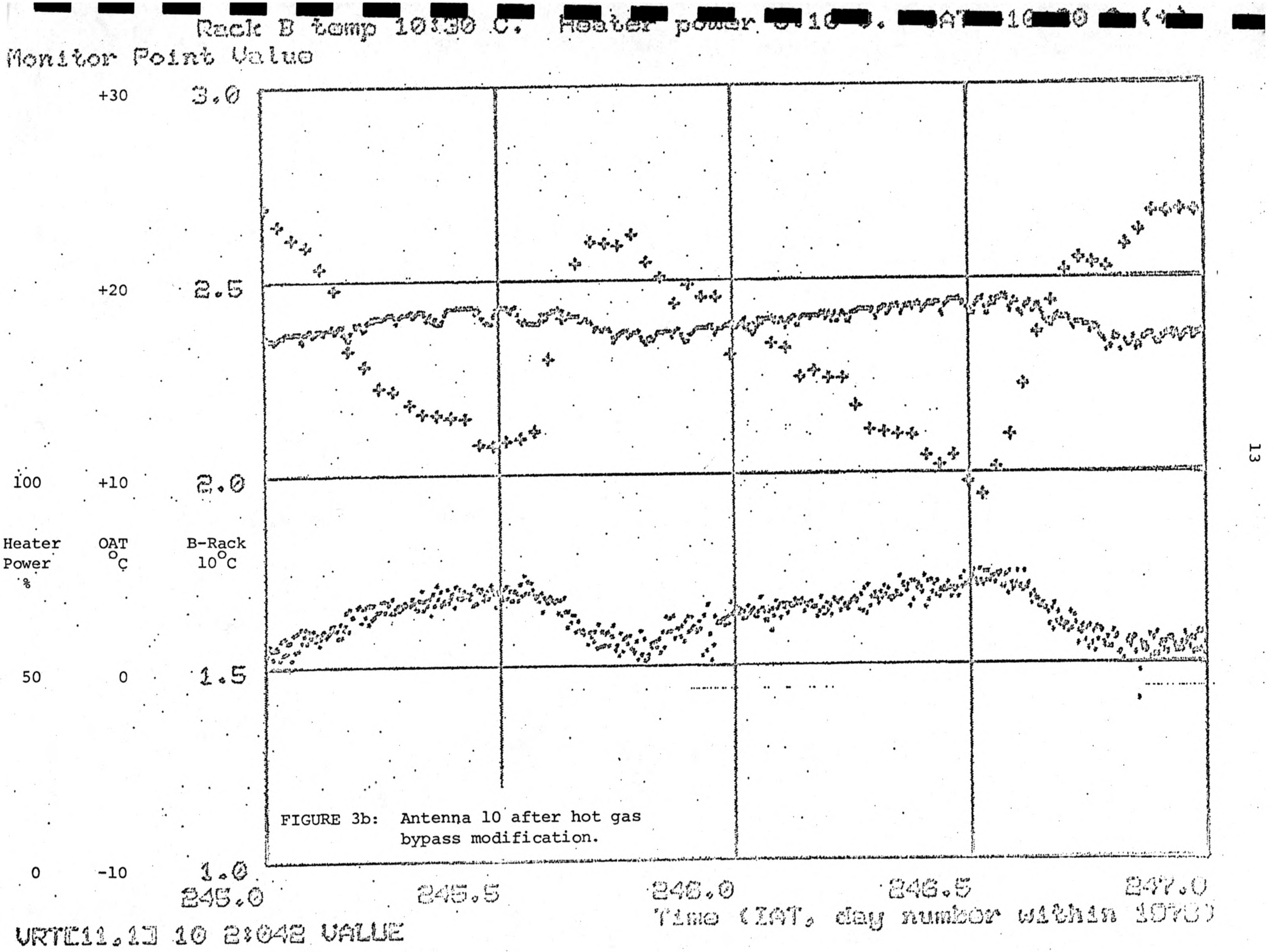


FIGURE 3b: Antenna 10 after hot gas bypass modification.

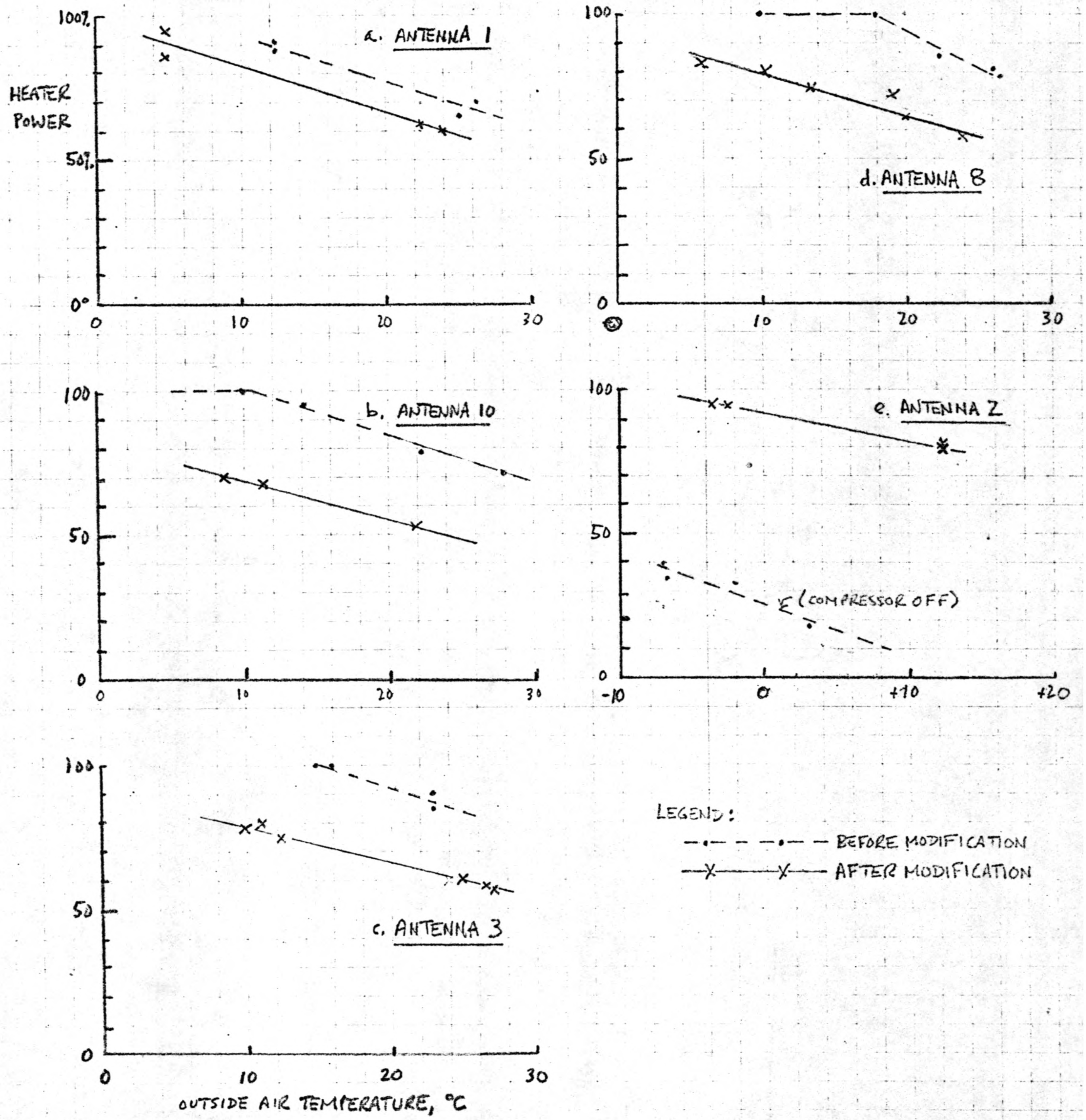


FIGURE 4

Heater power vs outside air temperature. a, b based on data from Figures 2 and 3 respectively; others based on similar data.

power is plotted against outside air temperature for these same antennas. Note that the slope of this relationship is not significantly changed by the modification, indicating that the hot gas bypass is not significantly modulating the amount of cooling over the observed range of outside air temperature. Plots similar to Figures 1 and 2 have been prepared for nearly all antennas; all behave about the same. Figures 4c-4e give the heater power vs. outside air temperature for several additional antennas.

It should be apparent from Figure 4 that for most antennas considerably more reduction in cooling capacity would be desirable, since even at high outside air temperatures (30°C) the heater is operating at 50% power. The slopes of the curves indicate that for most antennas a 60°C temperature range can be accommodated without exceeding the heater control range. This should be adequate to handle all but very unusual conditions at the VLA Site (if set at, say, -20 to +40°C). Additional range could be obtained by turning off the cooling compressor when the heater output power exceeds the cooling rate. Of course, the range obtained depends on how well insulated the vertex room is, and care must be taken that the insulation is not disrupted when new cables, pipes, waveguides, etc. are installed.

The data show clearly that both the heating and cooling capacity are very much greater than is needed. Perhaps the design calculations made by E-Systems[7] were too conservative in the estimate of the thermal resistances of the room boundaries.

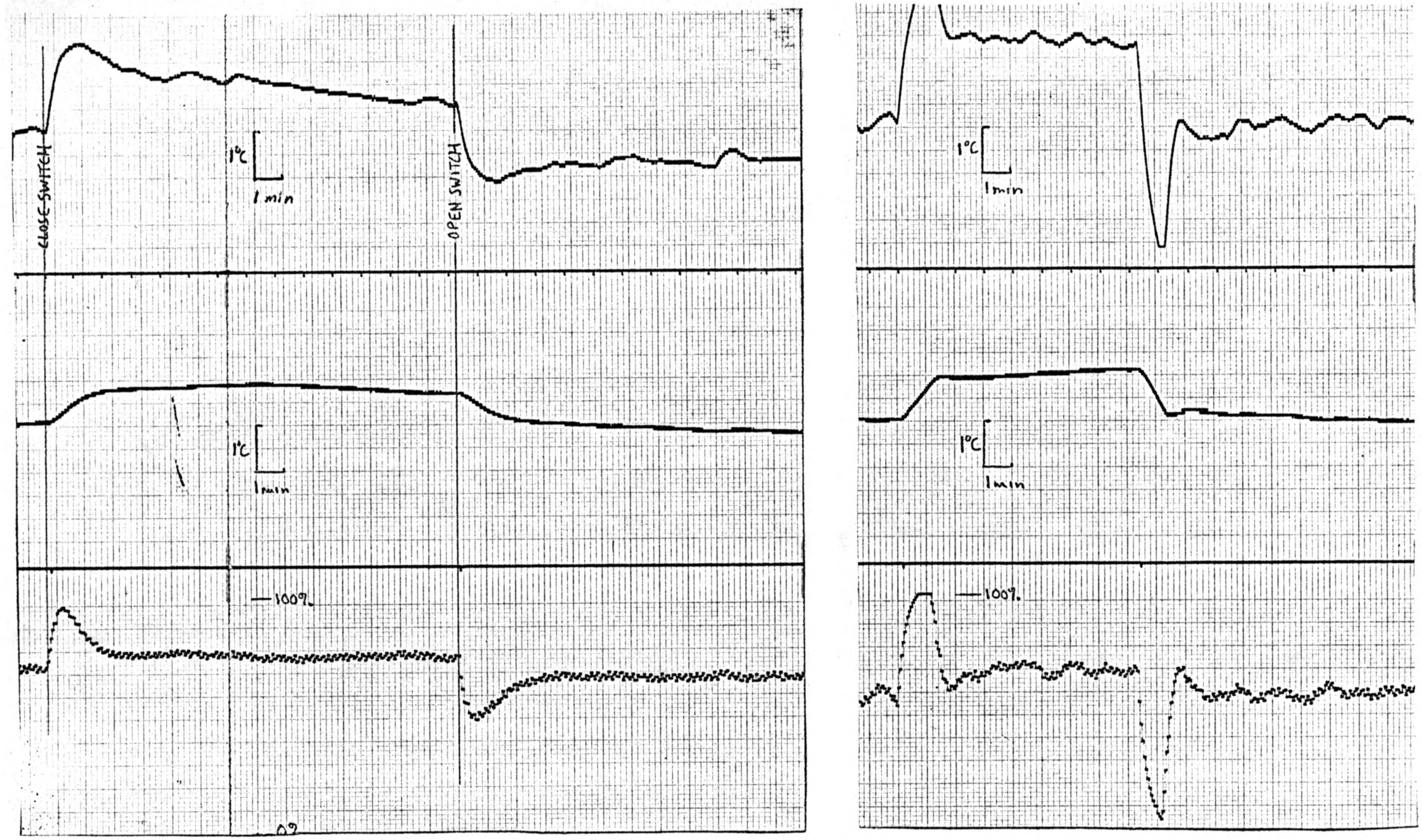
4.2 Behavior of the Heater Control Loop

In order to observe the step response of the heater control servo loop, a resistor and switch were connected across the thermostat control potentiometer at antenna 3 so that closing the switch produced about a 1°C increase in the thermostat setting. (The thermostat consists of a thermistor imbedded in a resistive bridge.) A chart recording was then made of the heater power, thermostat temperature, and Rack B temperature; the records are reproduced in Figure 5. The experiment was repeated at various gain ("span") settings of the heater controller. During the experiment, the outside air temperature was 23°C.

These significant phenomena were noted:

(1) At maximum gain, the loop oscillates with a period of about 48 seconds (Figure 5d). According to the manufacturer's literature (see Appendix A), maximum gain should correspond to a 100% change in output for a 1.1°C (2°F) change in thermostat temperature, and minimum gain should be 100% per 5.4°C (10°F). Although this is nominally a zero-order loop, which ideally would be unconditionally stable, the controller actually operates on a discrete 3.3 second time base; full power is applied to the heater for a fraction of this time proportional to the error voltage from the thermostat, and zero power is applied the rest of the time. Thus, a full analysis would require that the system be treated as a discrete-time (sampled) loop. Also, the heat capacity of the room and air plus the nonzero time required for a parcel of air to circulate contribute at least one pole to the closed loop response. Oscillation at high gains is therefore not surprising. To achieve high dc gain without oscillation, a higher-order loop is required.

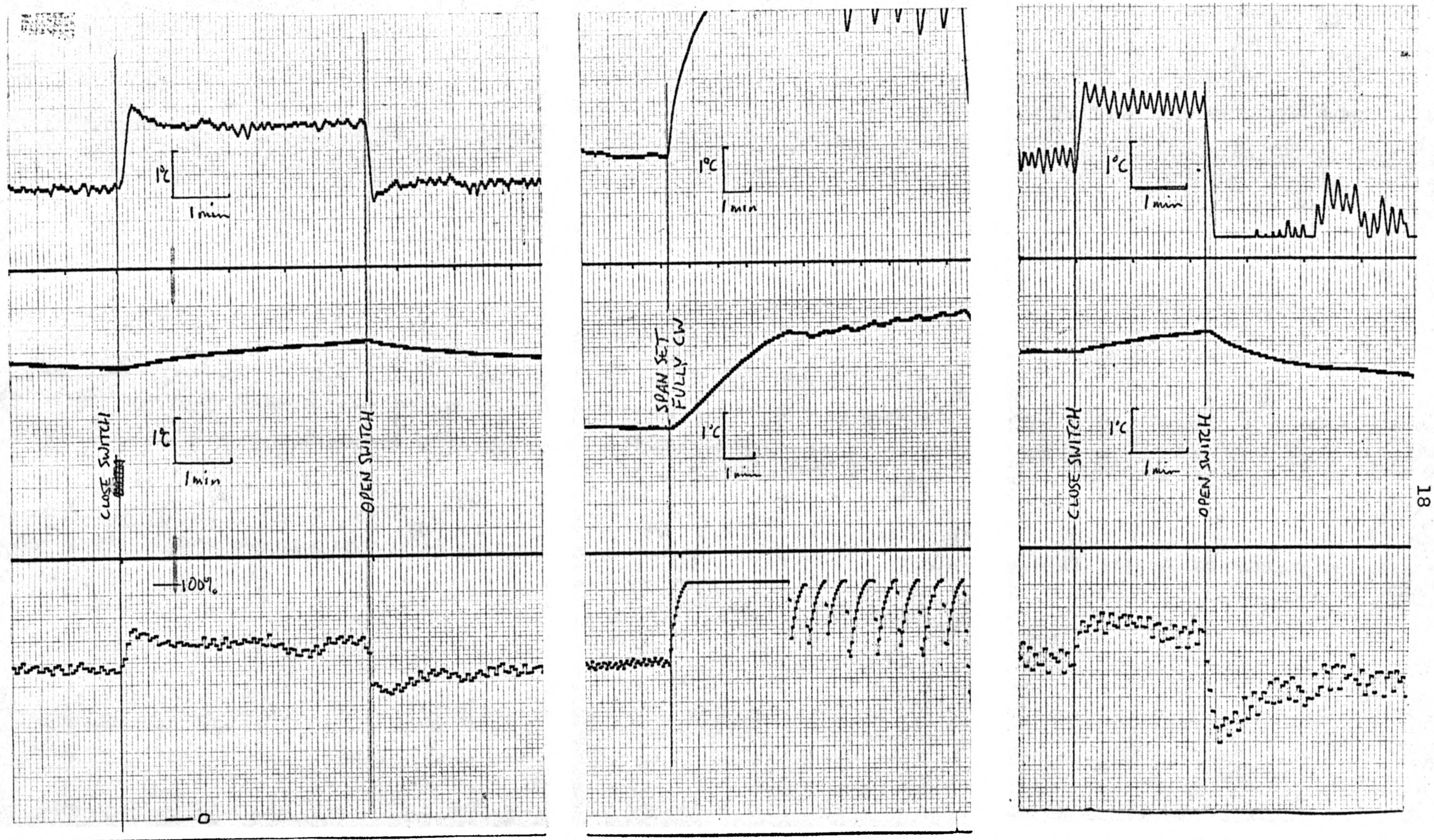
(2) At lower gains, a closed-loop time constant of about 60 seconds was observed in the heater current and thermostat temperature (Figures 5a, 5b). The Rack B



a: Thermostat behind Rack A, "span" fully counterclockwise
(minimum gain).
Overshoot 200-300%; 70 sec to peak response.
No oscillation.

b: Thermostat behind Rack A, "span" 80%
clockwise.
Overshoot 550%; 60 sec to peak response.
Oscillation period, 95 sec.

FIGURE 5: Transient response of VR temperature control loop. In every case, time increases from left to right and the three traces are, from top to bottom: temperature at the thermostat, temperature inside Rack B and heater power. Thermostat settings were varied slightly in order to keep the heater controller within its range.



c: Thermostat at louver nearest to heater, span 80% clockwise. Overshoot 50%; 20 sec to peak response. No oscillation.

d: Thermostat behind Rack A, "span" fully clockwise (max gain). Oscillation period, 48 sec.

e: Thermostat at louver nearest heater; span fully clockwise.

Oscillation period, 9 sec.

FIGURE 5: Continued

temperature showed a much slower response, presumably because of the heat capacity of the rack and modules. (The Rack B thermometer measures the temperature of the free air after it passes through two of the four bins of modules.)

(3) Moving the thermostat from its original location (at the louver which discharges air into the room behind A-Rack) to the louver closest to the heater causes a significant increase in the response speed and reduces the tendency to oscillate at high gains (Figures 5c, 5e).

4.3 Temperature Drop Across Room

A portable electronic thermometer (Yellow Springs Instrument Co. Model 43TC) was used to check the temperature at various points in the air circulation over a short period of time. The results are summarized in Figure 6.

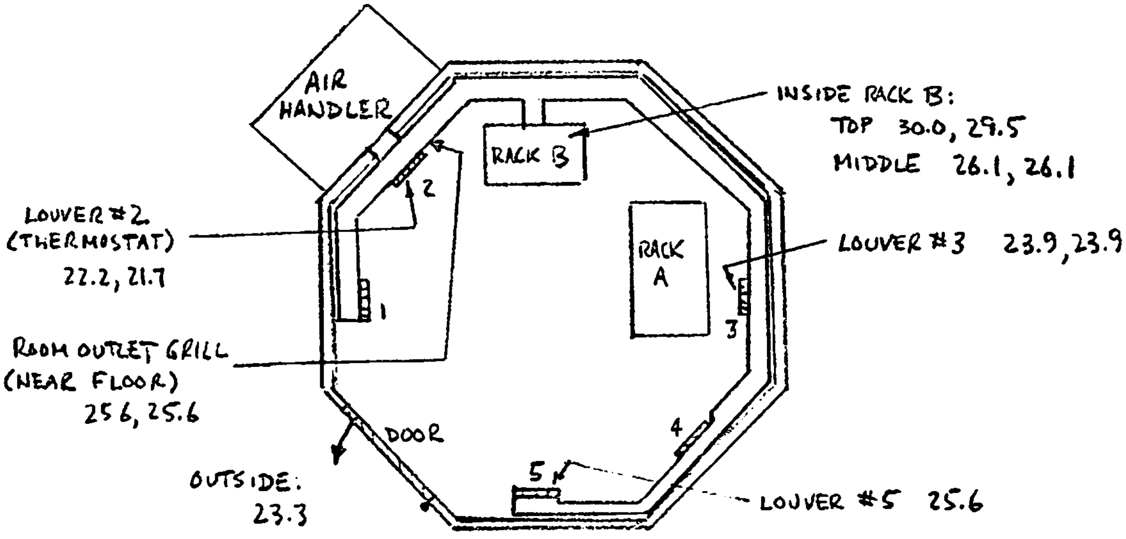


FIGURE 6: Plan view of vertex room with temperatures measured at antenna 3. Temperatures are in degrees C; first number is with all louvers open, second number with louvers 1, 4 and 5 closed.

The measurements were made with the thermostat mounted at louver #2, nearest to the heater. The temperature drop from the thermostat to the room outlet was about -4°C. Note that the outside air temperature was close to the room temperature at the time of these measurements; at more extreme outside temperatures, the magnitude of the drop should be larger. No significant change was seen when some of the louvers were closed.

5.0 RECOMMENDATIONS

5.1 Thermostat Location

In order to obtain the tightest control without oscillation, the thermostat should be close to the heater. The time required for air to flow from the heater to the present thermostat location (in the duct behind Rack A) probably accounts for most of the time constant observed in Section 4.2 above. Consideration could be given to placing the thermostat on a particularly temperature-sensitive component further downstream; but the control response would then be dominated by the thermal properties of materials near that component, and parallel air paths would be subject to larger temperature fluctuations. The thermostat must therefore be in the common airstream, and need only be far enough from the heater to ensure that the air is well mixed. I propose placing it in front of the first louver which discharges air from the duct into the room; i.e., the louver closest to the heater and upstream of the ducting to both Rack B and Rack A.

5.2 Modification of Heater Control Loop

The servo loop should be modified to provide an integrator between the thermostat and the present proportional controller. This will create a nominal first-order loop, with very high dc gain and hence tight controls. To insure stability, the integrator rate will have to be slow, perhaps 100 seconds for a full-scale change, but this should be adequate to track changes in thermal load caused by outside temperature changes and antenna tipping. Consideration should be given to digital implementation.

Details of the operation of the present controller are given in Appendix B.

5.3 Cooling Circuit Adjustment Procedure

As shown in Figure 1, the set point of the hot gas bypass valve is adjustable. To obtain a heater control range of, say, -20 to +40°C, the valve should be set to obtain a cooling rate which causes the heater to operate at 50% when the outside air temperature is +10°C. Since it will be inconvenient to wait until the outside air is just +10°C before making the adjustment, a chart can be constructed which gives the nominal heater output for each outside air temperature. The set point of the hot gas bypass valve should then be adjusted to obtain the specified heater output corresponding to the outside temperature at the time the adjustment is made. Of course, after each trial adjustment, sufficient time must be allowed for the system to come to equilibrium before reading the heater output; this may amount to 10-20 minutes.

5.4 Cooling Circuit Shutdown in Cold Weather

In order to waste less input energy, as well as to increase the total control range, it may be desirable to shut down the cooling compressor in cold weather. In order to avoid loss of temperature control, it is essential that the shutdown occur only when the heater output exceeds the cooling rate. Even then, the large change in heater output required would necessitate a large change in equilibrium temperature if the zero-order loop is retained; but this should not occur with the first-order loop suggested in Section 5.2 above.

The present system includes an outside air thermostat to control the compressor. This may be adequate, but a preferable method would be to tie the compressor control to the heater output power. It is unlikely that the cooling rate will be greater than 70% of the heater power (i.e., 7 kW or 24,000 btu/hr) for any antenna, so the compressor could be shut down when the heater output exceeds 70%. In this case, the 50% point might be raised to +20°C, making the control range about +8 to +50°C with the compressor on, and -40 to +8°C with the compressor off (assuming 5 kW cooling rate and 6°C/kW thermal resistance to outside).

5.5 Insulation of Air Ducts

The data presented in Section 4.3 show that a large temperature drop occurs across the room, even at a moderate outside temperature. This is not a serious problem if the temperature of the air delivered to the racks can be held constant. But the data also shows that half of the temperature drop occurs by the time the air reaches Rack A, and virtually all of it occurs by the time air is discharged from louver #5. To stabilize the temperature of the rack air in the presence of large variations in external load [cf., equation (6)], the ducting from the thermostat to Rack B and Rack A should be heavily insulated.

REFERENCES

[1] NRAO. Request For Proposal VLA-6; Antenna Procurement, Paragraph 03.2.6.1.

[2] NRAO. Amendment 20 to RFP VLA-6.

[3] delGiudice, W. Report in preparation.

[4] Bagri, D. S. 1978, "Phase Stability of Some Components and Subsystems in VLA Electronics." VLA Electronics Memorandum No. 168.

[5] Bagri, D. S. 1978, "50 MHz Harmonic Generator," VLA Technical Report No. 33; "LO Transmitter," VLA Technical Report No. 34; "Modifications in 1977 to Some of the LO Modules," VLA Technical Report No. 36.

[6] NRAO Specifications A13190N1 thru A13190N7.

[7] B. E. Duff 1977, "Vertex Room Air Conditioning." E-Systems design notes dated 1-27-77.

APPENDIX A
MANUFACTURERS' LITERATURE

Major components of the vertex room temperature control equipment include the following:

1. Electric heat controller, Johnson Service Company model DQ-4401-16.
2. Compressor unit, General Electric model BTR036A300A0.
3. Resistance heating element, Gould Inc. model DC3000B.
4. Air handler, General Electric model BWE060C400B0 (providing a measured air flow rate of approximately 1500 ft^3/minute).
5. Temperature sensing element (thermistor and potentiometer, for room air thermostat), Johnson Service Company model TE-2800.

Selections from the manufacturers' literature for items 1 and 2 are reproduced in the following pages.

JOHNSON SERVICE COMPANY
507 EAST MICHIGAN STREET • MILWAUKEE, WISCONSIN 53201

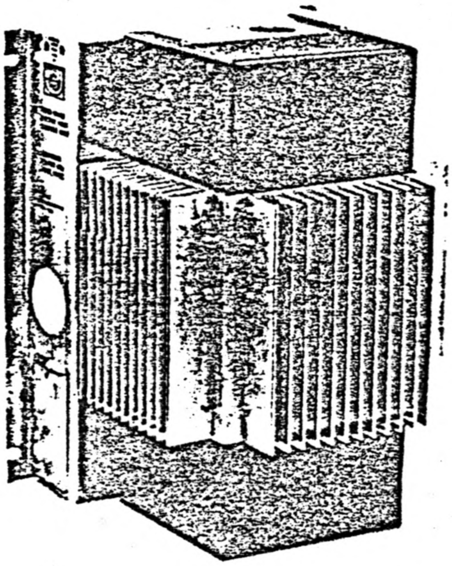
PRODUCT
DATA
DQ-4400

JOHNSON DQ-4400
Solid-State Three-Phase Electric Heat Control Units

The Johnson DQ-4400 Solid-State Electric Heat Control Units provide time proportioning control of 3-phase electrical power to electric resistance heaters. The zero phase-angle switching technique is utilized in all models to minimize radio frequency interference and waveform distortion in the power lines.

Models

DQ-4400 models are furnished with various combinations of line current ratings, 3-phase supply voltages and control input signals. The 208/240 and 416/480 volt models are furnished with a tap on the power supply transformer to facilitate changing the respective 208 and 480 volt factory wiring to 240 and 416 volts respectively, in the field. Pneumatic input models have an integral transducer that converts the 0 to 20 psig signal from the pneumatic controller to a proportional electronic signal to operate the electric heat control unit. Universal electronic input models have a slide-switch to select the appropriate electronic control signal; 0 to 135 ohm proportional resistance control signal, thermistor temperature sensor input, or 0 to 16 volt D.C. proportional control signal. A DQ-4400 universal electronic control input model can be used as a slave unit for any other DQ-4400 unit by selecting the 0 to 16 volt D.C. control mode on the unit used as the slave.



DQ-4400 Universal Electric Heat Control

Zero and span adjustments are provided; the zero adjustment is used to vary the starting point and the span adjustment determines the change in control signal required to modulate the output between 0 and 100%.

Operation

DQ-4400 units contain a timing circuit, a trigger circuit and a power control circuit (SCR and

Specifications

PRODUCT		DQ-4400 THREE-PHASE ELECTRIC HEAT CONTROL UNITS
CONTROL INPUTS	PNEUMATIC	0 TO 20 psig FROM PNEUMATIC CONTROLLER
	UNIVERSAL ELECTRONIC (MANUAL SELECTION)	0 TO 16V D.C. CYBERTRONIC CONTROL SIGNAL, 0 TO 135 OHMS FROM TRANSDUCER OR THERMOSTAT, OR RESISTANCE INPUT FROM THERMISTOR TEMPERATURE SENSOR
SUPPLY VOLTAGES		208/240, 416/480 OR 600 VOLTS, 50/60 Hz, 3–ϕ
MAXIMUM LINE CURRENTS		20, 30 OR 50 AMPERES
MINIMUM CURRENT		5 AMPERES
TIME BASE		3.3 SECONDS
ADJUSTMENTS		ZERO AND SPAN
AMBIENT TEMPERATURE LIMITS		32 TO 120F (0 TO 49C)
OVERLOAD PROTECTION		FUSES FOR ALL MODELS (ORDER SEPARATELY)

diode) for each phase. The timing circuit establishes a time base of 200 cycles (400 half cycles) of the 60 Hz power line frequency. The control signal determines the number of cycles within the time base during which the SCR's will conduct. The trigger circuit generates a signal to turn on the SCR's and synchronizes this firing with the respective line voltage of each phase. The SCR's switch power to the heater only when the voltage is zero and just increasing.

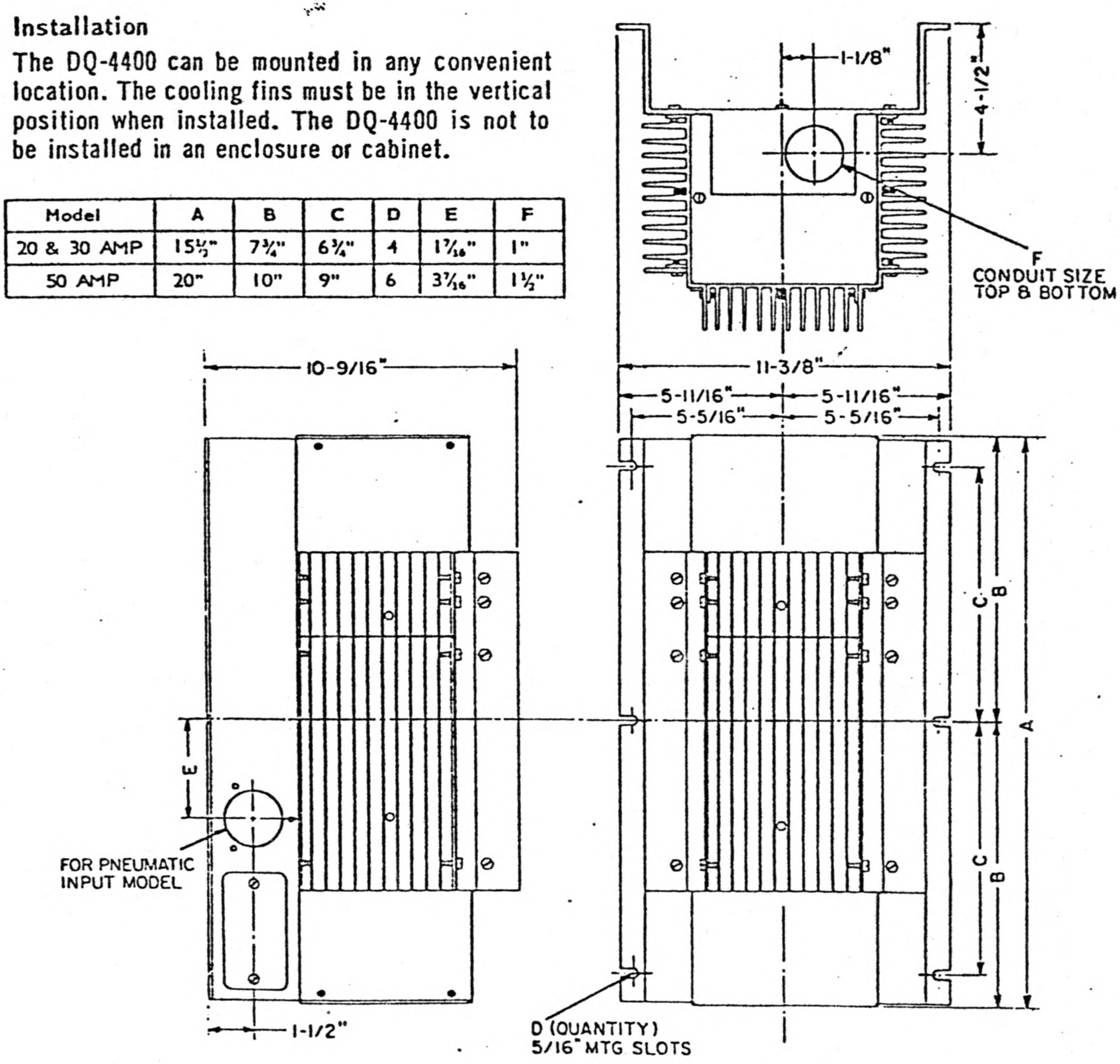
Installation

The DQ-4400 can be mounted in any convenient location. The cooling fins must be in the vertical position when installed. The DQ-4400 is not to be installed in an enclosure or cabinet.

Model	A	B	C	D	E	F
20 & 30 AMP	15½"	7¾"	6¾"	4	1⁷⁄₁₆"	1"
50 AMP	20"	10"	9"	6	3⁷⁄₁₆"	1½"

The 50 amp DQ-4400 has two 1-1/2" conduit openings; the 20 and 30 amp models each have two 1" conduit openings for high voltage wiring. The control signal connections are in an attached handi-box. All wiring must be in accordance with applicable electrical code requirements.

High speed fuses for SCR protection are available for the DQ-4400.



DQ-4400 Dimensions

variations. Place slide switch in thermistor position and proceed as follows:

Zero Adjustment

1. Adjust the set point knob to the prevailing ambient temperature conditions.
2. Adjust the span potentiometer fully clockwise.
3. Adjust the zero potentiometer, fully counterclockwise.
4. Connect the voltmeter across output terminals T1 and T2.
5. Rotate the zero potentiometer clockwise until the meter goes to zero. Then, very slowly rotate the zero potentiometer counterclockwise until the meter indicates full voltage to the heater load.

Span Adjustment

1. To adjust the span, set the set point on the sensing element assembly to the point where full power should be applied to the heater. For example, assume the ambient temperature is 72F, the zero adjustment has been made and the desired span is 4F°. To adjust the span, the set point should be set at 76F.
2. Connect the voltmeter across output terminals T1 and T2.
3. Rotate the span potentiometer counterclockwise until the meter starts pulsing. Then, very slowly rotate the span potentiometer clockwise until the meter just stops pulsing and shows full output voltage.

~~0 to 16 Volt Control Input~~

~~Place slide switch in 0 to 16 volt position and proceed as follows:~~

~~*Zero Adjustment*~~

1. ~~Adjust the input control signal to the desired starting point (0 to 12 volts D.C.)~~
2. ~~Adjust the span potentiometer fully clockwise.~~
3. ~~Adjust the zero potentiometer fully counterclockwise.~~
4. ~~Connect the voltmeter across output terminals T1 and T2.~~
5. ~~Rotate the zero potentiometer clockwise until the meter goes to zero. Then, very slowly rotate the zero potentiometer counterclockwise until the meter indicates full voltage to the heater load.~~

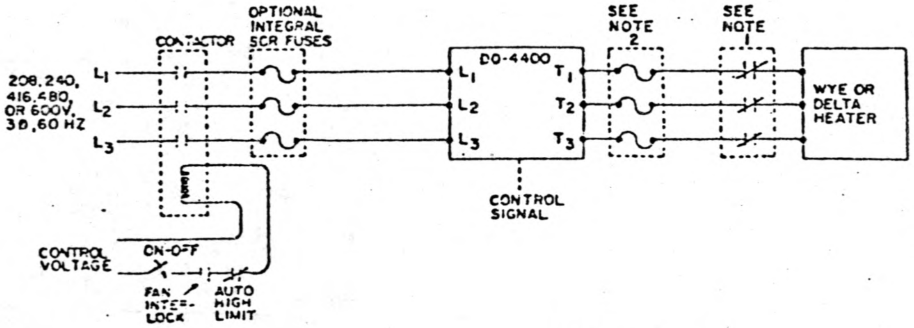
~~*Span Adjustment*~~

1. ~~Increase the control signal to an amount required to produce full power to the heater (4 to 16 volts D.C.).~~
2. ~~Connect the voltmeter across output terminals T1 and T2.~~
3. ~~Rotate the span potentiometer counterclockwise until the meter starts pulsing. Then, slowly rotate the span potentiometer clockwise until the meter just stops pulsing and shows full output voltage.~~

~~**DQ-4400 Universal Electronic Input Model Slave Application Adjustments**~~

~~To use the universal electronic input model in a slave application, place the slide switch in the 0 to 16 volt position, connect the slave to the master as shown and make the following adjustments to the slave:~~

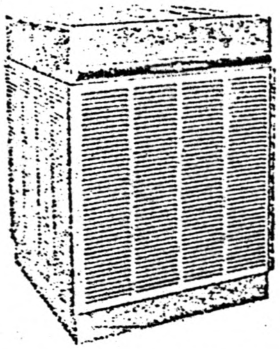
1. ~~Adjust the span potentiometer fully clockwise.~~
2. ~~Adjust the input control signal to 3.5 volts D.C.~~



NOTES:

1. Manual High Limits – If only one manual high limit is provided and cannot be connected to directly interrupt current flow, it must operate a separate contacto to de-energize the entire heater.
2. Branch Circuit Fusing – Each circuit is limited to 48 amperes per line by the N.E.C.

Wiring Diagram



BTR-A CONDENSING UNITS

23,000 — 36,000 BTUH

INDEX

VLA

MODELS ①	VOLTS	CYCLES (HZ.)	PHASE	② COOLING CAPACITY BTUH	KW COOLING ONLY	REFRIGERANT CHARGE		OIL CHARGE	MODEL VARIATIONS (SEE NOTES)	FUNCTIONAL PARTS	OPERATION – HOW IT WORKS	TROUBLE SHOOTING	REFRIGERANT CIRCUIT	SERVICE KITS	WIRING/SCHEMATIC DIAGRAMS	PERFORMANCE CURVES	CHARGING CHARTS	PARTS IDENTIFICATION	A M F S
						lbs.	oz.	oz.											
BTR924A100A0	230	60	1	23,000 – 26,000	3.3 – 3.6	4	2	32		2	3	4	6	7	9	11/12	14	15	30
BTR930A100A0	230	60	1	28,000 – 30,500	4.0 – 4.2	4	8	32		2	3	4	6	7	9	12	14	15	30
BTR936A100A0	230	60	1	32,500 – 36,000	4.6 – 4.8	6	12	64		2	3	4	6	7	9	12/13	14	15	40
BTR036A300A0	200/230	60	3	32,500 – 36,000	4.6 – 4.8	6	12	64	A	2	3	4	6	7	10	12/13	14	15	25

A. Three phase unit has service valves and brazed connections.

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① All information contained in this manual subject to change without notice.

② A.R.I. Rating Conditions (see back page).

– Indicates information not available at time of printing.

HOW THE SYSTEM OPERATES

This unit, when combined with a prescribed indoor section or evaporator coil, is designed primarily for cooling. To complete the air conditioning system a separate heating plant or electric heaters may be utilized. Only the cooling cycle will be described here.

COOLING OPERATION

(Refer to Schematic Diagram Page 5)

① With the disconnect in the "ON" position, current is supplied to the sump heaters (not
⑦ used on Single Phase units.) The sump heater supplies heat to the compressor to prevent
liquid refrigerant from accumulating in the compressor during the off cycle.

Single phase equipment, BTR924, 930, 936A100A0, does not have sump heaters, instead
current is set up through a capacitor to establish a trickle circuit. This circuit provides
continuous heat (approximately 40 watts) through the compressor start winding which
⑩ has the same effect of preventing the accumulation of liquid refrigerant in the compressor
during the off cycle.

If electric heaters are used in the indoor section, refer to the service booklet covering the specific air handler for additional information on how they are wired and their operation.

② The control transformer located in the indoor section provides 24 volts to the main
starter on the condensing unit.

⑬ Using a single stage cooling or cooling/heating thermostat, current is supplied from one
side of the 24 volt secondary of the control transformer to the R terminal of the thermostat.
⑭ The other side of this control transformer connects to the main starter coil and then
③ to the Y1 terminal of the thermostat. With the thermostat fan switch set in the Auto
position and the cooling dial set to call for cooling, a circuit is completed R to Y1
thereby energizing the MS starter coil. At the same time this call for cooling also picks
up the indoor fan relay which is wired in a parallel circuit to the MS starter coil and
⑮ internally wired from G to Y1 in thermostat.

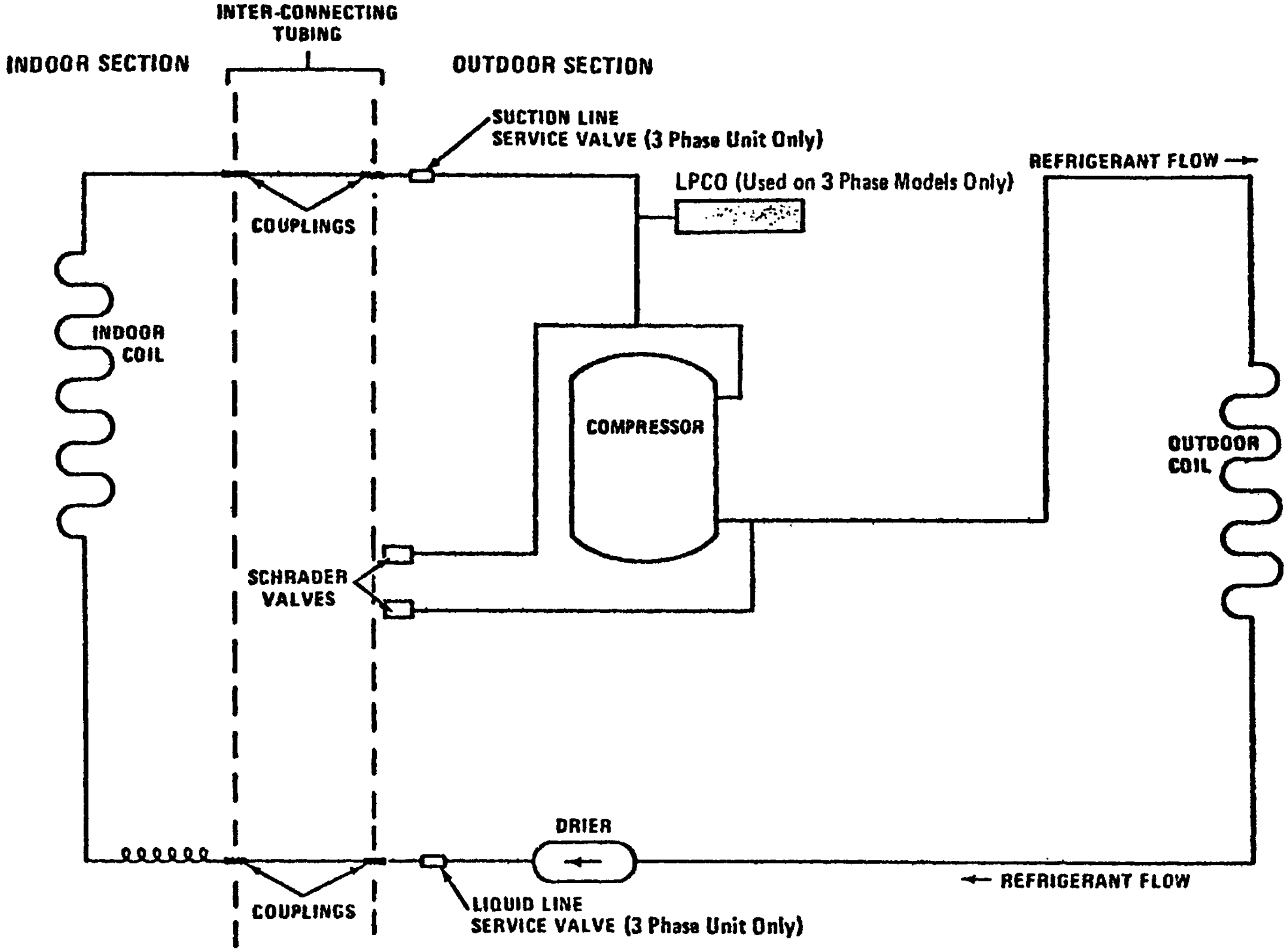
BTR036A300A0 models have a low pressure cut out in series with the main starter.
This must be closed for the starter to pick up. Closing the contacts of the MS starter
㉖ will start the outdoor fan motor and compressor simultaneously.

All single phase "A100" models include an outdoor motor speed change thermostat. As the outdoor temperature falls, the outdoor fan speed changes from high to low or vice versa. The low speed would only be used during low ambient conditions, such as night time operation.

ANTICIPATOR CIRCUIT

Thermostats are normally provided with a cooling anticipator which is a fixed-type resistor designed for the best on-off timing of the cooling cycles. This resistor provides false heat to the thermostat element and therein makes it call for cooling in anticipation of an increase in the room temperature.

BTR-A-A MODELS

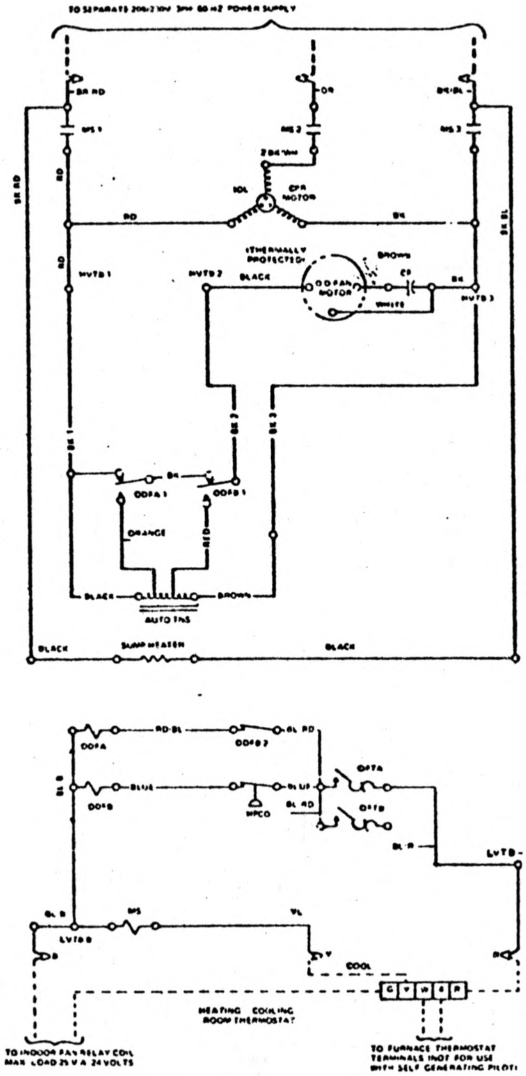


HEAD PRESSURE CONTROL KIT AY28X096

(Not used on any single phase equipment)

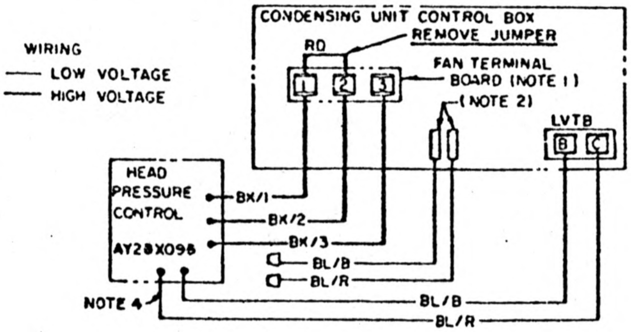
Head pressure control kits are wired into the system per diagram. They are normally required if the systems operate below 30°F. outdoor temperature. They are not to be used without an evaporator defrost control installed in the indoor section.

SCHEMATIC DIAGRAM WITH HPC INSTALLED ①



From Dwg. 21C119210 Rev. 2

HOOK-UP DIAGRAM AY28X096



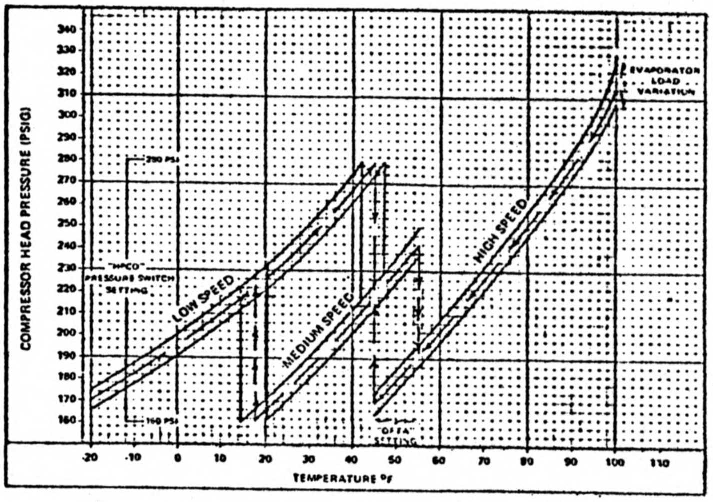
NOTES.

1. TWO ADJACENT BOARDS IN 460 VOLT MODELS.
2. THESE LOW VOLTAGE LEADS ARE NOT USED ON THESE MODELS.
3. BUNDLE EXTRA LOW VOLTAGE LEADS AND SECURE IN PLACE WITH GOOD QUALITY ELECTRICAL TAPE.

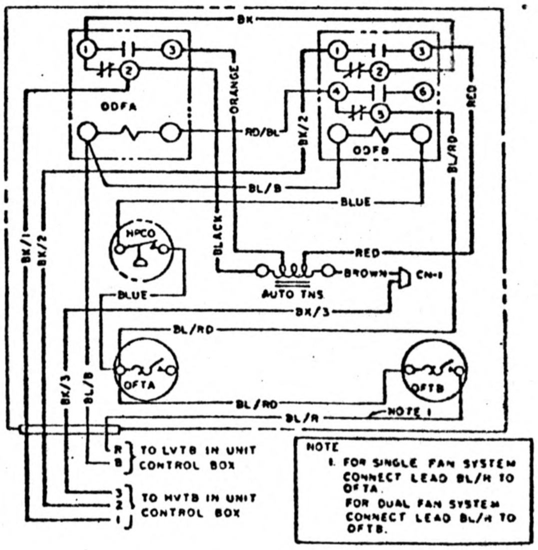
From Dwg. 21D115846 Rev. 3

When the unit starts on call from room thermostat, the outdoor fan will start in high speed if the outdoor temperature is above 55°F. or start in low speed if the outdoor temperature is below 45°F. When the unit starts in low speed, the fan will go to medium speed if the head pressure rises to 280 psi. See graph below for a typical operating characteristic. The arrows indicate operating characteristics during a rise or declining temperature condition.

This graph is based on a calm day, correct refrigerant charge, average indoor loading, and rated line voltage. The graph is to show fan speeds relative to head pressure readings. Variations in outdoor temperatures will have NO effect on fan speed modulation at a given head pressure, PSIG.



WIRING DIAGRAM



NOTE

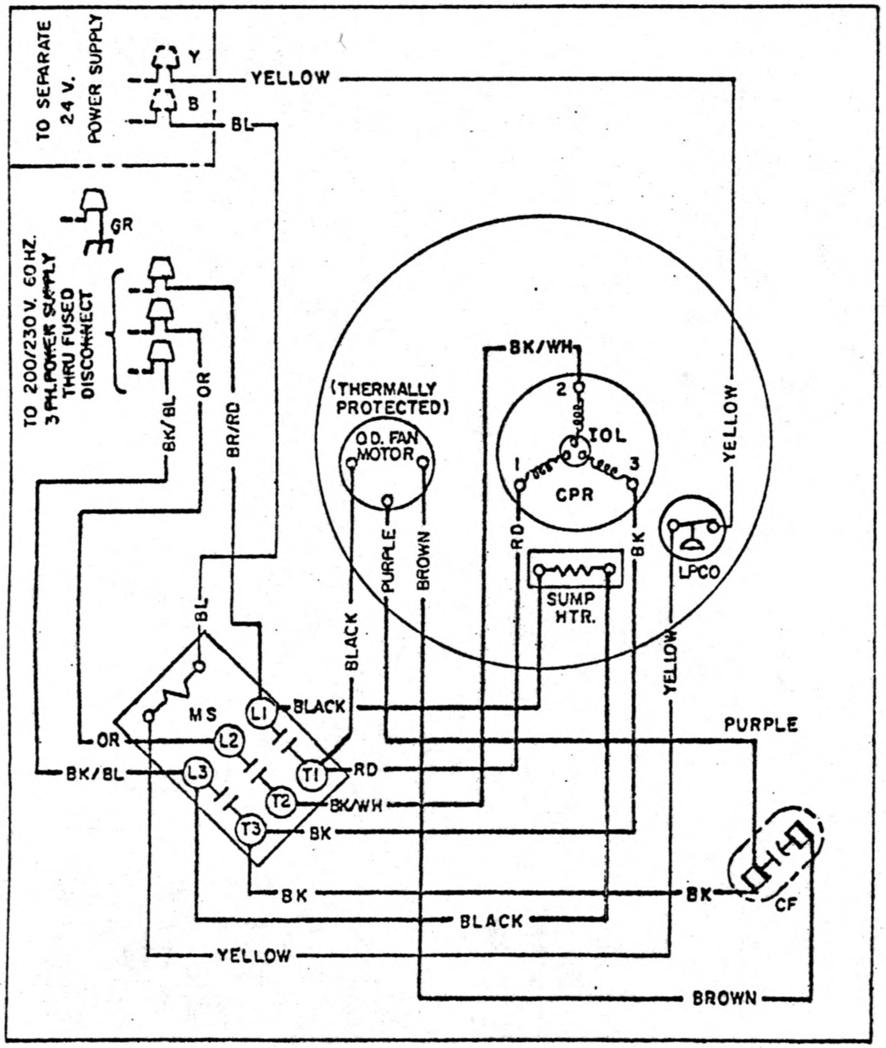
1. FOR SINGLE FAN SYSTEM CONNECT LEAD BL/R TO OFTA.
FOR DUAL FAN SYSTEM CONNECT LEAD BL/R TO OFTB.

From Dwg. 21C119210 Rev. 2

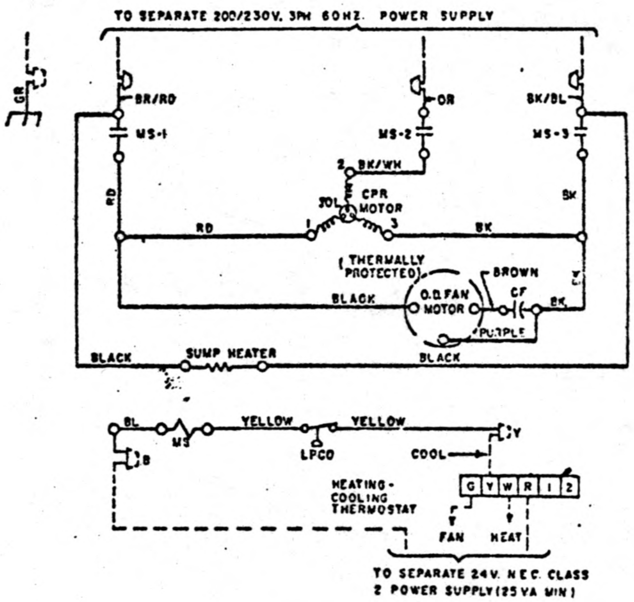
BTR036A300A0

(Abbreviations and Symbols — see back page)

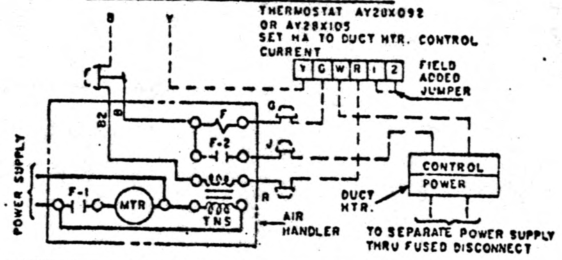
WIRING DIAGRAM



SCHEMATIC DIAGRAM



DUCT HEATER SCHEMATIC



FOR USE WITH APPROVED SUPPLEMENTARY HEATERS, SEE WIRING DIAGRAM ON SUPPLEMENTARY HEATER CONTROL BOX.

NOTES:

1. LOW VOLTAGE (24V.) FIELD WIRING MUST BE NO. 18 A.W.G. MINIMUM.
2. DUCT HEATER INTERLOCK (F-2 CONTACTS) CLOSE DURING FAN OPERATION.
3. ROOM THERMOSTAT OPENS DUCT HEATER CIRCUIT DURING COOLING OPERATION.

From Dwg. 21C123185 Rev. 0

COOLING PERFORMANCE – 60 HZ.

Outdoor unit performance and charge can only be checked when hooked up to a specified Indoor Air Handler. The following charts relate these two sections as they are normally combined.

The Cooling Performance may be checked if outdoor temperature is higher than 75°F.

The following sample procedures should be used in checking performance.

1. Read outdoor temperature.
2. Measure indoor wet bulb temperature.
3. Measure liquid and suction pressures AT THE OUTSIDE PRESSURE TAPS.
4. To check either LIQUID or SUCTION PRESSURE enter the chart on the bottom scale marked OUTDOOR TEMPERATURE.
5. Draw a vertical line up to the INDOOR TEMPERATURE and read SUCTION PRESSURE or LIQUID PRESSURE horizontally to the left.
6. EXAMPLE: BTR924A100A0 with a XA031 Coil

   (Chart Below)

   Outdoor temperature, 85°F.

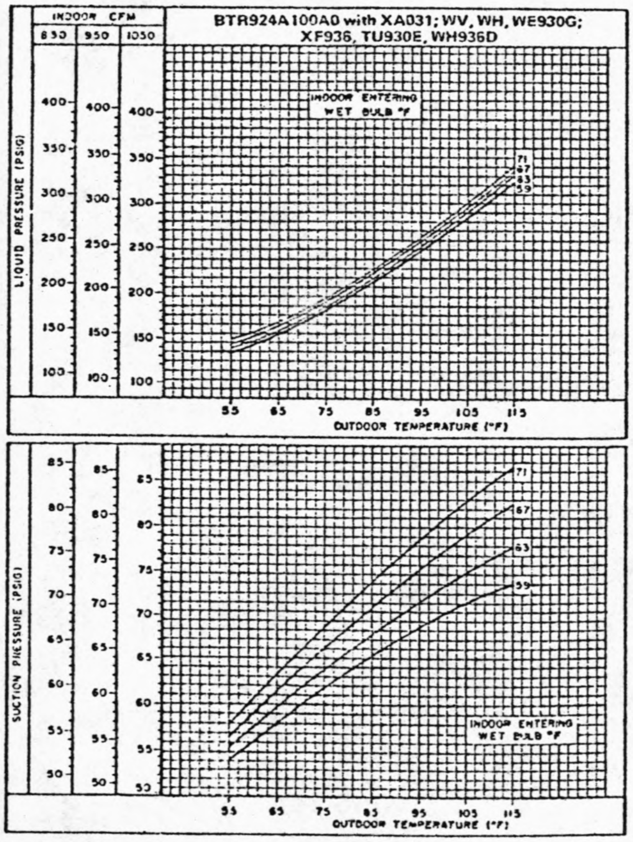
   Indoor W.B. temperature, 67°F.

   Suction pressure, 70 PSIG at 950 CFM.

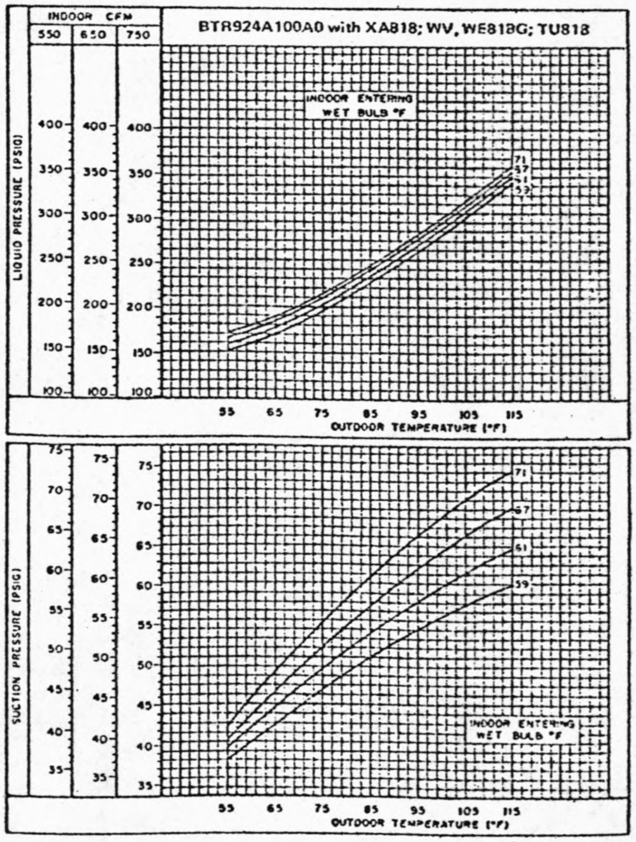
   Liquid pressure, 218 PSIG at 950 CFM.
7. a. The LIQUID PRESSURE reading on the gauge should be within ± 10 PSIG of the chart heading.

   b. The SUCTION PRESSURE reading on the gauge should be within ± 3 PSIG of the chart reading.
8. If pressures are not within tolerance refer to next pages and check charge.

NOTE: Condensing unit motor must be operating at high speed when making this check. Therefore, be sure OFT is connected between terminals 1 and 2. Disconnect wire from terminal 3. Reconnect wires after making performance check.



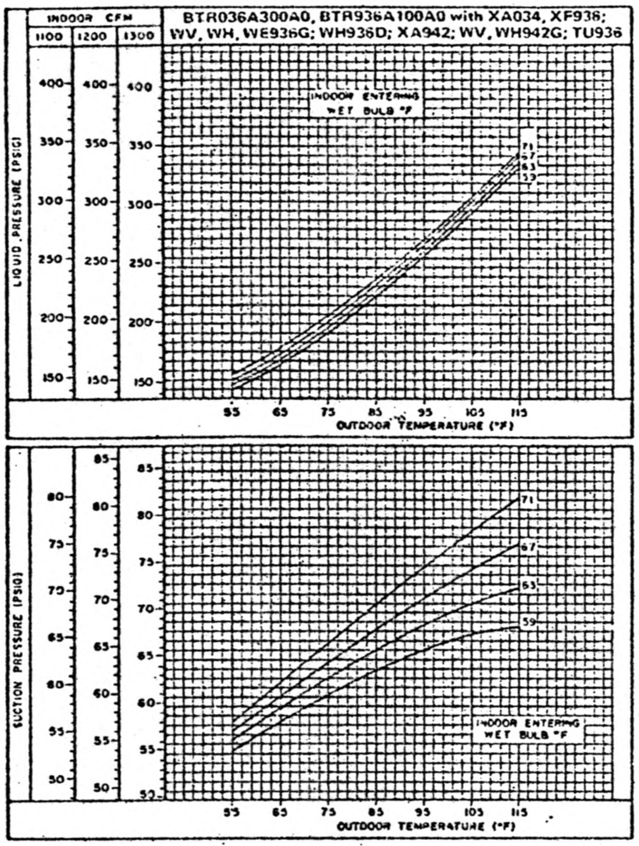
From Dwg. 21B124744 Rev. 0



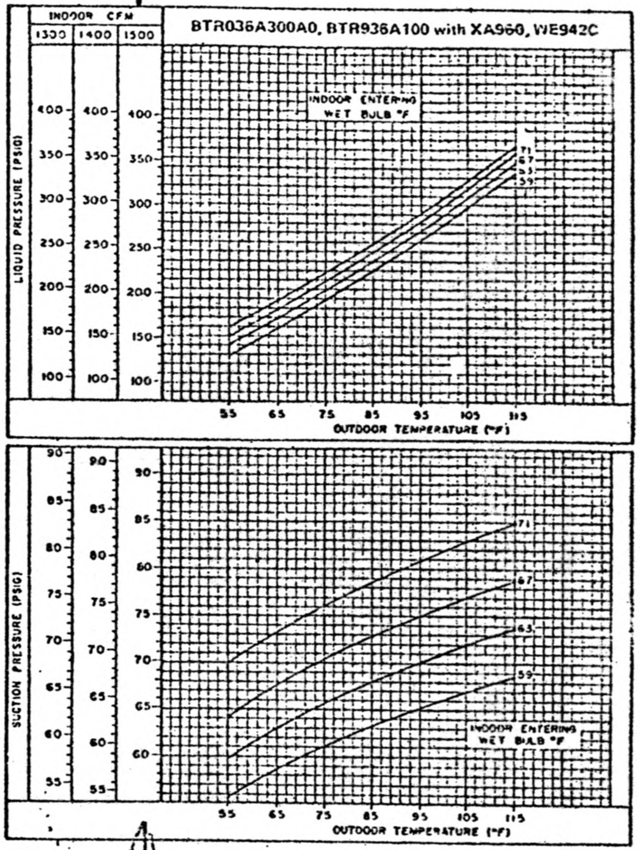
From Dwg. 21B124745 Rev. 0

COOLING PERFORMANCE & CHARGE CHECKING – 60 HZ.

(For instructions on use of charts, refer to page 11.)

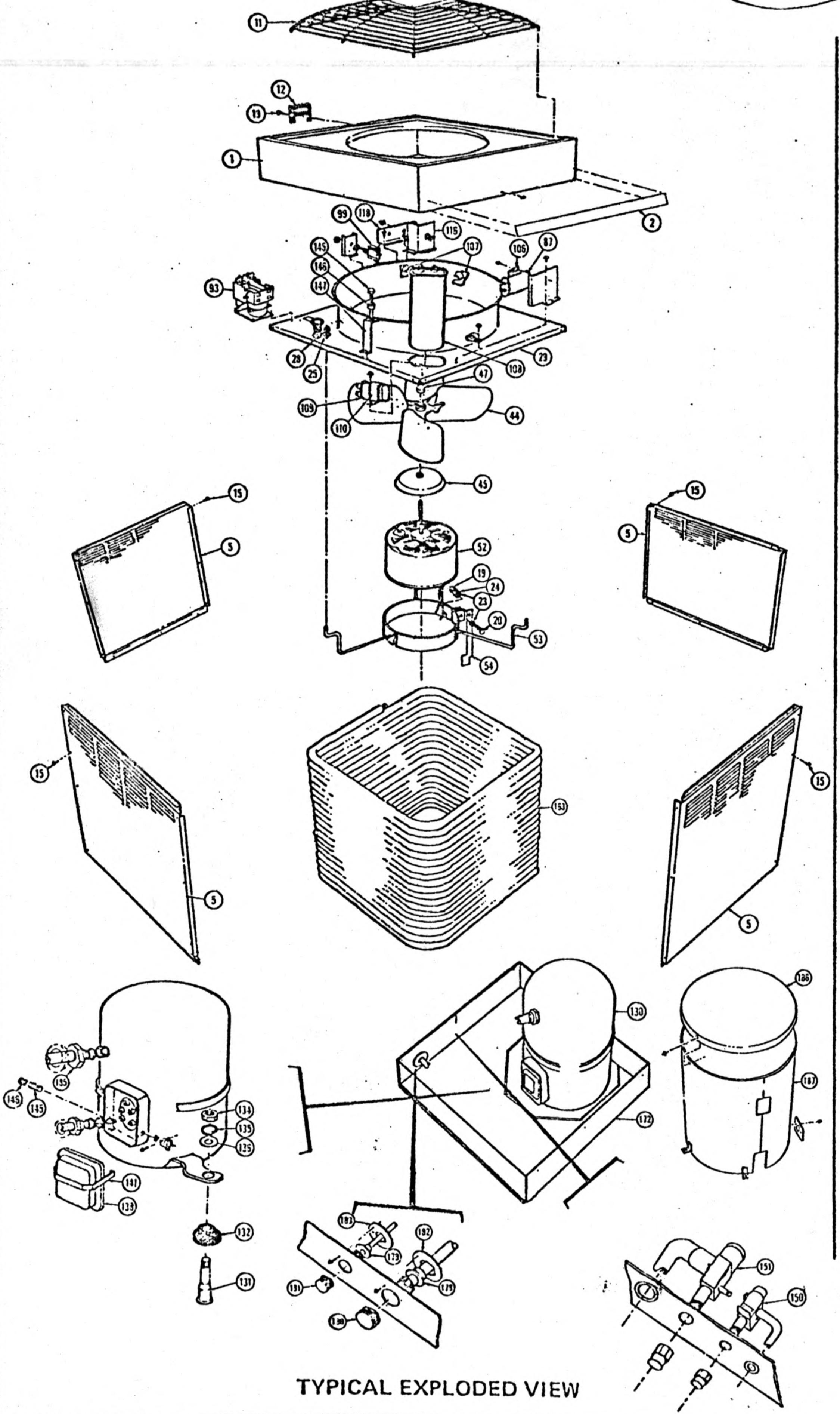


From Dwg. 21B124750 Rev. 0



From Dwg. 21B124751 Rev. 0

BTR924, 930, 936, 036A



TYPICAL EXPLODED VIEW

PARTS DESCRIPTION

Ref. No.	
1	Top Cover
2	Nameplate
5	Louvered Panel
11	Fan Guard
12	Cover Seal
13	Screw
15	Screw, Panel
19	Nut
20	Screw
23	Washer
24	Lockwasher
25	Washer
28	Nut, Thread Cut, Motor Mount
44	Fan
45	Slinger
47	Cap, Hub
52	Motor
53	Motor Mount
54	Hanger, Motor
87	Fan Capacitor
93	Contactor, MS
99	Thermostat, Speed Control OFT
106	Strap, Fan Capacitor
107	Clamp, Run Capacitor A
108	Run Capacitor A
109	Run Capacitor B
110	Strap, Run Capacitor B
130	Compressor
131	Bolt
132	Grommet
134	Nut
135	Lock Washer
136	Washer
138	Terminal Box Cover
141	Spring Clip
143	Sump Heater (3 Ph. only, not shown)
144	Spring, Heater (3 Ph. only, not shown)
145	Fuse (BTR 924 Only)
146	Fuse Holder (BTR 924 Only)
149	Cap, Liquid Service Valve
150	Service Valve, Liquid
151	Service Valve, Suction
152	Cap, Suction Service Valve
153	Schrader Valve (not shown)
154	Cap, Schrader Valve (not shown)
162	Drier (not shown)
163	Condenser Coil
172	Base Pan
178	Coupling, Suction
179	Coupling, Liquid
180	Cap, Suction Line
181	Cap, Liquid Line
182	Flange, Suction
183	Flange, Liquid
184	Nut, Compr. Suction
185	Nut, Compr. Disch.
186	Top, Compressor Enclosure
187	Side Compressor Enclosure

From Dwg. 21D123840 Rev. 0

APPENDIX B
HEAT CONTROLLER DETAILS

The Johnson Service Company series DQ-4400 controllers operate by switching 3-phase, 208 V ac to delta-connected resistive heating elements using SCR's. Switching is synchronized to the line so that it occurs at zero-voltage points. A free-running oscillator in the controller generates a 3.3 sec time base, during which the heater is on for a time proportional to the thermostat error voltage.

A simplified block diagram is given in Figure B-1, and a detailed schematic (derived from a sample unit by D. Grant) is given in Figure B-2.

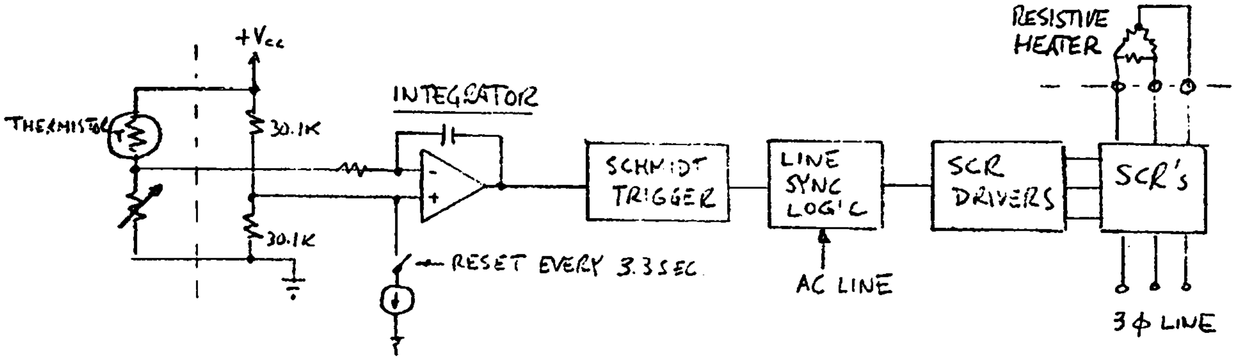
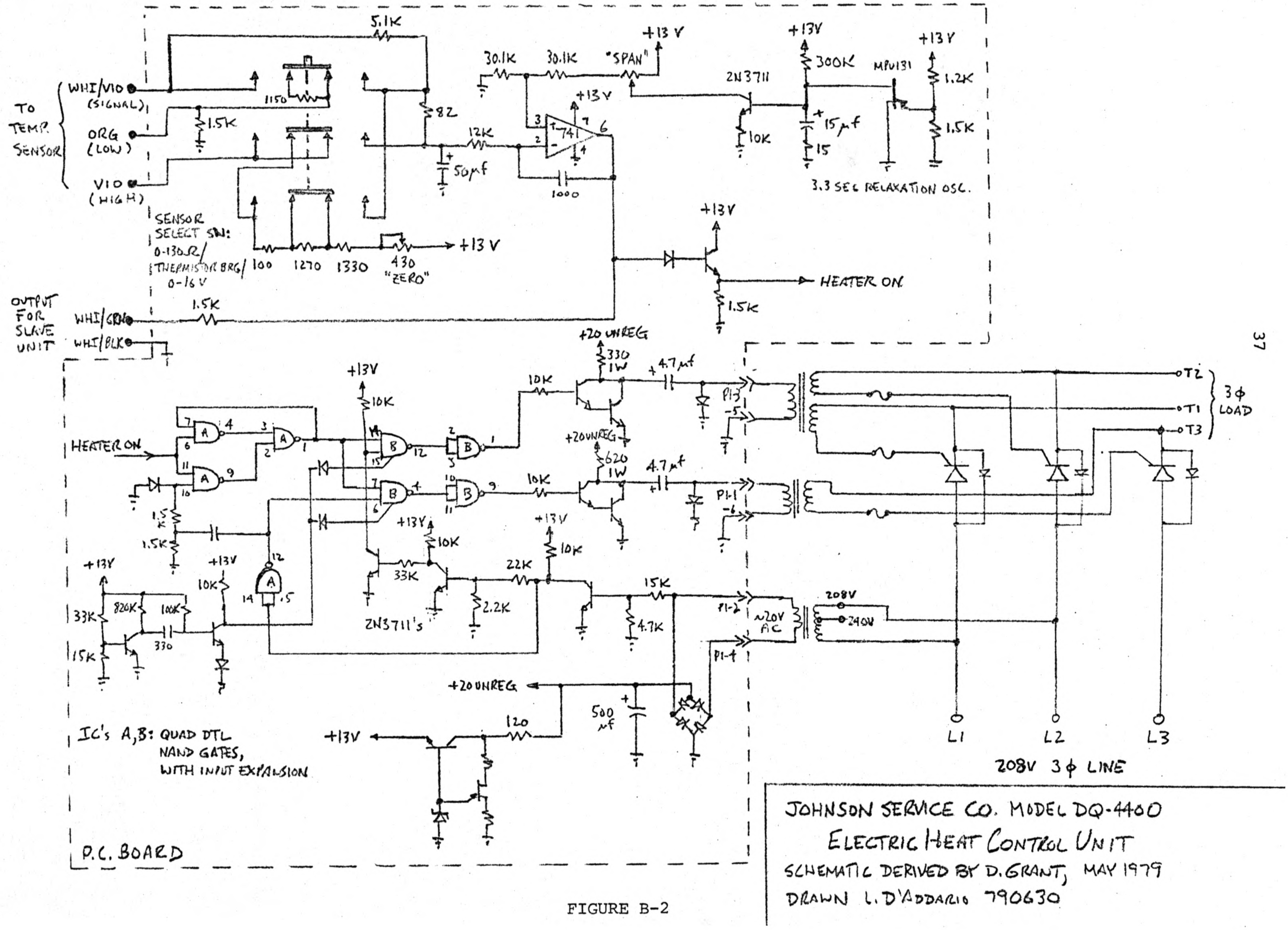


FIGURE B-1



JOHNSON SERVICE CO. MODEL DQ-4400
ELECTRIC HEAT CONTROL UNIT
SCHEMATIC DERIVED BY D. GRANT, MAY 1979
DRAWN L. D'ADDARIO 790630

FIGURE B-2

ADDENDUM TO VLA ELECTRONICS MEMORANDUM NO. 184

L. R. D'Addario
July 2, 1979

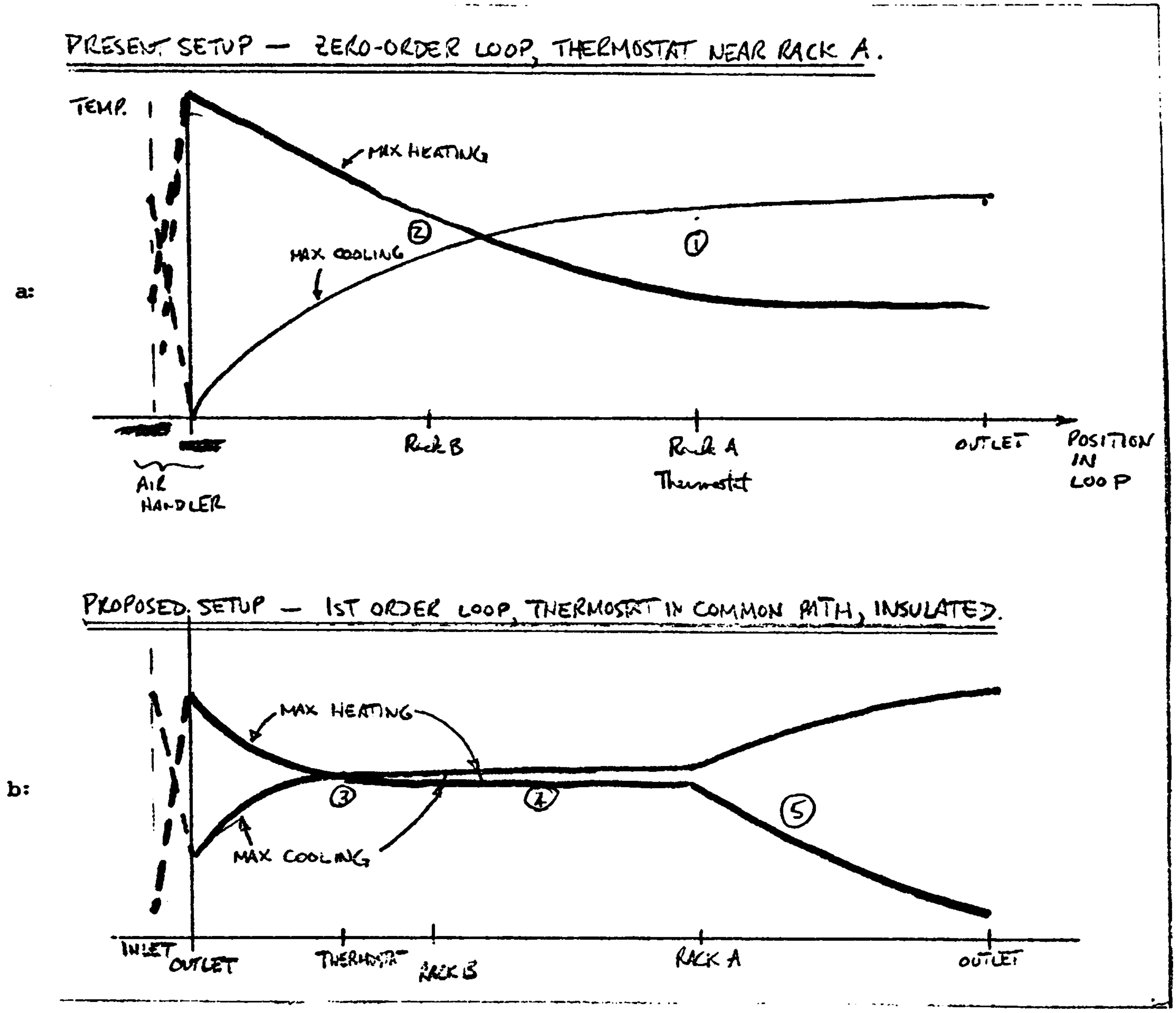
In view of the results of Section 4, especially that (1) the zero-order loop requires temperature variations at the thermostat of >1°C over normal ranges of outside air temperature, and (2) the temperature drop across the room is ~4°C, it is perhaps hard to understand the excellent temperature stability measured in Rack B of some antennas. (As mentioned, <0.3°C diurnal variation has been observed.)

This result can be explained by a simple model. In the present arrangement, temperature-controlled air for Rack B is tapped off the main air duct at a point prior to the thermostat. If we model the air circuit as a simple series loop (although actually there are parallel paths), then we must regard Rack B as upstream of the thermostat. Plotting air temperature as a function of position in the loop, we obtain something like Figure 1a; the curves represent the extremes of maximum heating and maximum cooling. It should be apparent that there must be a point upstream of the thermostat where the temperature varies little or not at all with the heat load, even though the temperature at the thermostat varies considerably. The location of this point is a sensitive function of the control loop's gain and of the temperature drop across the room (which depends on how well it is insulated). Under the right conditions, this stable point could easily correspond to the monitoring point in Rack B.

This arrangement cannot be considered satisfactory, partly because of its sensitivity to adjustments but mainly because we desire tight temperature control at more than one point -- especially Rack A and Rack B -- and the points are widely separated.

Figure 1b shows the predicted situation if all the recommendations of Section 5 are adopted.

FIGURE 1: VR Temperature Control -- Steady State Performance



Notes:
① Temperature at thermostat is allowed to vary because of zero-order loop.
② Temperature at Rack B stays quite constant because, luckily, it is near the crossover point.
③ Temperature at thermostat held constant by first-order loop.
④ Temperature drop from thermostat to racks held small by insulating the ducts.
⑤ Most of the loop temperature drop occurs across the room rather than in the ducts.