No further work as of 9 July 68 - R.M.

FINAL REPORT

OF STUDY EFFORT AUTHORIZED UNDER

ALSEP CCP 90

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1.0 INTRODUCTION

At the request of NASA-MSC, a study was undertaken to investigate the use of the excess power from the RTG to provide positive assistance to the thermal control of the ALSEP central station which is presently maintained by completely passive means. This report presents descriptions of four concepts which, to varying degrees, might reduce the range of temperature swing during the lunar diurnal cycle. These concepts are also compared on the basis of thermal support effectiveness against the cost in terms of complexity, weight, and the feasibility of integrating into the existing hardware.

2.0 A REVIEW OF PERTINENT SYSTEM DEVELOPMENT

The temperature of the electronic equipment mounted in the ALSEP central station is constrained to acceptable limits during the changes of lunar surface temperature (Figure 2.1) by suitable use of surface finishes and coatings, special insulation materials and physical configurations. This concept of "static" thermal control was originally proposed when the electrical power being dissipated within the electronics items was essentially constant. This was valid until the regulator for the RTG output was transferred from pallet 2 to within the electronics bay of pallet 1. The net result of this action was to make the dissipation of the central station dependent on the amount of reserve power in the system. Since the reserve power varies as a function of both RTG output and equipment power demand, the electrical dissipation within the central station became a complex function of system operation. Thus, the mechanical design of the central station for its thermal control and the electrical design of the regulator controlling both RTG temperature and all the system voltages became tightly coupled, imposing severe constraints on each other.

In the early days of ALSEP design the dynamic range of the electrical regulator (located partly in the PCU and partly external to the temperature-controlled area) was restricted to 30 watts because of the limitations imposed by stated variations in central station dissipation. As the design of the RTG and the experiments progressed it became evident that this regulator range was inadequate to cope with expected operational conditions. As confidence in the ALSEP thermal design was gained this regulator range was increased first to 40 watts and then to 55 watts. As illustrated in Figure 2.2 each increase in the dynamic control range of the regulator increased the range of variation of PCU internal dissipation for given variations in PCU output power.

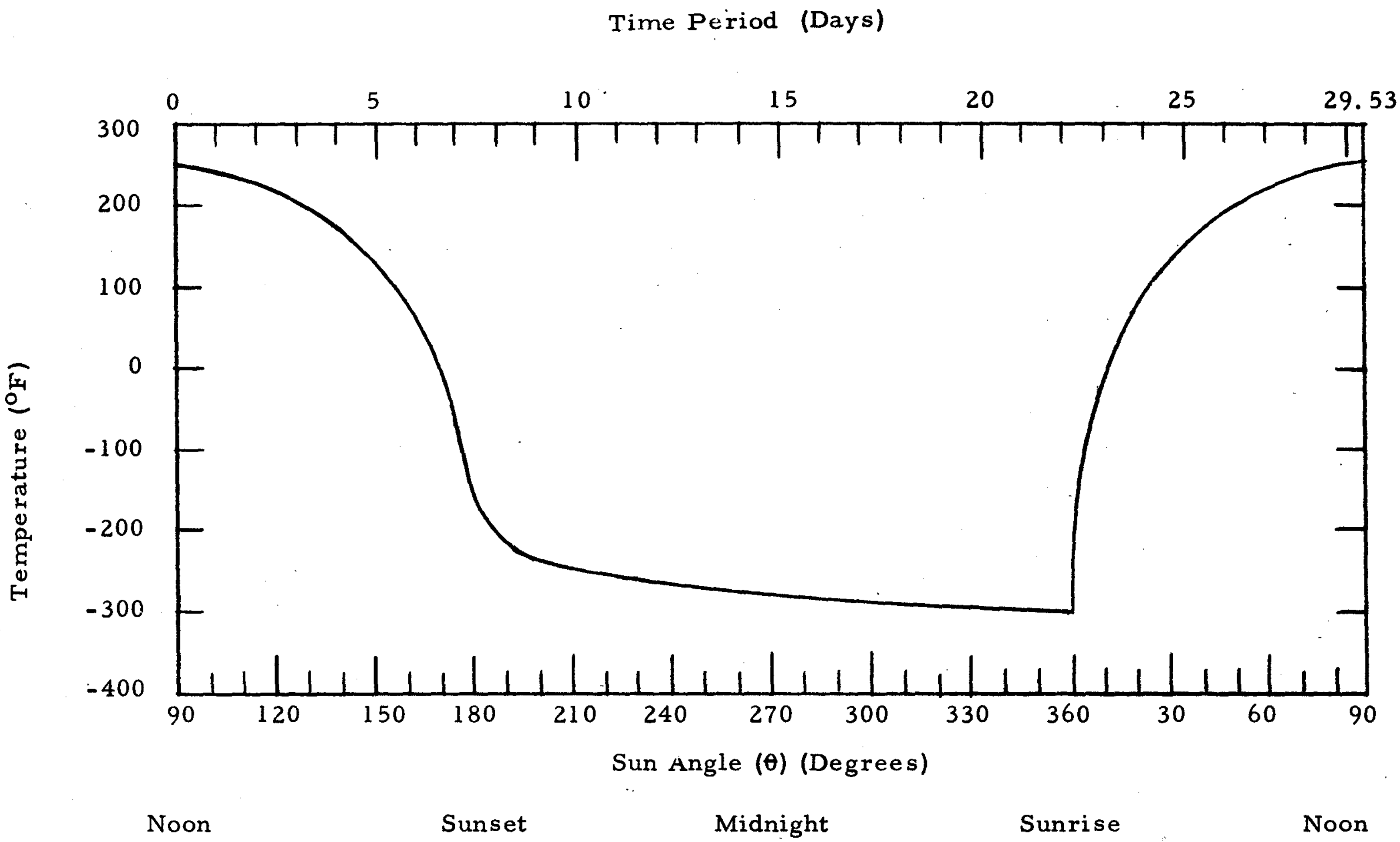
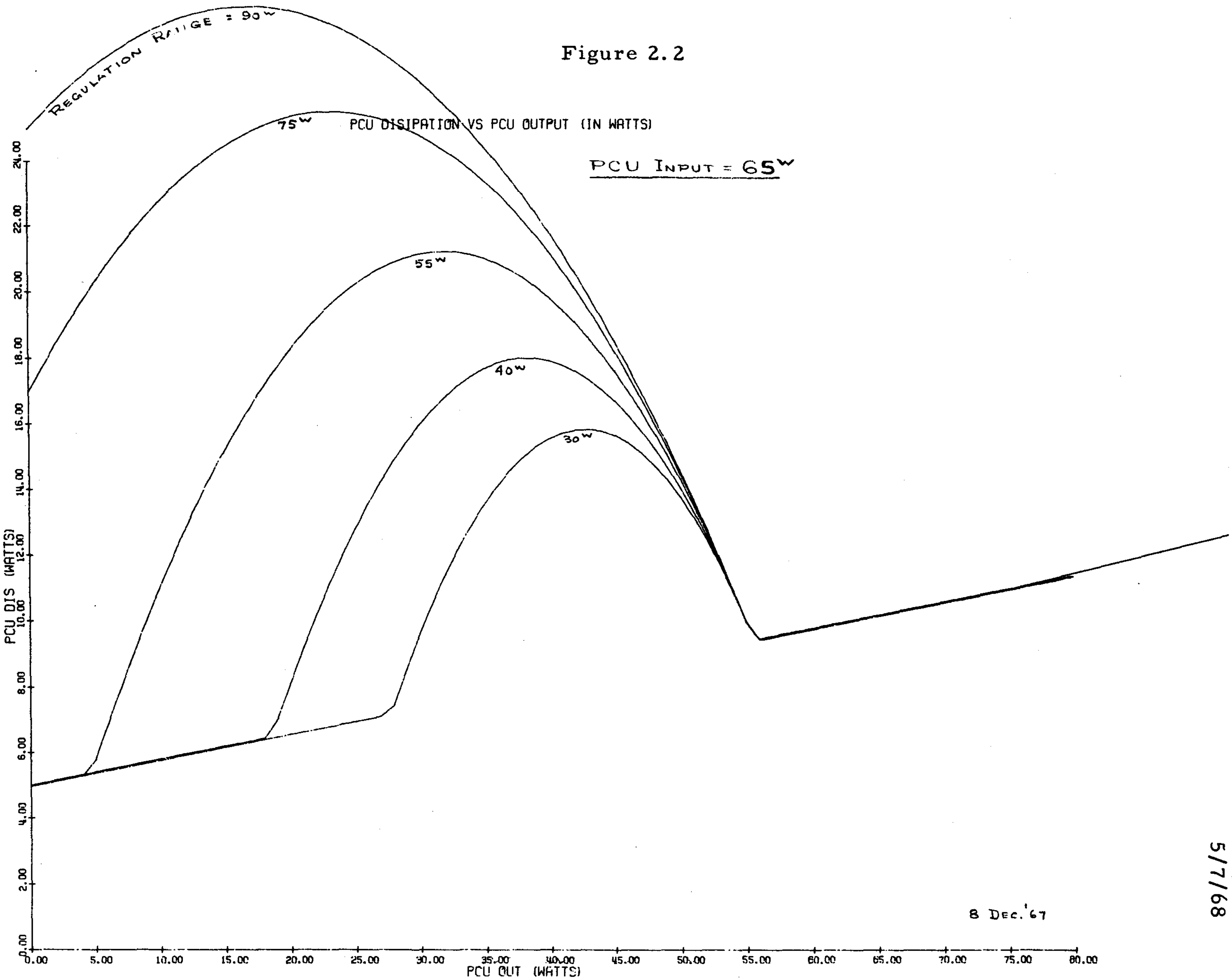


Figure 2.1 Variation of Lunar Surface Temperature (Subsolar Point) During a Complete Lunation

Figure 2.2


PCU DISIPATION VS PCU OUTPUT (IN WATTS)
PCU INPUT = 65W
REGULATION RANGE = 90W
75W
55W
40W
30W
PCU DIS (WATTS)
PCU OUT (WATTS)
8 Dec. '67

Because of the large number of possible operational configurations of an ALSEP system attainable either by command or by equipment failure (an example is given in Table I) it is not possible to precisely forecast the load on the PCU at any particular time during the year's mission. As further illustrated by Table I each configuration has a different (higher) load demand during lunar night than during lunar day. Similarly the RTG output is sensitive to ambient temperature.

To relieve the impact on the central station thermal control of this wide range of unschedulable loads on the PCU a number of emergency features have been incorporated into the system design. These are:

a) 2 commandable resistive loads connected to the 29V line but physically dissipating electrical energy outside the thermally-controlled area. By suitable use of ON/OFF commands for each resistor load, increments of 7, 14 or 21 watts (nominal) may be added to the PCU output.

b) a commandable resistive load connected to the 29V line and dissipating electrical energy into the thermal plate to which all electronic units are mounted. This resistive circuit is provided with a series-connected thermostat (sensing thermal plate temperature) which closes at about -10°F. These resistors will dissipate nominally 10 watts.

c) 2 commandable resistive loads connected to the 29V line which will dissipate into the thermal plate (upon suitable commands) zero, 5 or 10 watts.

These facilities make it possible for the controller at MCC to make gross incremental changes (increases) in the load on the PCU in reaction to those contingent situations, such as failure of one or more experiments, in which the dissipation of excess power within the central station temperature-controlled area threatens to raise the thermal plate temperature above its design maximum.

It is apparent that the effectiveness of this control feature depends on

- continuous monitoring of central station temperatures and available reserve power
- continuous availability of the MSFN and monitoring personnel

TABLE I
RANGE OF OPERATIONAL POWER DEMANDS

EXPERIMENT STATUS				LOAD ON PCU (WATTS)	
1	2	3	4	LUNAR DAY	LUNAR NIGHT
				16.0	13.5
X				21.1	21.3
X		X		25.4	27.8
X	S	S	S	26.1	30.3
X	X			25.1	30.3
X			X	27.1	31.3
X	S	X	S	27.4	33.8
X	S	S	X	30.1	34.3
X	X	X		29.4	36.9
X		X	X	31.4	37.8
X	S	X	X	31.4	37.8
X	X	S	S	30.1	39.3
X	X		X	31.1	40.3
X	X	X	S	31.4	42.9
X	X	S	X	34.1	43.9
X	X	X	X	35.4	46.8

LEGEND

SYMBOL	STATUS
Blank	OFF
S	Standby
X	Operational

-a power management computer program available to the controller to permit him to take proper corrective action in any situation using the various commandable loads. (Both central station and lunar surface temperatures and gradients will determine whether the power should be dissipated in-board or outboard). Since it is very possible to overload the power source with these commandable loads, and hence put the system voltages out-of-regulation, considerable discretion must precede their usage.

3.0 STUDY OBJECTIVES

In the context of this present status of dependence of central station electronics thermal control on the system electrical operation, a study was undertaken at the request of NASA-MSC to investigate alternate methods of using the available excess power, under any and all conditions of operation, to assist in the temperature control of the central station electronics units. The following objectives were established to guide in the selection and evaluation of alternate concepts:

a) maximum improvement in mission operation reliability

b) reduced range of temperatures of central station electronics during lunar diurnal cycle.

c) reduced dependency of central station performance (under contingency conditions) on MSFN availability.

d) reduction or elimination of the dependency of central station electronics temperature on system operational mode.

e) minimum impact on central station design to integrate a given concept into the system.

Four concepts were devised which were considered feasible and showed promise of meeting some or all of these objectives. The suggested concepts are:

Concept I - An additional set of voltage regulator resistors physically mounted within the thermally-controlled area and electrically selected (in place of the external resistors) at a pre-set temperature of the thermal plate.

Concept II- Similar to concept I but with proportioning of the power fed into the external and internal regulator resistors as a function of thermal plate temperature.

Concept III- Removal of the active element of the voltage regulator from the thermally-controlled area of the central station, to make the power dissipated within that area less variable.

Concept IV- Incorporation of a load on the 29V output of the PCU which varies dynamically in such a manner as to maintain a constant current in the PCU regulator and which dissipates its energy inside or outside the thermally-controlled area as a function of the temperature of the thermal plate.

These concepts are described and evaluated in the following sections.

4.0 DESCRIPTION OF SELECTED CONCEPTS

The scope of this study was established to investigate three alternate approaches to the usage of available reserve power to support the temperature control of the central station electronics. The most obvious fund of available reserve power is that dissipated in the externally mounted resistor element of the regulator circuit. (See Figure 4.1.) It is evident that it would be a help to dissipate this power inside the temperature-controlled area during lunar night. So the first concepts investigated (I and II) looked into the feasibility and impact of adding this particular increment of reserve power to the central station thermal plate upon demand (see Figure 4.2).

To investigate the feasibility of reducing the dissipation in the central station electronics during lunar daytime, two different concepts were studied, (a) Concept III, which proposed the removal of the reserve power dissipation from the PCU and from the electronics bay (i.e., from the thermally controlled area) of the central station (Figure 4.3), and (b) Concept IV, which proposes adding to the present central station design a dynamic load which stabilizes the PCU dissipation and places the available reserve power inboard or outboard as required by temperature, (see Figure 4.4).

Figure 4.1
Present ALSEP Configuration

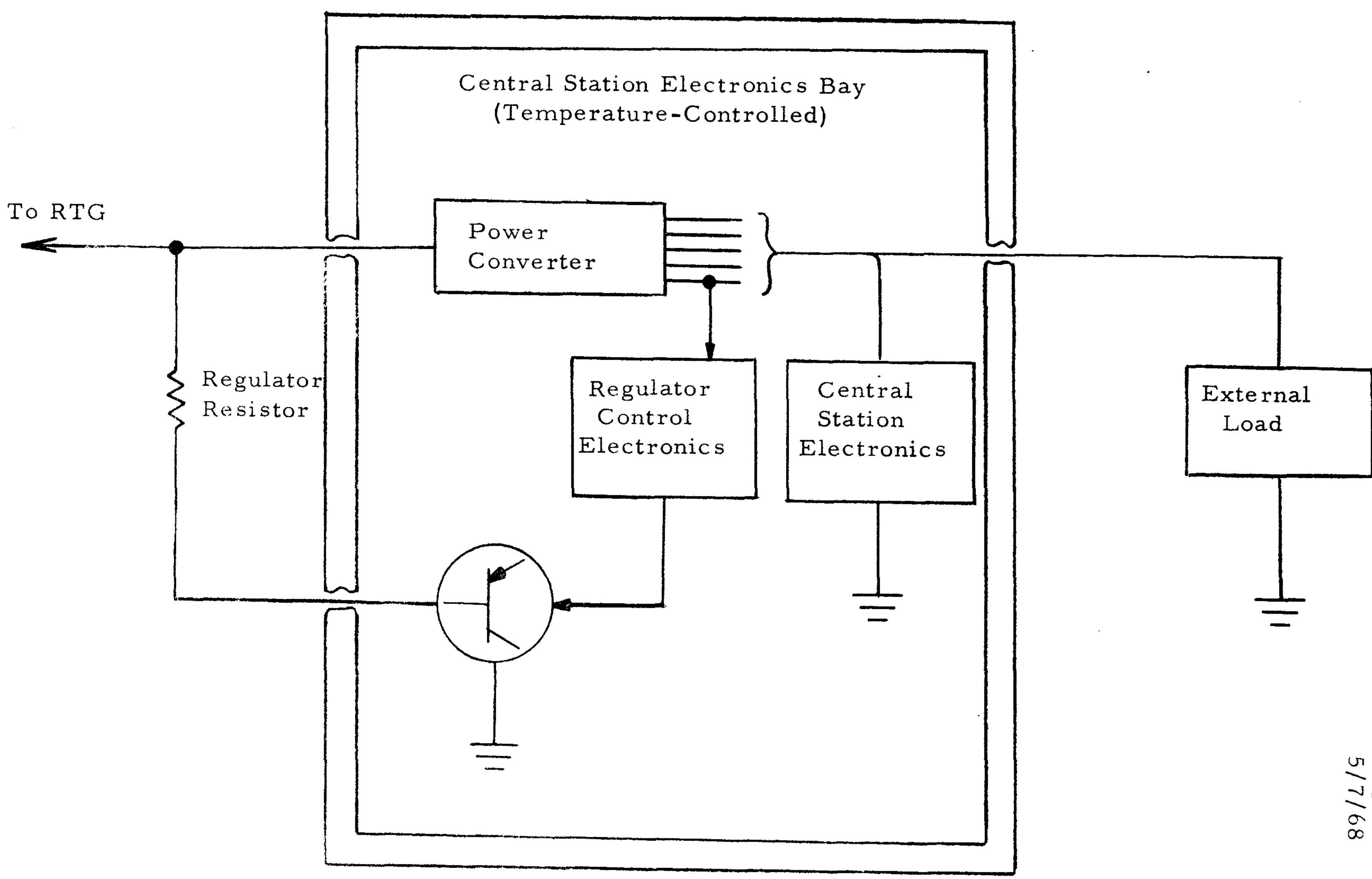


Figure 4.2
Functional Diagram - Concepts I & II

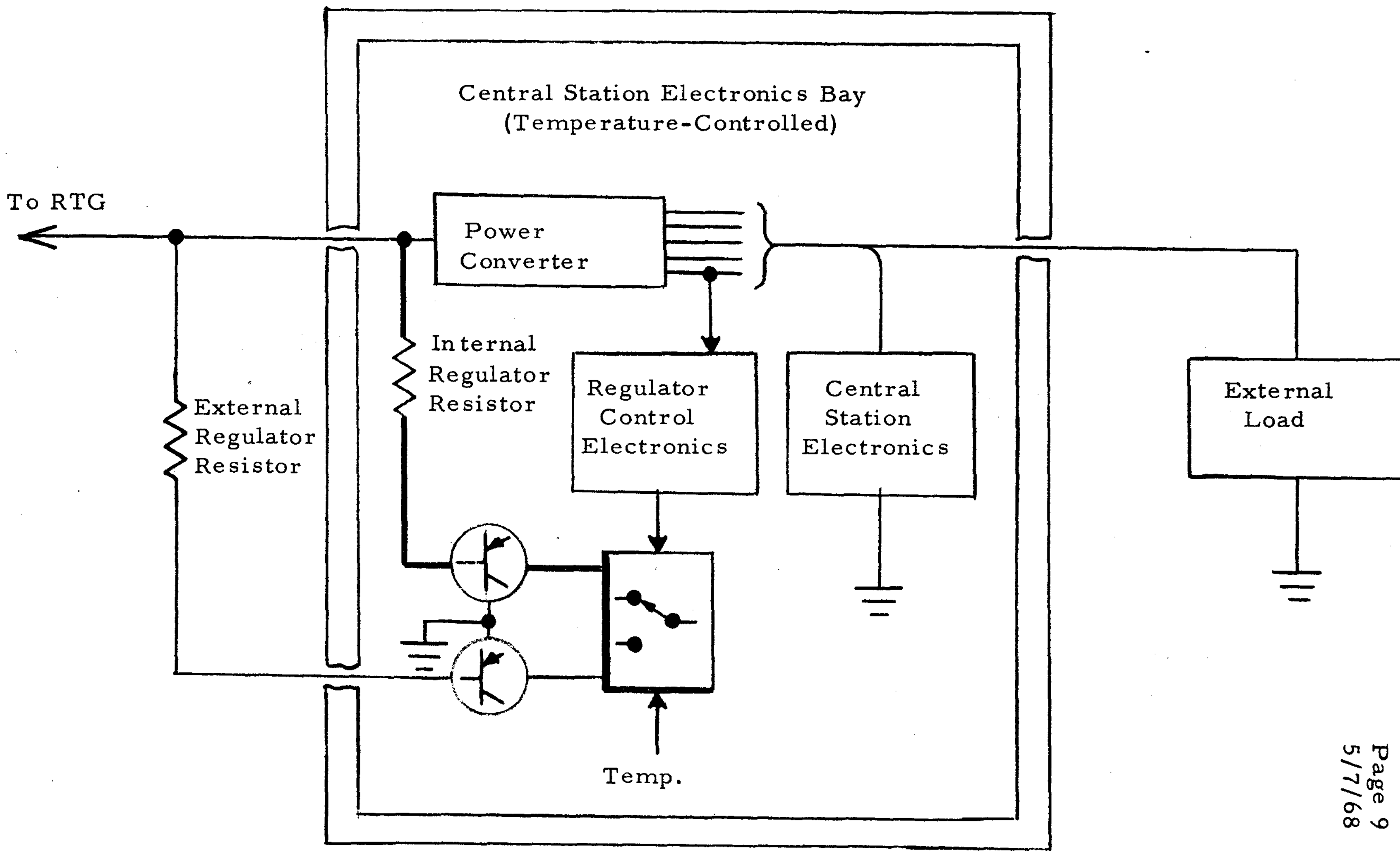


Figure 4.3
Functional Diagram - Concept III

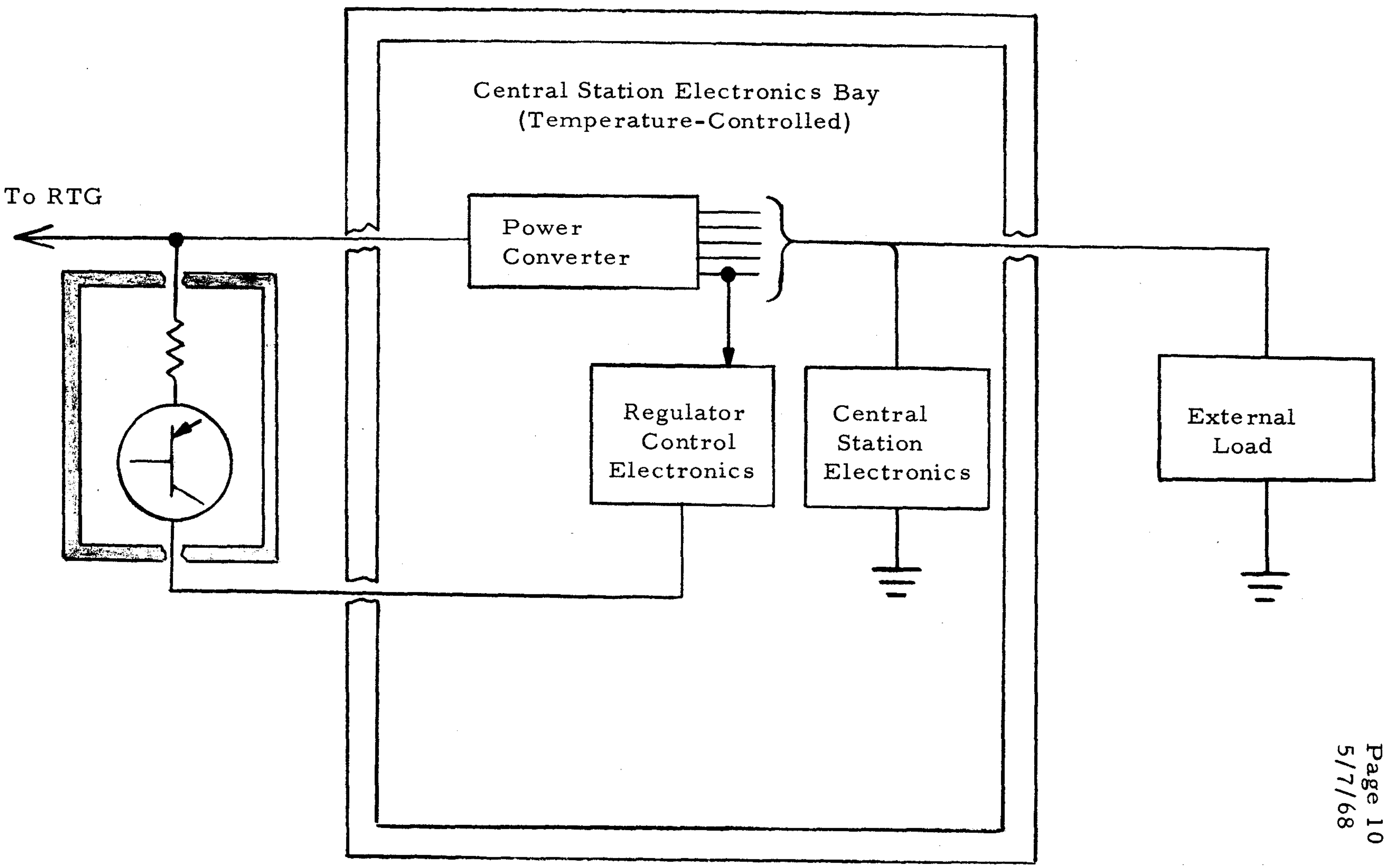
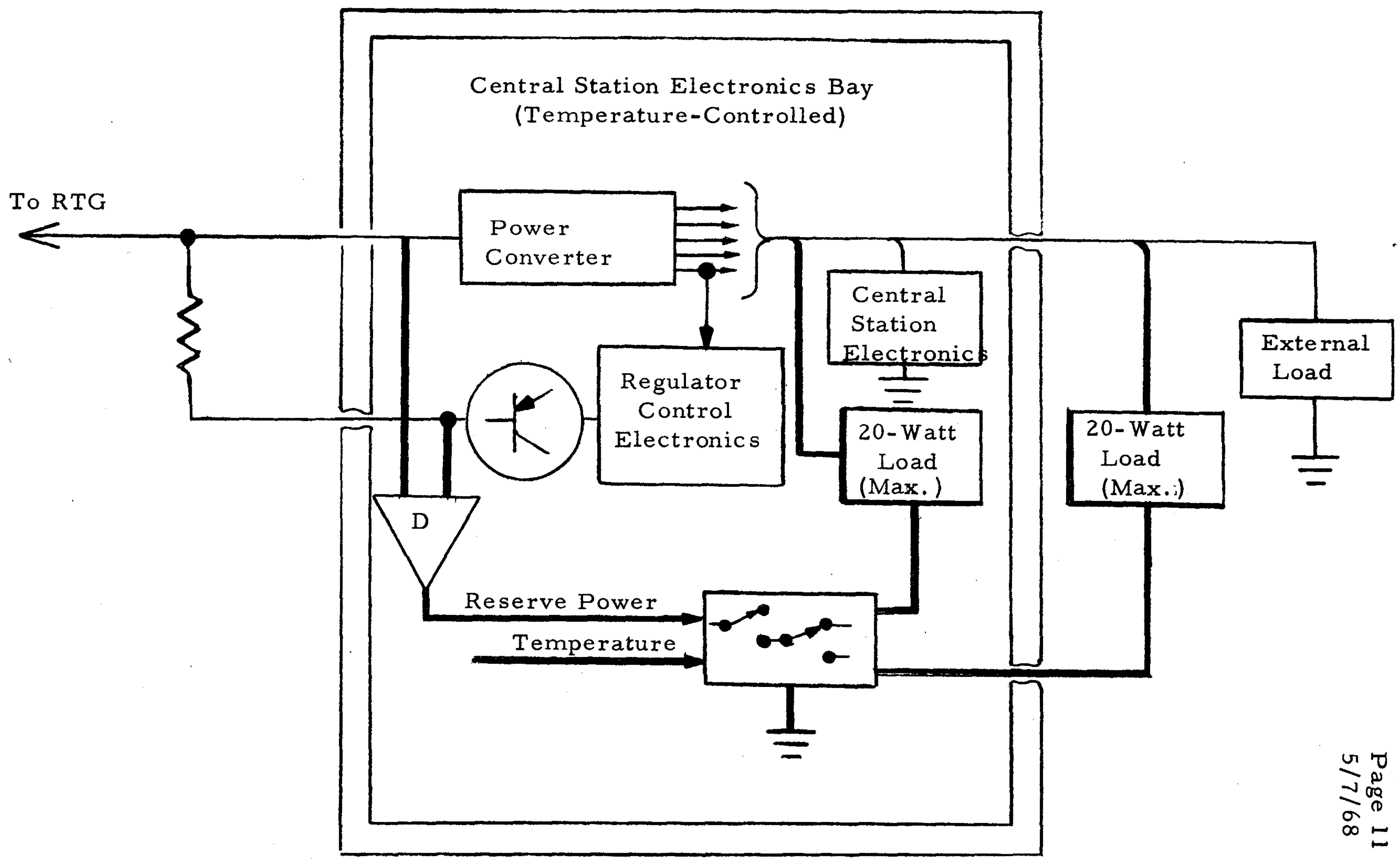


Figure 4.4
Functional Diagram - Concept IV



4.1 CONCEPT I

4.1.1 Description

This concept can be implemented by a circuit such as that shown in Figure 4.5. The thermal plate temperature is sensed by the thermistor (R4) and converted to an ON/OFF signal by the bridge network and amplifier. Each of the present regulator shunt networks is replaced by two such networks, one with an externally-mounted resistor, and one with an internally-mounted resistor (i.e. mounted on the thermal plate). The appropriate regulator network is selected by the temperature-dependent signal from the bridge amplifier. The temperatures at which transition from IN to OUT and OUT to IN are made can be independently set. With the circuit values shown the IN/OUT transfer is made at a thermal plate temperature of 75°F and the OUT/IN transfer at 25°F. The transfer rate between regulators is slow relative to the regulator time constant and at no time during switchover are both regulators open. This feature ensures that the effect of transfer on system voltage regulation is negligible. For compatibility with the present "ripple-off" circuit, a resistor/diode network is required to add in a measure of the current in the new regulator.

All the necessary control circuits for concept I can be packaged very compactly either in the form of a card similar to the dust detector electronics in the PDU or in a module form for mounting separately to the thermal plate. If the dust detector electronics were eliminated this control circuit could be integrated into the PDU by replacing the dust detector electronics printed circuit assembly with a new assembly. The central station harness would require modification to accommodate the circuit changes, and in addition, the new regulator resistors must be mounted to the thermal plate in appropriate locations. The PDU mother board and connectors would not require change since elimination of the dust detector would provide adequate input/output capability as presently designed.

If the controller were packaged in a separate module it could be mounted in the active seismic electronics location on ALSEP Flight Systems 1, 2, and 3. For Flight System 4, no space is available without reassignment of equipment locations. The central station harness would require modification and the thermal plate would require mounting holes for the control module and the regulator resistors.

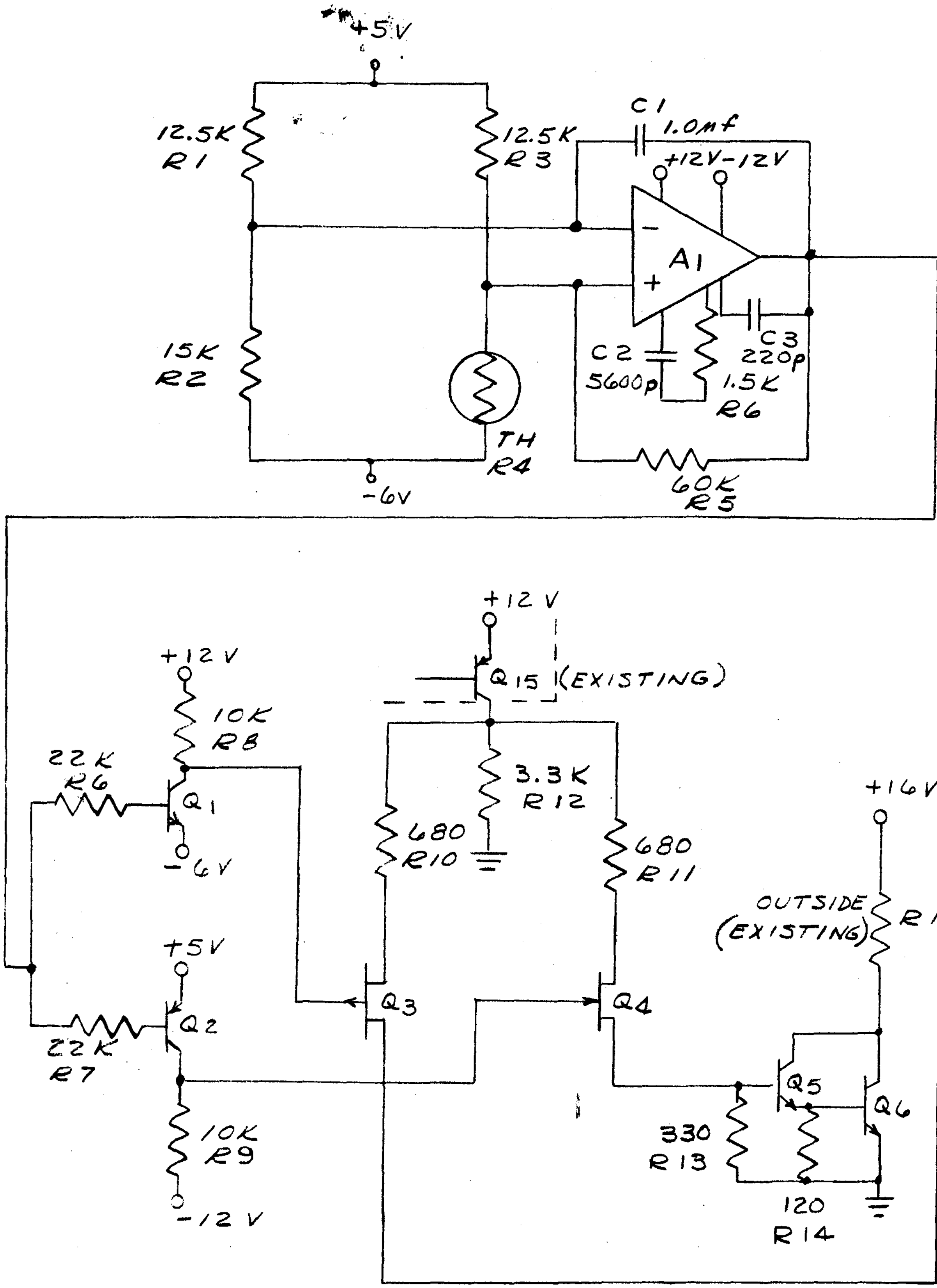


Figure 4.5

THERMAL DIFFERENTIAL CONTROLLER

4.1.2 System Performance

The thermal support provided to the electronics bay by concept I is limited to the increment of thermal dissipation that is contained in the regulator resistor added to the thermal plate when the internal regulator network is selected. The power dissipated in the regulator resistor is a non-linear function of PCU output for any given input power, as shown in Figure 4.6. Unfortunately, when this dissipation is added to the thermal plate (during lunar night) the power level is low, i.e. from 1 to 5 watts. The transfer temperatures established for concept I are as follows:

- central station temperature decreasing (transfer from external to internal regulator) 25°F.

- central station temperature increasing (transfer from internal to external regulator) 75°F.

The present design of ALSEP, as stated in section 2, has a number of commandable inboard (heater) and outboard loads which can be used to alter the central station power dissipation within the constraints of operational power requirements. Table II lists the ranges of temperature swing of the central station electronics for three values of input power and optimum usage of the various commandable loads.

TABLE II
CENTRAL STATION THERMAL CONTROL-PRESENT PERFORMANCE

			C/S Temperature Range, °F			
ALSEP Model	RTG Power, Watts	PCU Loads, Watts	Passive	With 21-Watt Dump	With 10-watt Heater	With 21-watt dump & 10-watt Heater
Flights 1, 2	63	38/49	148	133*	146**	131
	68		139	128*	135**	124
Flight 3	63	32/44	142	121	131	110
	68		134	120	115	101
Flight 4	63	36/42	136	121	122	107
	68		130	110	111	91

*14 watt daytime commandable dump load. Ripple off of Experiment 4 occurs with 21 watt dump load.

**5 watt nighttime heater. Ripple off of Experiment 4 occurs with 10 watt heater.

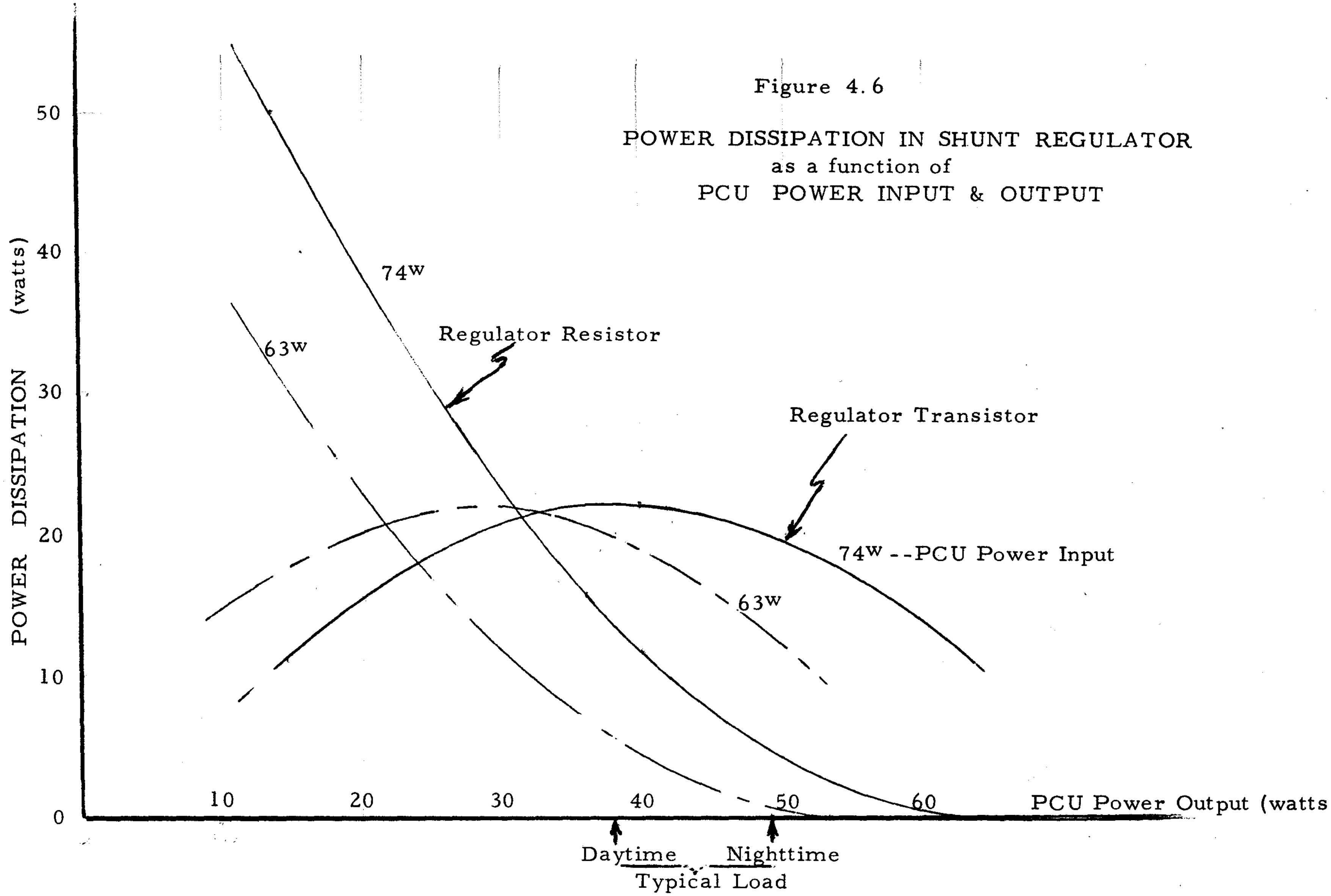


Figure 4.6

POWER DISSIPATION IN SHUNT REGULATOR
as a function of
PCU POWER INPUT & OUTPUT

An analysis was performed of the impact of adding this increment of power dissipation to the central station. A set of typical operating conditions were assumed as follows:

- -ALSEP 1 equipment array
- -RTG power at central station input: 68 watts
- -PCU regulator range: 55 watts (nominal)
- -PCU output (functional) loads
  - -during daytime: 38 watts
  - -during nighttime: 49 watts

It was determined that the extra power dissipated inside the temperature-controlled area would raise the nighttime temperature by approximately 8°F. That is the temperature range for the passive thermal control method would be reduced from 139°F (Table II) to 131°F.

4.1.3 Reliability Considerations - Thermal Differential Controller

Table III provides a failure mode summary of the electronics associated with concept I. Although this concept is an integral part of the PCU regulator, the failure mode analysis is confined to the thermal controller. The effects of these failures are considered in their relation to the PCU regulator and ALSEP system.

The failure modes of the differential controller circuit can be categorized into three general classifications, and are summarized in the following paragraphs.

1. Degradation of the temperature sensing function, causing the differential temperature set-point levels to shift. Refer to paragraphs 1.1, 1.2, 1.3, 2.2, and 2.3 of Table III. This will cause the shunt regulator reserve power dissipation to be switched from internal to external (or vise versa) loads at different temperature limits. Aside from some deterioration in Central Station thermal control, the failure mode is not catastrophic in nature. This degraded mode of operation represents approximately 34% (Q_1 = .00094692) of the failure probability of the Regulator/Differential controller circuit.

TABLE III
FAILURE MODES ANALYSIS OF CONCEPT I

Component/ Part	Failure Mode	Failure Cause	Probability of Occurrance	Failure Effect		Remarks
				Assembly	System	
1.0 Temperature Sensing Circuit	1.1 Sensing circuit erroneously indicates high Central Station temperature	1.1 Part failure causing the Op-Amp output voltage to swing negative	.00010182	1.1 If error signal is greater than differential range (75°F) the regulator will switch to the External Shunt Resistor/Xstr.	1.1 The C/S will operate cooler during the lunar night.	
	1.2 Sensing circuit erroneously indicates Low Central Station temperature	1.2 Part failure causing the Op-Amp output voltage to swing positive	.00036463	1.2 If error signal is greater than differential range (below 25°F set-point) the reg. will dissipate the reserve pwr. through the internal shunt resistor/transistor	1.2 The C/S temperature will increase during the lunar day.	
	1.3 Sensing circuit becomes unstable. Op-Amp goes into oscillation.	1.3 Failure within Op-Amp's frequency compensation and/or feedback circuit.	.00013155	1.3 The control loop switching hysteresis and/or slow switching rate will be affected.	1.3 Negligible effect on the system.	
2.0 Level Shifting Circuits	2.1 Internal level shifting circuit erroneously defects and/or simulates a high Central Station temp.	2.1 The P-Channel FET Q4 is either biased off and/or failed source-to-drain infinite impedance.	.00015483	2.1 PCU Regulator will function normally during the lunar Day. When the C/S temp. drops below 25°F, the level shifter will not be able to switch to internal shunt regulator transistor.	2.1 PCU will go out of regulation during Lunar Night. If failure is in PCU #1 automatic switch-over will occur.	
	2.2 Internal level shifting circuit erroneously defects and/or simulates a low C/S temperature.	2.2 The P-Channel FET, Q4 is either biased on and/or failed low impedance source-to-drain.	.00019017	2.2 PCU Regulator will function normally during the lunar night.	2.2 During the lunar day the C/S will operate hotter since reserve pwr. cannot be completely switched outside the C/S. However, regulation will be maintained.	

TABLE III (Continued)

Component/ Part	Failure Mode	Failure Cause	Probability of Occurrance	Failure Effect Assembly	Failure Effect System	Remarks
Level Shifting Circuits (cont.)	2.3 External level shifting circuit erroneously detects and/or simulates a high C/S temperature.	2.3 The N-Channel FET, Q3, is either biased ON, and/or failed/ON impedance source-to-drain.	.00015876	2.3 PCU will function normally during the lunar day.	2.3 During the lunar night, the C/S will operate cooler because the reserve power cannot be switched completely into the C/S. Regulation will be maintained.	
	2.4 External level shifting circuit erroneously detects and/or simulates a low C/S temperature.	2.4 The N-Channel FET, Q3, is either biased OFF, and/or failed infinite impedance source-to-drain.	.00019017	2.4 PCU will function normally during the lunar night. When the C/S temp. increases above 75°F, the level shifter will be unable to switch to the External Shunt regulator transistor.	2.4 PCU will go out-of-regulation during the lunar day. If the failure is in PCU #1 automatic switchover will occur.	
3.0 Shunt Regulator Transistor Stage (Internal)	3.1 Internal Shunt Regulator transistor fails in the cut-off mode.	3.1 Shunt transistor Q5 fails open c_e or drive circuit fails such that Q5 is biased OFF.	.00023589	3.1 PCU regulator will be controlled via the External Shunt Regulator Transistor during the lunar day.	3.1 Above the set-point temperature of 75°F, the PCU regulator will function as the existing design does. Between 25°- 75°F the External Shunt Regulator Transistor will absorb reserve power for the Internal Shunt Reg. Trans. Below 25°F PCU will not regulate.	3.1 Automatic switchover will occur if failure is in PCU #1.
	3.2 Internal Shunt Regulator Transistor fails in the ON mode.	3.2 Shunt Transistor Q5 fails short c_e, or drive fails such that Q5 is biased on or into saturation.	.00024795	3.2 The PCU will probably go out-of-regulation. In addition the shunt regulator will dissipate more power.	3.2 If PCU goes out-of-regulation, automatic switchover to PCU #2 will occur. If regulation is maintained but reserve power depleted, the Exp. Ripple-Off function will occur.	

2. If either the internal or the external shunt regulator transistor is inhibited (e.g. biased off), the PCU output voltages will remain in regulation during the time the "off" mode represents the normal operating state. (See Table III, para. 2.1, 2.4, and 3.1.) However, when the lunar environment requires a transition to the converse state (e.g. lunar day to lunar night), the PCU will not be able to maintain regulation. This failure mode represents approximately 28% (Q_2 = .00077695) of the Regulator/ Differential failure probability.

3. The third failure classification is excessive power dissipation in the regulator shunt loads. (See Table III, para. 3.2.) If the power dissipation becomes too excessive the PCU will go out-of-regulation. If operating on PCU #2 switching PCU's would probably be required via ground command. The PCU regulator would be expected to fail in this manner approximately 18% (or Q_3 = .0004959).

If the reliability objectives for ALSEP are to be retained, it is essential that the thermal Differential controller be redundant. That is, each PCU regulator be designed to operate with its own independent thermal control circuit. This is essential since the second failure category would constitute a single point failure source.

4.2 CONCEPT II

This concept is very similar to concept I in that an inside/outside shunt regulator is employed. In place of IN/OUT switching of the regulator resistor power, the amount of power in each regulator is proportionately controlled according to the central station thermal plate temperature.

This proportional control is accomplished by sensing the thermoplate temperature with a thermistor/amplifier combination and using this signal to control the dissipation in each regulator. Since the thermal time constant is very large, the response of this closed loop system will be very slow, and therefore will cause negligible effect on the output voltages. The circuit constants shown in Figure 4.7 provide this proportional control feature between the limit temperatures of 40° F and 60° F. That is, all reserve power is dissipated internally at thermal plate temperatures lower than 40°F and the resisistor dissipation is all external to the central station at temperatures higher than 60° F. The thermal support of the central station with this concept is the same as with concept I when the thermal plate temperature is outside the proportional control limits. The smoother control of resistor power inboard and outboard provides a more favorable temperature inside the electronics bay during the transitional period.

4.2.1 Description

Referring to Fig 4.7, the thermal plate temperature is sensed by the thermister bridge network. At the center temperature (50° F), the output of amplifier A1 is biased to equal approximately +4 Volts by resistor R3 in the bridge network. This balances the differential pair; Q_1, such that both of the shunt regulators are operating. The reserve power is then proportionally controlled inside and outside depending on the temperature of the Central Station Thermal plate.

The differential pair (Q_1) is added to the second last stage of the regulator Q_{15} (See Figure 4.7) as shown. Q_1B is based at 4VDC. The current to the shunt transistor can be directed to either shunt regulator dependent upon the voltage at the ouput of amplifier A1 and hence the temperature. The loop gain of this controller is set by the feedback element of A1, and must take into account the slow thermal time constant and the gain in A1 and P1.

The packaging requirements of the thermal proportional controller are identical to concept I. This circuit can also be located in the PDU with little impact to that unit or in a module on the thermal plate. The same trade-offs exist with both concepts I and II.

4.2.2 Reliability Considerations

A failure mode summary of the thermal Proportional Controller circuit design is provided in table IV. Like concept I, the Proportional Controller design also becomes an integral part of the PCU regulator. The comparative reliabilities of the two concepts indicates the proportional controller has a slight edge. An approximate reduction of 7% to the probability of failure (Q) would be realized using this concept. The general

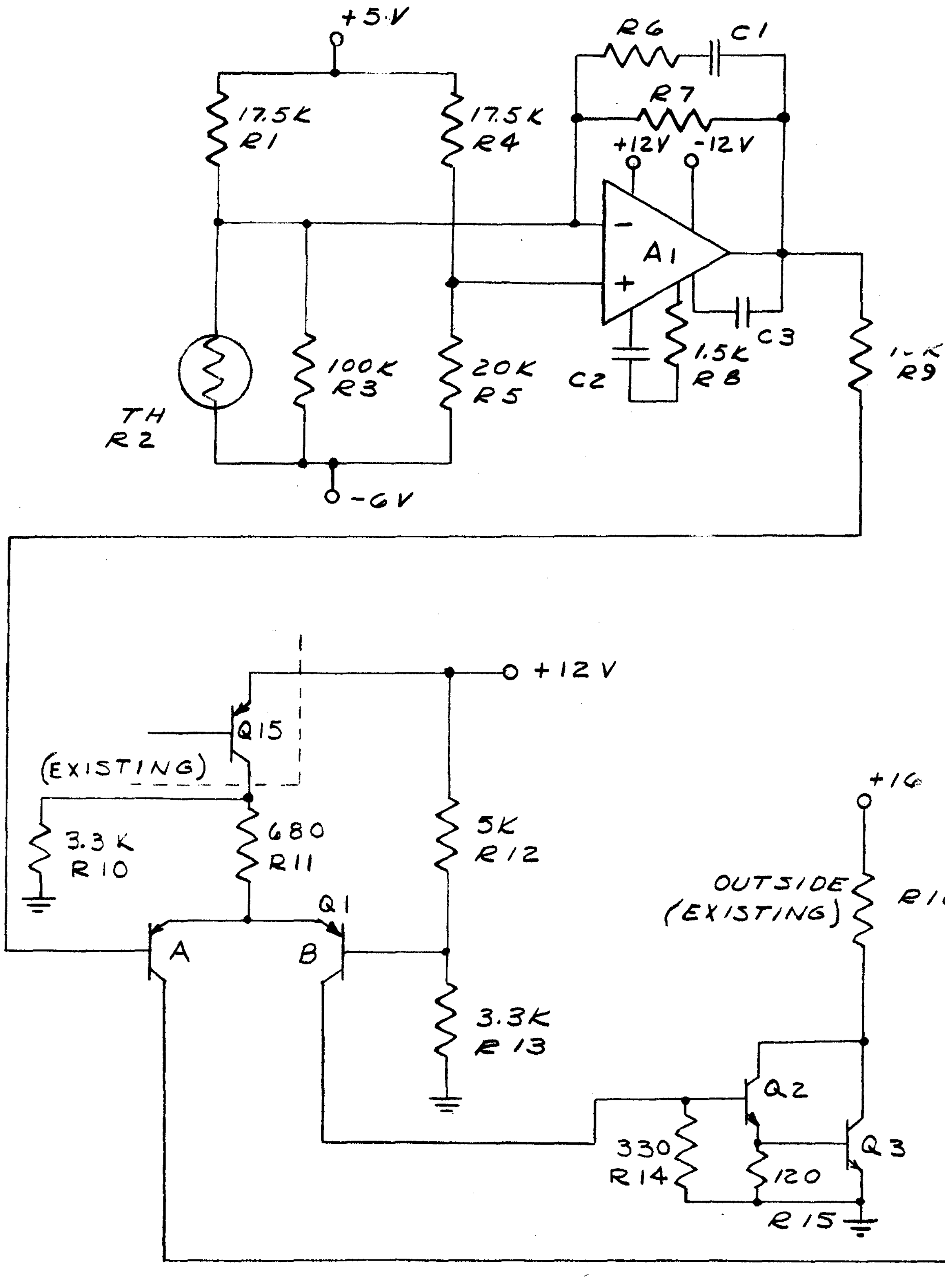


Figure 4.7

THERMAL PROPORTIONAL CONTROLLER

TABLE IV
FAILURE MODES ANALYSIS OF THERMAL PROPORTIONAL CONTROLLER CIRCUIT (CONCEPT II)

Component/ Part	Failure Mode	Failure Cause	Probability of Occurrance	Failure Effect		Remarks
				Assembly	System	
1.0 Temperature Sensing Circuit	1.1 Sensing circuit erroneously indicates high C/S temperature.	1.1 Part failure causing the Op-Amp output voltage to swing positive.	.00010155	1.1 Proportional to the signal error, the PCU Reg. will dissipate the reserve power primarily through the External Shunt Resistor.	1.1 Degradation of C/S thermal control during the Lunar Night causing the C/S temp. to decrease.	
	1.2 Sensing circuit erroneously indicates low C/S temperature.	1.2 Part failure causing the Op-Amp output voltage to swing negative.	.0003646	1.2 Proportional to the signal error, the PCU Reg. will dissipate the reserve power primarily through the Internal Shunt Resistor/Transistor	1.2 During the Lunar Day, the C/S thermal control system cannot minimize the Reserve Power Dissipation in the C/S, thus causing a higher operating temp.	
	1.3 Sensing circuit becomes unstable Op-Amp goes into oscillation.	1.3 Failure within Op-Amps' frequency compensation and/or feedback circuit.	.00013139	1.3 Regulator will switch shunt regulators in and out. similar to a differential control system.	1.3 Negligible	
2.0 Differential Amplifier Stage	2.1 Differential Amp. erroneously responds to a high C/S temperature condition.	2.1 Part failure or parameter shift causing a bias offset or hard-over output signal.	.00024367	2.1 Proportional to the signal error, the differential stage will drive the External shunt reg. transistor harder.	2.1 The C/S will operate cooler during the Lunar Night. If the error signal is "hard over" the PCU will function similar to present design capability.	
	2.2 Differential Amp. erroneously responds to a Low C/S temperature condition.	2.2 Same as 2.1 except in reverse direction.	.00023137	2.2 Proportional to the signal error the differential stage will drive the Internal shunt reg. transistor harder.	2.2 The C/S will operate hotter during the Lunar Day. If error signal is "hard-over" the PCU will go out-of-regulation if C/S temp. increase above set-point level of 50°F.	2.2 Automatic switch-over will occur if operating on PCU #1.
	2.3 Differential Amp. fails to provide sufficient drive signal to either shunt regulator transistors.	2.3 The diff.-pair transistors fail in cut-off mode, or the emitter resistor opens.	.00002093	2.3 PCU regulator becomes inoperative.	2.3 Loss of PCU regulation. Automatic switchover will occur if failure is in PCU #1.	

TABLE IV (Continued)

Component/ Part	Failure Mode	Failure Cause	Probability of Occurrance	Failure Effect Assembly	System	Remarks
Differential Amplifier Stage (cont.)	2.4 Differential Amp. provides too much drive signal to both shunt regulator transistors simultaneously.	2.4 Resistor fails open or diff-pair transistor are simultaneously driven into saturation.		2.4 Both the Internal and External shunt regulator transistors will be "tracking" on and off together. As the drive from the diff. stage increases the reserve power decreases proportionately. PCU will probably go out-of-regulation.	2.4 If the reserve power is depleted, the Exp. Ripple-off function will occur. The C/S thermal control capability will become erratic. The PCU will probably go out-of-regulation. Auto switchover will occur if failure is in PCU #1.	
3.0 Shunt Regulator Transistor Stage (Internal)	3.1 Internal shunt regulator transistor fails in the cut-off mode.	3.1 Shunt transistor Q8 fails open c_e, or drive circuit part fails such that Q8 is biased off.	.00023582	3.1 PCU Regulation will be controlled via the External Shunt reg. transistor.	3.1 PCU Regulator will function similar to present design above the set-point level of 50°F. Below this temp. PCU will not regulate (i.e. Lunar Night).	3.1 Automatic switch-over will occur if failure occurs in PCU #1.
	3.2 Internal Shunt regulator transistor fails in the "on" mode.	3.2 Shunt transistor Q8 fails short c_e, or drive circuit fails such that Q8 is biased on or into saturation.	.00024812	3.3 The PCU will probably go out-of-regulation. In addition the shunt regulator will dissipate more power.	3.3 If PCU goes out-of-regulation automatic switchover to PCU #2 will occur. If regulation is maintained but reserve power depleted, the Exp. ripple-off function will occur.	

categories of failure for the proportional controller break down as follows.

1. Degredation of thermal control capability. The maximum utilization of the PCU reserve power cannot be effected so as to minimize the central station thermal swing. However, PCU regulation will be maintained, hence this failure category is not catastrophic in nature. This degraded mode of operation represents approximately 27% (Q_1 .00070982) of the failure probability of the Regulator/ proportional Controller.

2. Similar to the second failure classification of the differential control of the proportional controller fails in a manner such that power dissipation through either shunt regulator transistor is preclude the PCU will go out of regulation as the C/S temperature swings past the set-point level of of the failed shunt transistor. Refer to failure modes 21, 2.2 & 3.1 of table IV. This failure mode renders the PCU regulator inoperative effectively 50% of the time. The probability of this failure mode occuring is Q_2 .00070310 or approximately 28% of the Regulator/Proportional Controller total probability of failure.

3. If both shunt transistors are biased off simultaneously, the PCU regulator becomes inoperable. Refer to 2.3 of table IV. The probability of failure, Q_3 .00002093 or less than 1% of the Reg/Prop. Cont probability of failure.

4. The fourth failure category will cause the depletion of the available reserve power, thus causing the experiment ripple-off function to occur. This failure mode is similar to thd third category of failure documented for the Differential Controller. The probability of occurrance is Q4 .00049624 of 18% of the total Q for the regulator.

Failure categories 2 and 3, above represent potential single point potential failure sources to the system if no redundancy were to be employed. Consequently, implementation of this thermal control concept would necessitate the utilization of redundancy.

4.3 CONCEPT III

When the dynamic regulator was originally incorporated in the PCU design an effort was made to minimize the dissipation within that unit by physically mounting the resistor elements outside the temperature-controlled area. The power transistor and control electronics were left in the controlled environment for reliability reasons. To determine the impact of removing the remaining portion of reserve power dissipation from within the central station concept III was postulated. This concept required, in its simplest form, that the power transistor in each shunt regulator be removed from the temperature-controlled area (see Figure 4.3). In practice, two configurations were considered but, because of shortcomings that became evident in the preliminary analysis, the integration requirements of these configurations were not analyzed in detail. This section describes methods of implementing this concept and the resultant impact on the temperature control of the central station.

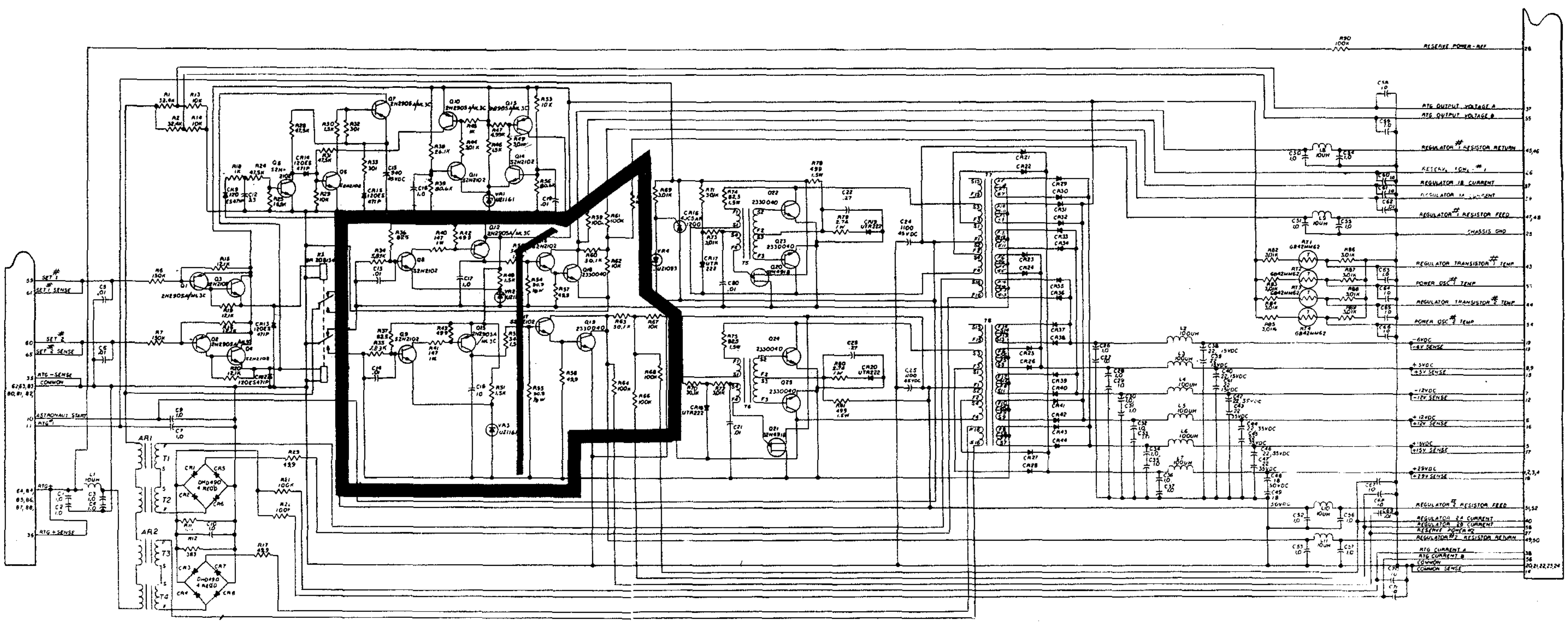
4.3.1 Description

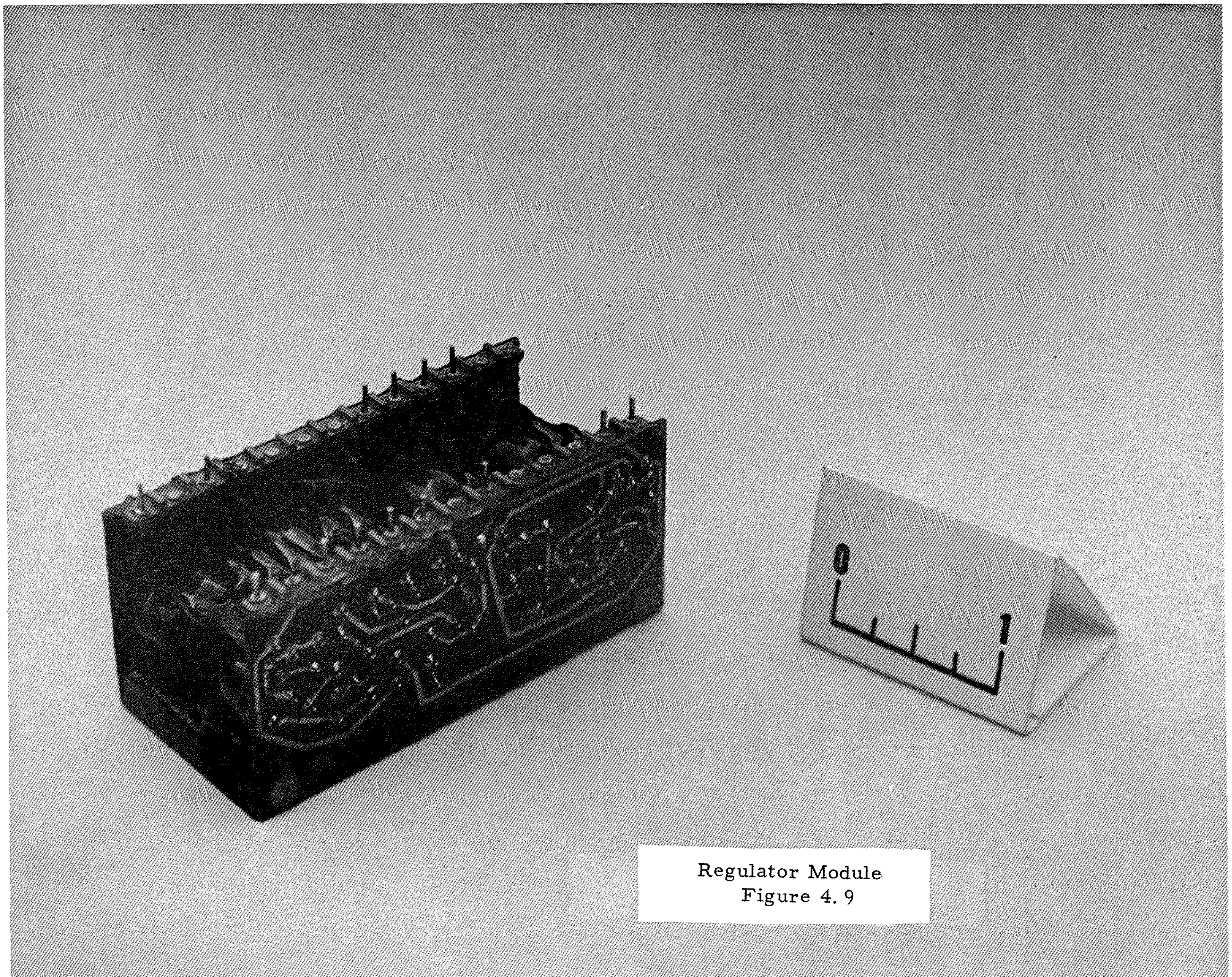
The major constraints on implementing this concept are

- selection of a suitable portion of the regulator circuit which could operate on the outside of the thermal barrier. The selected configurations must have minimum impact on both performance and mechanical design of the PCU and the central station.
- thermal control of the externally-mounted regulator.

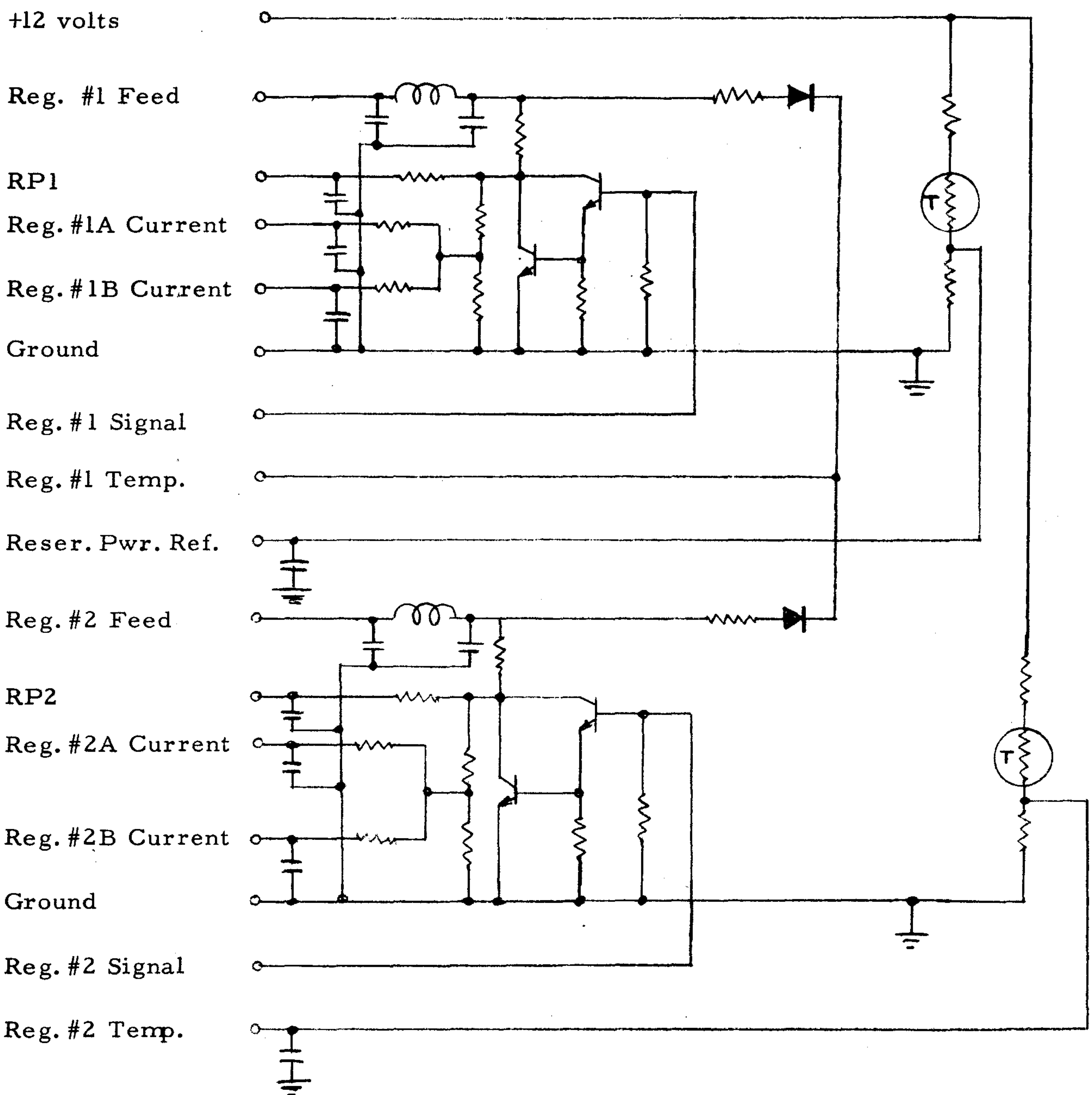
Figure 4.8 shows the complete circuit of the PCU. That portion of the circuit enclosed in the (solid) outline indicates the components packaged together in the regulator module (Figure 4.9). The portion of the regulator module which is outlined represents the smallest group of components which could be segregated from the main unit within the constraints listed above. Either the complete module package or this subgroup of components form a feasible configuration to implement this concept. Both approaches require the use of interconnecting wires which may carry a current of up to 3.5 amps with a 700 milliamp, 10 KHz ripple. Therefore, considerable caution must be exercised to prevent the electrical noise on these lines, which pass through the central station, from interfering with the operation of the central station electronics. Figure 4.10 shows the subgroup of components in an isolated form complete with interference filters.

Figure 4.8
PCU Circuit Diagram





Regulator Module
Figure 4. 9



REGULATOR ELECTRICAL INTERFACE
Figure 4. 10

The thermally decoupled regulator concept requires redesign of the power conditioning unit. The extent of that redesign depends on which of two configurations are implemented. In Case No. 1, only the regulator transistors and associated circuits are moved to an isolated location. The redesign for this configuration consists of: -removing the transistors and resistors, -jumpering several points in the regulator module, and -adding a connector (or connectors) to accommodate four shielded cables. In addition to PCU redesign, the central station harness must be revised to accommodate wiring changes. Additionally a connector must be added to Sub Package I structure for the regulator interconnections with the PCU. It is estimated that there will be some loss of accuracy on the reserve power sensing for the "ripple-off" circuit due to the long leads and manganin wire required for interconnection.

In Case No. 2, the entire regulator circuit is thermally isolated from the central station. The PCU redesign for this configuration consists of: removing the regulator circuit, adding a connector (or connectors), and possibly changing the over-all package to eliminate unnecessary weight and volume resulting from the removal of the regulator circuit. The same changes to the central station harness and Sub Package I structure are required with this scheme as with the transistors only scheme.

The packaging of the externally-mounted regulator to ensure proper thermal control is described below. The size of this package, approximately 350 cubic inches, dictates a drastic redesign of the mounting provisions of at least one of the ALSEP subpackages to accommodate such a unit. It is proposed that the regulator package could be deployed on the lunar surface near pallet 1 or could remain on the sunshield in the manner of the dust detector. The only constraints on deployed location are that the package have a completely unobstructed view of space and that it be thermally isolated from the structure. Permitting it to remain on the structure has the obvious advantage of not requiring the astronaut to deploy it.

When evaluating the circuit reliability of this concept it is assumed that the electrical circuit is functionally unchanged, although physically redistributed. Since the temperature environment of the components would also be unchanged, it can be stated that the reliability is unchanged from that of the present design.

4.3.2 Packaging of the External Regulator

Unique to this concept is the necessity to provide a mounting for those electronic components outside of the central station electronics bay. A primary requirement of this new mounting is the maintenance of the temperature of the regulator elements within a range compatible with reliable operation for a 1-year mission. This range has been selected as -4°F to +185°F at the case of the power transistor during the ambient temperature conditions shown in Figure 2.1. Two designs are presented, either of which will meet this requirement over the full range of possible conditions of electrical dissipation within the components. One of these designs makes use of a heat pipe, the other uses thermal switches to control the heat flow out of the electronic units.

4.3.2.1 Heat Pipe Configuration

The thermal design of the heat pipe configuration is shown diagramatically in Figure 4.11. The regulator transistor is mounted on an isolated baseplate which is thermally coupled to the radiator by the heat pipe. The end of the heat pipe in direct contact with the radiator is the condensor end and the other, in contact with the baseplate, is the evaporator end.

The basic principle governing the operation of the heat pipe is vaporization of a liquid from a heat source and the condensation of the vapor and deposition of its latent heat of vaporization upon a heat sink. The entire process is one of mass transfer in which the vapor carries with it relatively large quantities of heat per unit mass. The vaporization and condensation occur under very small temperature differentials existing between the heat sink and heat source. Control of the process is inherent from the temperature-pressure laws governing the interaction between a pure liquid and its vapor.

During the night, when the thermal dissipation is at a minimum, the radiator temperature drops to a very low value. The low radiator temperature increases the viscocity of the condensate which reduces its return rate, thereby increasing the thermal resistance of the heat pipe as shown in Figure 4.12. During this time, then, the transistor is thermally isolated from the lunar environment except for the heat leaks through the multilayer insulation, any structural penetrations required, and the heat pipe. Thus, in order to maintain the transistor at or above its minimum operating temperature during this period of minimum thermal dissipation the internal electrical dissipation must be equal to or greater than the total heat leak out of the package.

During the day the temperature of the lunar environment and the internal electrical dissipation both increase to their maximum values. This results in an increase in the radiator temperature. As the temperature of the radiator increases, the resistance of the heat pipe decreases, thus providing a compensating control over the extremely wide variations of lunar environmental temperatures.

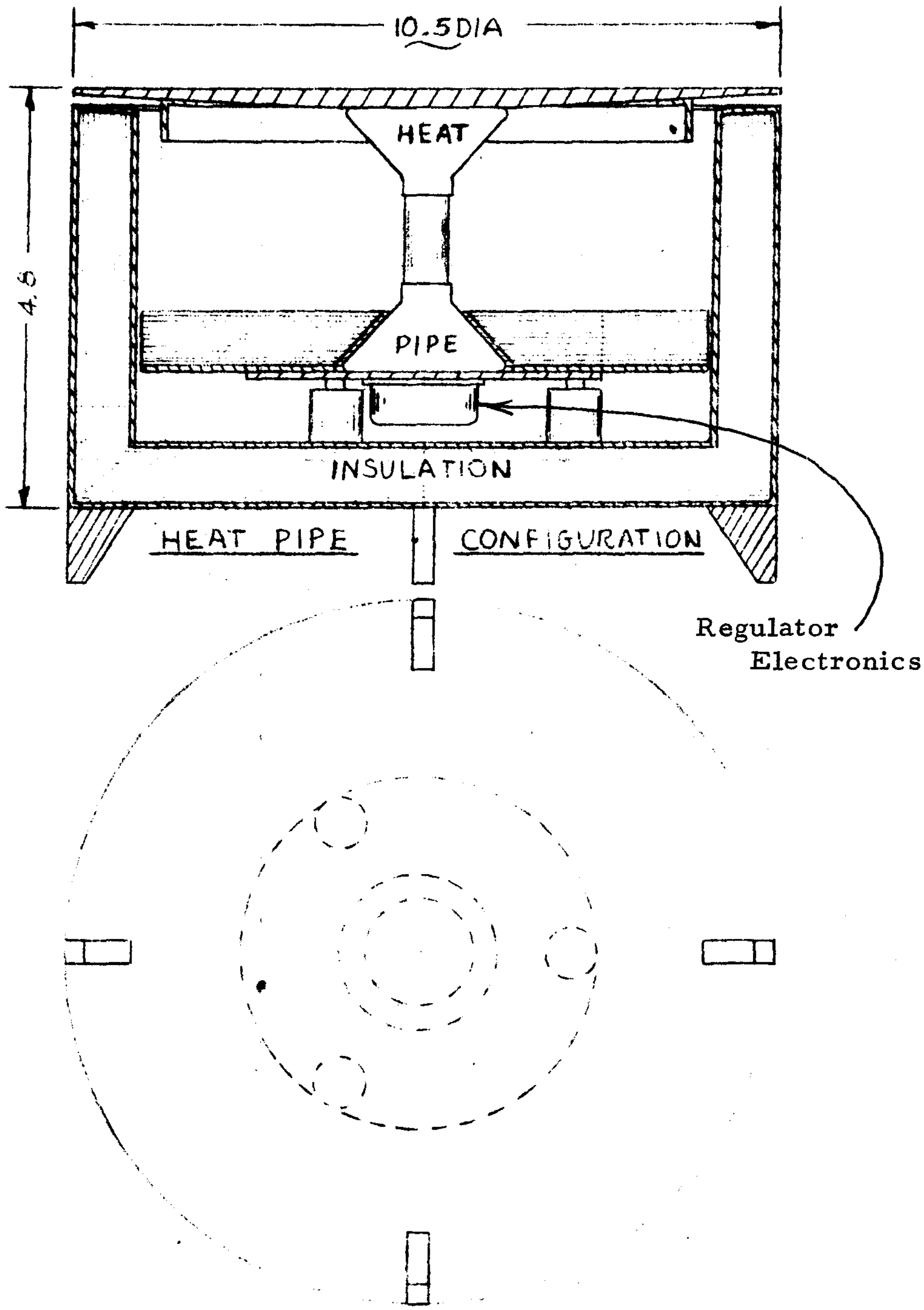
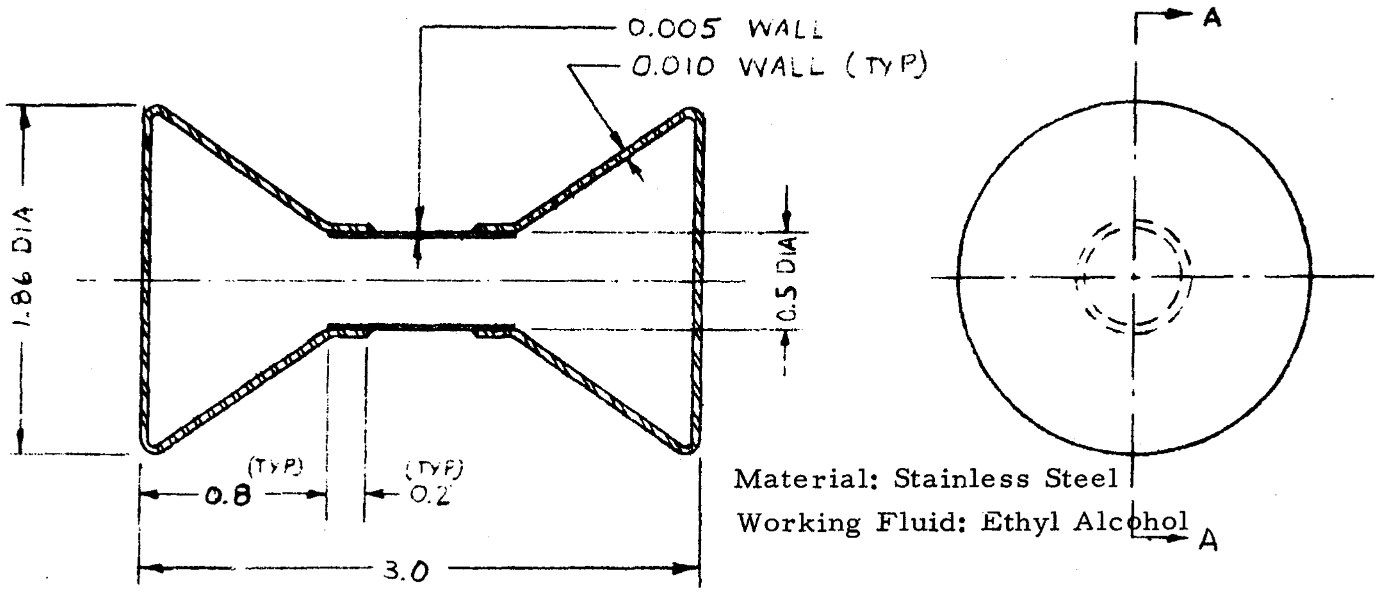


Figure 4.11 : THERMAL CONTROL--HEAT PIPE CONFIGURATION



Material: Stainless Steel
Working Fluid: Ethyl Alcohol

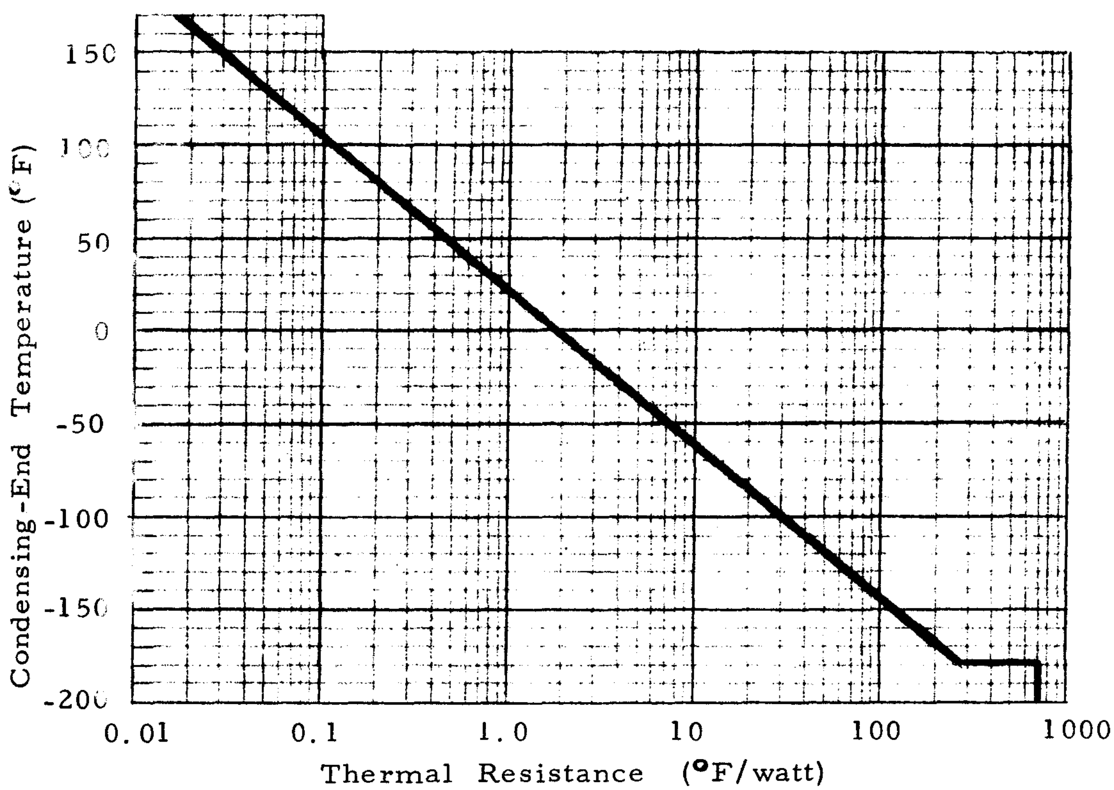


Figure 4.12: HEAT PIPE, CONFIGURATION & PERFORMANCE

A preliminary design for the heat pipe is shown in Figure 4.12. It consists of two flared ends joined by a very thin-walled tube of stainless steel. The purpose of the flared ends is to provide relatively large areas for heat transfer between the baseplate and the heat pipe and between the radiator and the heat pipe. The interconnecting tube is thin-walled in order to provide a high thermal resistance to heat conduction through the heat pipe structure. Since the heat pipe will be operated far below its capability[1], and in a 1/6 g environment the inside walls of the heat pipe may or may not be grooved to provide capillary channels for condensate return.

4.3.2.2 Thermal Switch Configuration

The thermal design of the thermal switch configuration is shown diagramatically in Figure 4.13. The design is essentially the same as the heat pipe configuration except that four thermal switch devices are required.

The thermal switch, shown in Figure 4.14 was developed by Hughes Aircraft Company for use on Surveyor. The switch design is held, under patent No. 3,177,933, by NASA. J. M. Bozajian of Hughes Aircraft is the inventor. The switch is capable of providing a resistance ratio of approximately 100 to 1 between the open condition and the fully closed condition, as shown in Figure 4.14. The contact surfaces, one being an integral part of the aluminum radiator substructure and the other a cylindrical aluminum plug, are forced together by four bimetallic elements which are attached to the base of the switch and engaged in a circumferential groove in the plug.

The plug contact surface is thinly coated with RTV-11 which in turn is charged with molybdenum disulfide (MoS_2) powder. The contact surfaces are lapped flat to within one light band and exhibit a mirror finish prior to coating. The total coating thickness is less than 3×10^{-4} in. A cruciform bundle of thin aluminum foils provide a lateral thermal conduction tie between the inner contact ring (mounting ring) and the inner contact plug. Hence, the bimetal beams are free to move the inner contact in response to changes in the mounting ring temperature.

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[1]See The Heat Pipe by G. Yale Eastman in Scientific American Volume 218, No. 5, May 1968.

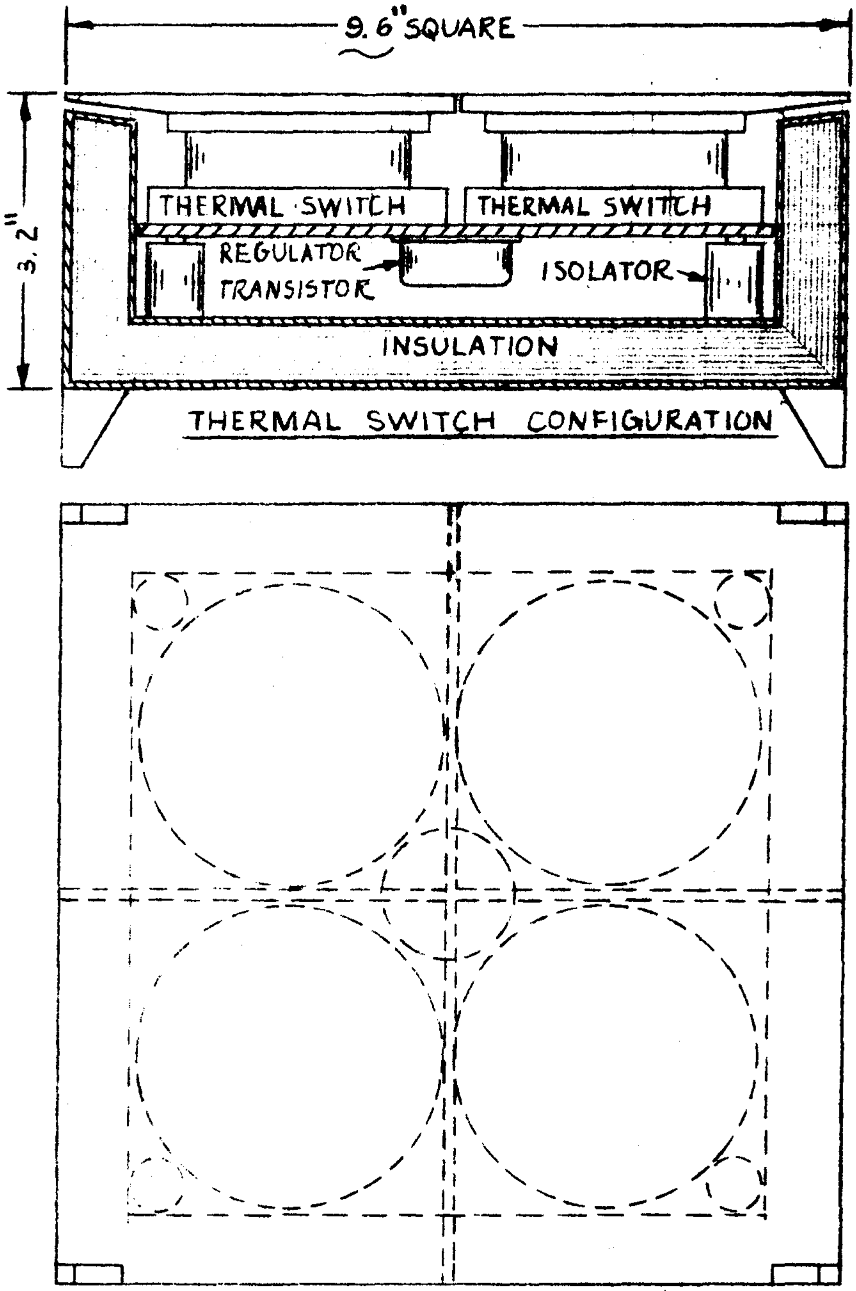


Figure 4.13 : THERMAL CONTROL -- THERMAL SWITCH CONFIGURATION

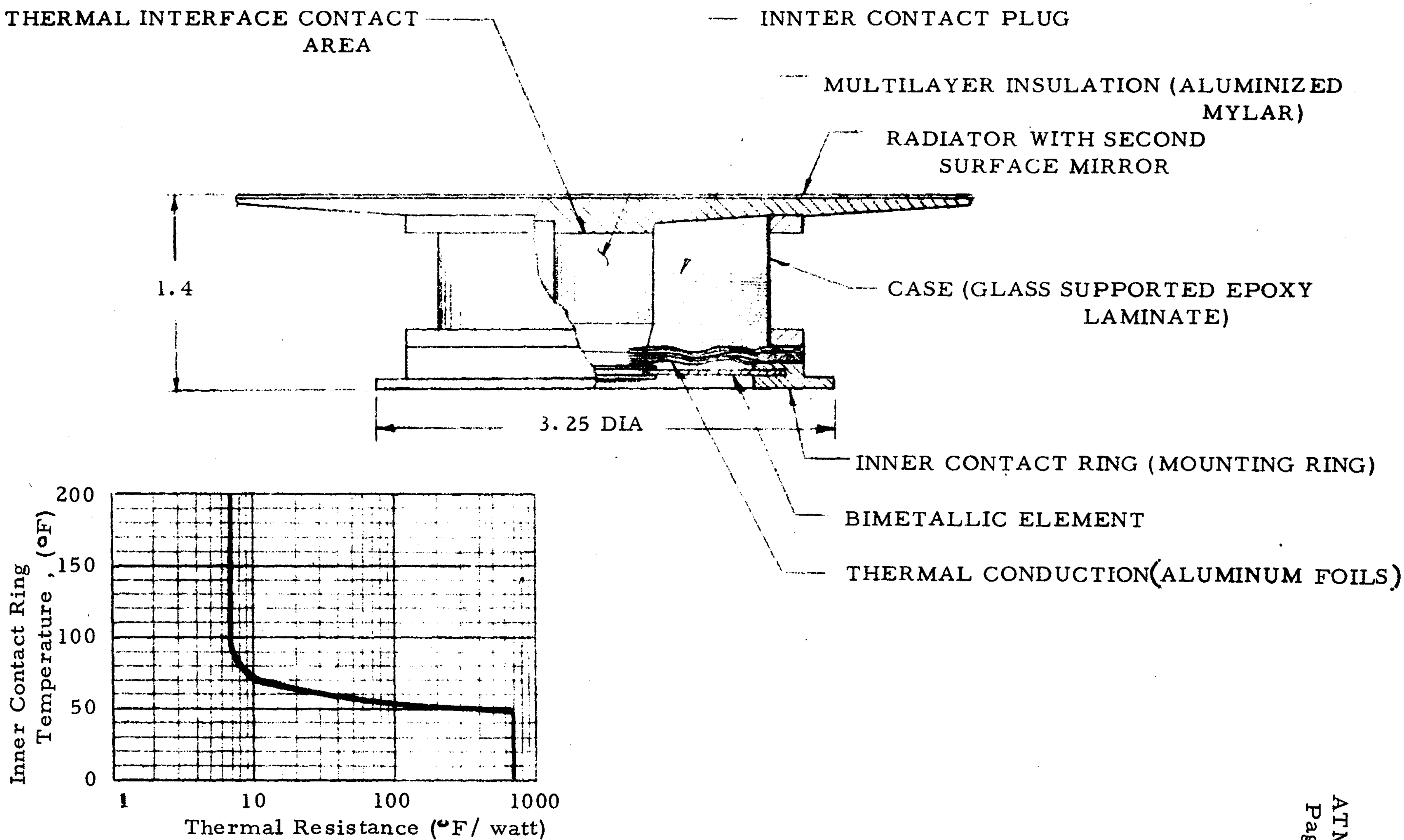


Figure 4.14 : HUGHES THERMAL SWITCH -- CONFIGURATION & PERFORMANCE

The bimetal system provides a deflection rate of 0.001 in. for each 3^oF temperature change and a buildup of pressure in the closed position of 1 lb/in^2 for each 5^oF temperature increase. The closing point can be controlled by adjusting the position of the inner contact with respect to the bimetals by means of a threaded adjustment nut.

The switch attains its maximum thermal resistance very shortly after opening of the contacts if the ambient pressure within the switch is 10^{-4} torr or less. The open resistance, approximately $700^oF/Watt$ has been maximized by the following features:

a. Utilization of the thinnest wall epoxy-glass laminated case consistent with the load carrying requirements imposed on it.

b. Blockage of radiant interchange in the case body with multilayer aluminized mylar insulation.

c. Sufficient venting to ensure that the pressure within the cask will not exceed 10^{-4} torr.

As the mounting surface temperature rises above the switch closure temperature, the contact load increases linearly with the temperature and, in turn, the contact resistance decreases. Thus, as the demand for energy dissipation increases, the switch resistance decreases, providing a measure of self compensation for varying rates of internal electrical dissipation.

Problems have been encountered with sticking contacts after being assembled in the closed position for several months. The sticking is thought to be caused by a migration of the MoS_2 into the RTV-11 coating on the contact. The resulting condition, then, would be that of RTV-11 being exposed directly to the mating aluminum contact surface on the radiator without the intended MoS_2 interface material. Pressure exerted on the contacts over a long time interval could result in adhesion.

Due to the tight schedules imposed upon the now closed-out Surveyor program, a permanent solution to the problem has never been found.

4.3.3 Thermal Control Performance

4.3.3.1 Externally-Mounted Regulator

Insulation: The high degree of thermal isolation required by the regulator makes it necessary to study in detail the insulation requirements and limitations. The multilayer insulation bag will be constructed of 1/4 mil mylar (60 layers/in.) with vapor deposited aluminum on both sides. Paper or nylon separators are included. The external layer of the bag will be protected from solar deterioration by the structure. Estimates have been made regarding the degrading effects of actual construction techniques (corners, bends, etc.) and penetrations through the bag. A bag with no penetrations or end effects has been estimated to have a thermal conductivity of 1.75×10^{-5} (Btu/hr)/ftF (0.513×10^{-5}w/ftF). The effect of the penetrations and construction techniques tend to increase this value and it is estimated that the theoretical value will be increased from 25 to 50 times. Thus, a carefully made bag using the best construction techniques is expected to possess a thermal conductivity of $25 \times 0.513 \times 10^{-5}$w/ftF or 12.8×10^{-5}w/ftF. However, it is expected that a less precise bag will exhibit a value up to 25.7×10^{-5}w/ftF.

As the degree of thermal isolation changes, the amount of heat available for thermal control also changes. The electrical dissipation of the regulator transistor varies from 4 to 17w. The heat leak has been estimated as a function of the insulation degrading factor (β = 25 and 50) and the number of layers (20, 40 and 60) of insulation. The heat leak is appropriately combined with the electrical dissipation in Table V to determine the total thermal dissipation of the package (q_t). Examination of the data shows that the degrading factor can not be allowed to exceed 25. The effect that the thermal dissipation has on the size of the radiator is examined next.

Radiator: The selection of a radiator as to area and surface properties is discussed in this section. In the present application the requirement for maximum power dissipation during periods of direct sun load requires that the surface exhibit as low an α/ϵ ratio as possible. Second surface Vycor glass mirrors were selected since they afford a low α/ϵ ratio of 0.11/0.79 and possess good stability under ultraviolet solar load. The size of the radiator is a function of the properties of its thermal coating, the quantity of heat to be dissipated and the temperature at which

TABLE V
POWER DISSIPATED IN REGULATOR PACKAGE FOR REPRESENTATIVE CONDITIONS

Nighttime/Minimum Case

Insulation / Watts Dissipated In	β = 25			β = 50		
	20 Layers	40 Layers	60 Layers	20 Layers	40 Layers	60 Layers
Transistor	4.0	4.0	4.0	4.0	4.0	4.0
Heat Leak *	-4.2	-1.7	-0.8	-8.9	-4.6	-.25
Total Package	-0.2	+ 2.3	+ 3.2	-4.9	-0.6	+ 1.5

Nighttime/Nominal Case

Transistor	9.0	9.0	9.0	9.0	9.0	9.0
Heat Leak *	-4.2	-1.7	-0.8	-8.9	-4.6	-2.5
Total Package	+ 4.8	+ 7.3	+ 8.2	+ 0.1	+ 4.4	+6.5

Daytime

Transistor	17.0	17.0	17.0	17.0	17.0	17.0
Heat Leak *	+ 0.6	+ 0.3	+0.2	+1.3	+ 0.6	+0.4
Total Package	+17.6	+17.3	+17.2	+18.3	+17.6	+17.4

*Heat leak out is negative; heat leak in is positive the heat is to be rejected. As discussed above the quantity of heat to be rejected is a function of the internal thermal dissipation and the effectiveness of the insulation. The temperature at which the heat is to be rejected is a function of the operating temperature of the transistor, the quantity of heat to be rejected and the thermal resistance between the transistor case and the radiator surface.

Using the parameters for β = 25 as discussed above, the radiator size has been calculated for each of the thermal control configurations. These are 0.605 ft^2 (10.5 in. dia or 9.4 in. square) for the heat pipe configuration and 0.638 ft^2 (9.6 in. square) for the thermal switch configuration as shown in Figure 4.14.

Summary: The performance of each of the thermal control configurations plus a completely passive system have been calculated on the basis of worst case lunar surface operating conditions or lunar noon and predawn. At noon the lunar surface temperature is taken as 250°F and the solar load at 130 w/ft^2. At predawn, the lunar surface temperature is assumed to be -300°F and the solar load is zero. The thermal control system performance summary is presented in Table VI and Figure 4.15.

4.3.3.2 Central Station Thermal Control

Mounting the regulator transistor externally to the Central Station, changes the operational temperature range of the radiator to the extent that a new mask size must be determined. On the other hand, it is also possible to consider a completely different thermal control system - namely - DRT. The following is a discussion of the central station electronics temperatures for both techniques under conditions imposed by concept III.

The electrical power dissipation within the electronics bay is essentially constant, varying between 24.5 watts at night to 26.0 watts during daytime. This change in dissipation requires a change in the unmasked area of the radiator surface. The computed results are shown in Table VII for three sizes of radiator mask.

TABLE VII
SUNSHIELD CONFIGURATION THERMAL PERFORMANCE

RADIATOR TEMPERATURES IN °F								
8" Mask			8 1/4" Mask			8 1/2" Mask		
Day	Nite	Swing	Day	Nite	Swing	Day	Nite	Swing
122	-24	146	127	-16	143	134	-8	142

TABLE VI
PCU REGULATOR PACKAGE THERMAL PERFORMANCE SUMMARY

THERMAL CONTROL SYSTEM CONFIGURATION: COMPLETELY PASSIVE

Performance Parameter	Nite/Min.			Nite/Nom.			Daytime		
Insulation Layers	20	40	60	20	40	60	20	40	60
Trans Diss. (w)	4.0	4.0	4.0	9.0	9.0	9.0	17.0	17.0	17.0
Total Rad. Diss. (W)	-	2.3	3.2	4.8	7.3	8.2	17.6	17.3	17.2
Rad. Temp. (F)	-	-135	-107	-69	-26	-12	121	119	119
Switch Res. (F/W)	-	0	0	0	0	0	0	0	0
ΔT, Rad. to Baseplate (F)	-	0	0	0	0	0	0	0	0
ΔT, Baseplate to Trans.	-	5	7	11	17	19	40	39	39
Trans. Temp. (F)	-	-130	-100	-58	-9	7	161	158	158

THERMAL CONTROL SYSTEM CONFIGURATION: HEAT PIPE

Performance Parameter	Nite/Min.			Nite/Nom.			Daytime		
Insulation Layers	20	40	60	20	40	60	20	40	60
Trans Diss. (w)	4.0	4.0	4.0	9.0	9.0	9.0	17.0	17.0	17.0
Total Rad. Diss. (W)	-	2.3	3.2	4.8	7.3	8.2	17.6	17.3	17.2
Rad. Temp. (F)	-	-147	-120	-84	-43	-30	105	103	103
Switch Res. (F/W)	-	99	50	20	6.4	4.5	0.11	0.12	0.12
ΔT, Rad. to Baseplate (F)	-	227	160	95	47	37	1.9	2.0	2.0
ΔT, Baseplate to Trans.	-	5	7	11	17	19	40	39	39
Trans. Temp. (F)	-	85	47	22	21	26	147	144	144

THERMAL CONTROL SYSTEM CONFIGURATION: THERMAL SWITCH

Performance Parameter	Nite/Min.			Nite/Nom.			Daytime		
Insulation Layers	20	40	60	20	40	60	20	40	60
Trans Diss. (w)	4.0	4.0	4.0	9.0	9.0	9.0	17.0	17.0	17.0
Total Rad. Diss. (W)	-	2.3	3.2	4.8	7.3	8.2	17.6	17.3	17.2
Rad. Temp. (F)	-	-151	-125	-89	-48	-36	100	98	97
Switch Res. (F/W)	-	84	53	28	133	10.4	1.7	1.7	1.7
ΔT, Rad. to Baseplate (F)	-	193	169	135	97	85	30	29	29
ΔT, Baseplate to Trans.	-	5	7	11	17	19	40	39	39
Trans. Temp. (F)	-	47	51	57	66	68	170	166	165

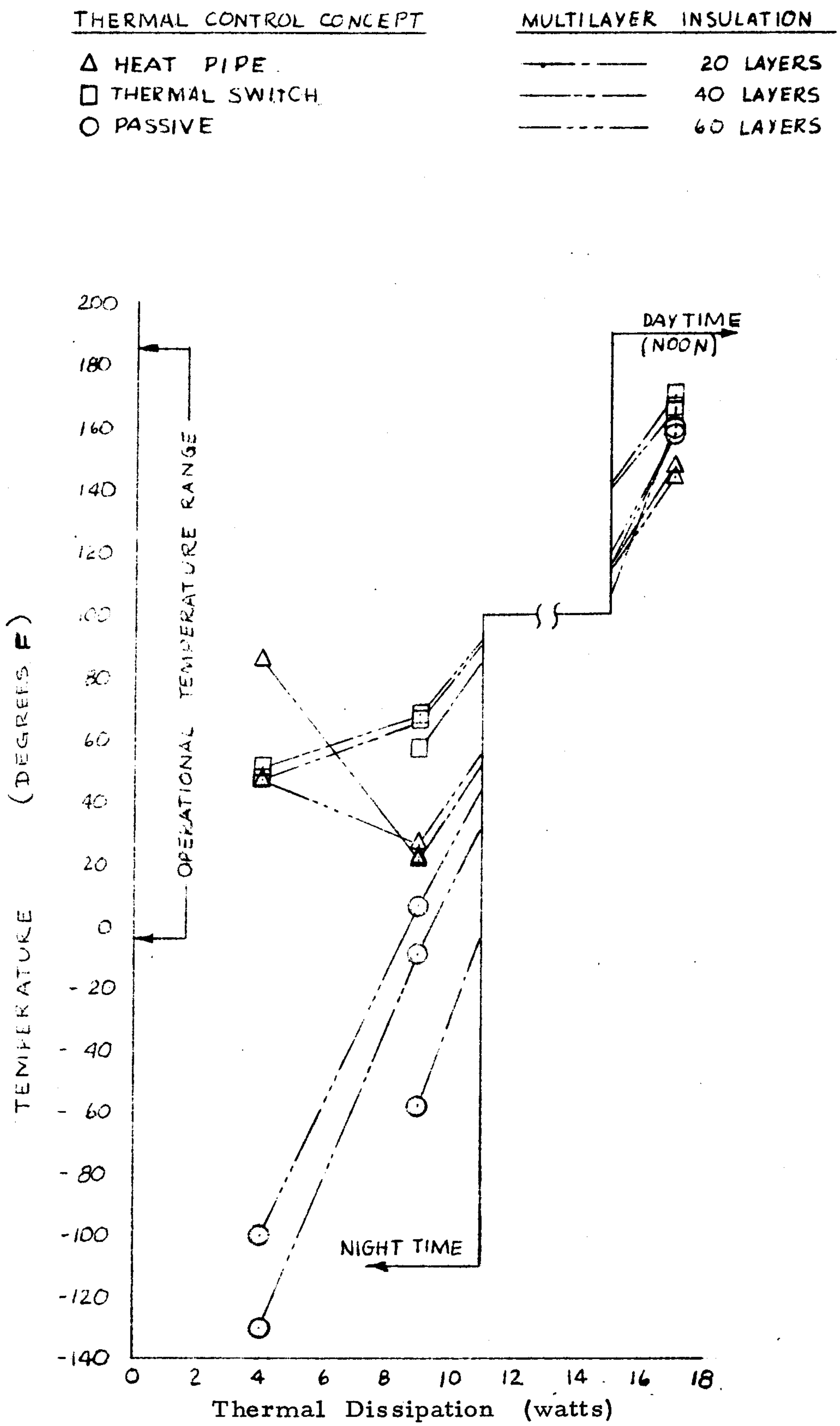


Figure 4.15 REGULATOR TEMPERATURE FOR VARIOUS THERMAL CONTROL CONCEPTS

These calculations indicate how the severe temperature swings of the lunar environment become the predominantly controlling factor as the central station electrical dissipation is decreased.

For purposes of comparison it is interesting to note the thermal control provided to the central station electronics bay by a direct radiative thermal control system under conditions of concept III. The results of such an analysis are shown in Table VIII.

TABLE VIII
DRT CONFIGURATION THERMAL PERFORMANCE

RADIATOR TEMPERATURES IN °F											
1.000 ft^2 Rad			0.903 ft^2 Rad			0.821 ft^2 Rad			0.748 ft^2 Rad		
Day	Nite	Swing	Day	Nite	Swing	Day	Nite	Swing	Day	Nite	Swing
100	9	91	110	21	89	120	32	88	130	44	86

4.4 CONCEPT IV

This concept is an attempt to integrate the better features of each of the previous concepts and in simplest terms in an automated and improved version of the functions now expected to be performed by the mission controller in the optimum use of reserve power to thermally support the central station electronics. This concept proposes to reduce to an absolute minimum the amount of reserve power dissipated into the thermal plate during lunar day and to ensure that all reserve power available is dissipated into it at night. Without compromising or interfering with the normal operation of ALSEP, it is not possible to make better use of reserve power for this purpose than is proposed by this concept. This is what the mission controller is expected to do within the constraints imposed by a limited number of incremental loads applied through use of a command link which at best is available to him for only a percentage of time.

This section describes a circuit which could implement an automatic proportional control of reserve power and an evaluation of the integration requirements and thermal control performance which result.

4.4.1 Description

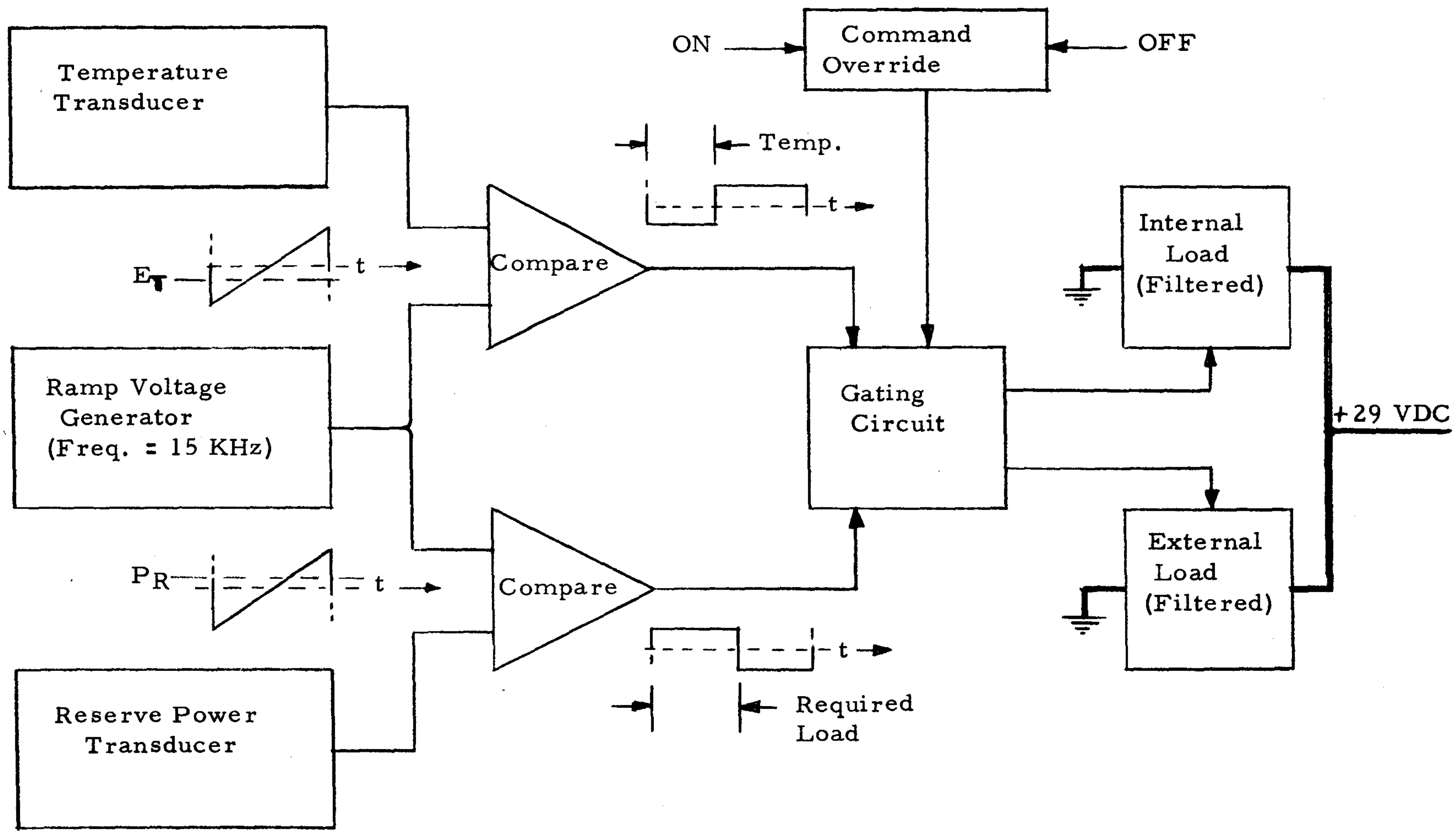
As illustrated in the functional diagram of this concept (Figure 4.4), a load on the 29v output of the PCU is controlled dynamically to absorb all of the reserve power above a specified minimum necessary to ensure proper operation of ALSEP. This load consists of two parts--one mounted internal to the electronics bay, and one outside the temperature-controlled area. An independent control circuit assigns this segregated power (which represents all the reserve power available at a particular instant) inboard or outboard as dictated by the thermal plate temperature. Because the PCU operates at a constant reserve power in this concept, the PCU internal dissipation is constant for all system operational modes, day and night. This assumes that available reserve power does not exceed 23 watts: a figure obtained by evaluation of power available and system requirements under contingency conditions. The end result then, is to reduce the central station daytime dissipation by approximately 14 watts under normal operating conditions and to provide maximum reserve power on a continuous control basis for thermal assistance at night.

A functional diagram of the control circuits is presented in Figure 4.16. A dc voltage is generated having a potential proportional to the temperature of the thermal plate. This, through comparison with a ramp voltage generator, is converted into a pulse duration modulated signal having a pulse ratio of zero corresponding to $60^{\circ}F$ and a ratio of 100% corresponding to $40^{\circ}F$.

Similarly, the measurement of reserve power is changed into a pulse ratio modulated signal, which, by suitable biasing, represents the load which must be applied to the 29 volt line to maintain 3 watts of reserve power in the PCU shunt regulator. A pulse ratio of zero represents zero watts load. A 100% pulse ratio represents 20 watts.

The load applied to the 29v PCU output is controlled by this reserve power signal by gating the current through a resistance network for the duration of the pulse. A filter network reduces the load variations to an acceptable level. The load network consists of two resistor groups, one mounted on the thermal plate and the other (as in the present design) on the power dissipation module. Each resistor group will dissipate 20 watts when connected across the 29 volt supply. The gating circuit is so designed that only one of these 20 watt loads is applied to the line at any instant. Within the temperature control range of $40^{\circ}F$ to $60^{\circ}F$, the loads are selected

Figure 4.16
Concept IV - Functional Flow Diagram

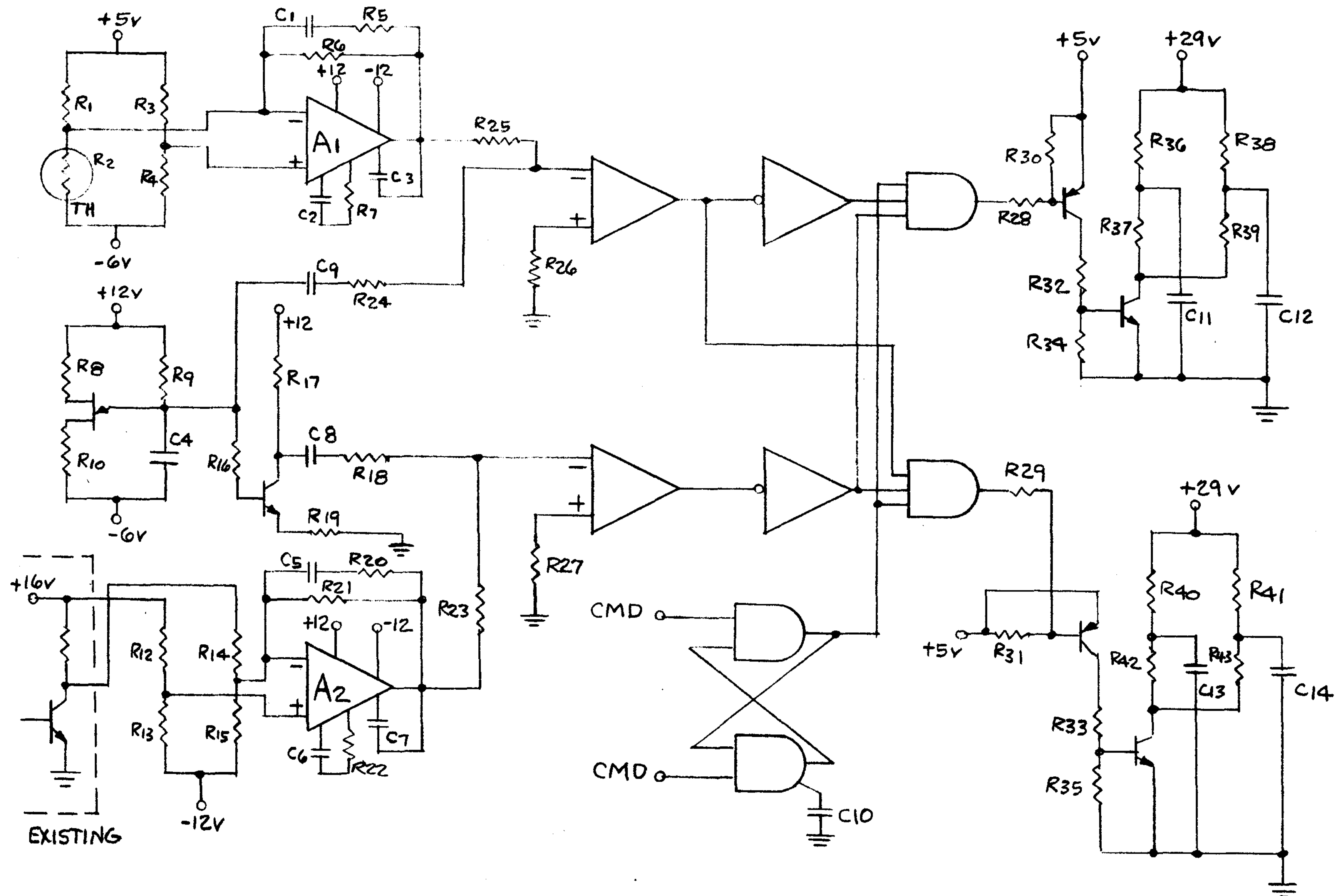


by the gating circuit in accordance with the pulse duration modulated signal representing temperature. The outboard resistors are in the circuit for the full gating cycle (67 microseconds) when the temperature of the thermal plate is higher than 60°F. The inboard resistors are selected for the full cycle when the temperature is lower than 40°F.

The operation of the gating circuit to control the magnitude and distribution of power into the dynamic loads can be determined from either the schematic diagram (Figure 4.17) or the timing diagram (Figure 4.18). Four mission situations are identified in Figure 4.19 to illustrate some typical control gating conditions. The instantaneous current circulating in each load (which is represented as a power load) is represented by vertical displacements. Two successive gating cycles are shown horizontally. Superimposed on the horizontal scale are the functional calibrations of the pulse duration modulated signals representing required load and temperature. The total instantaneous load, as well as an approximate representation of the filtered waveform, are presented for each mission condition.

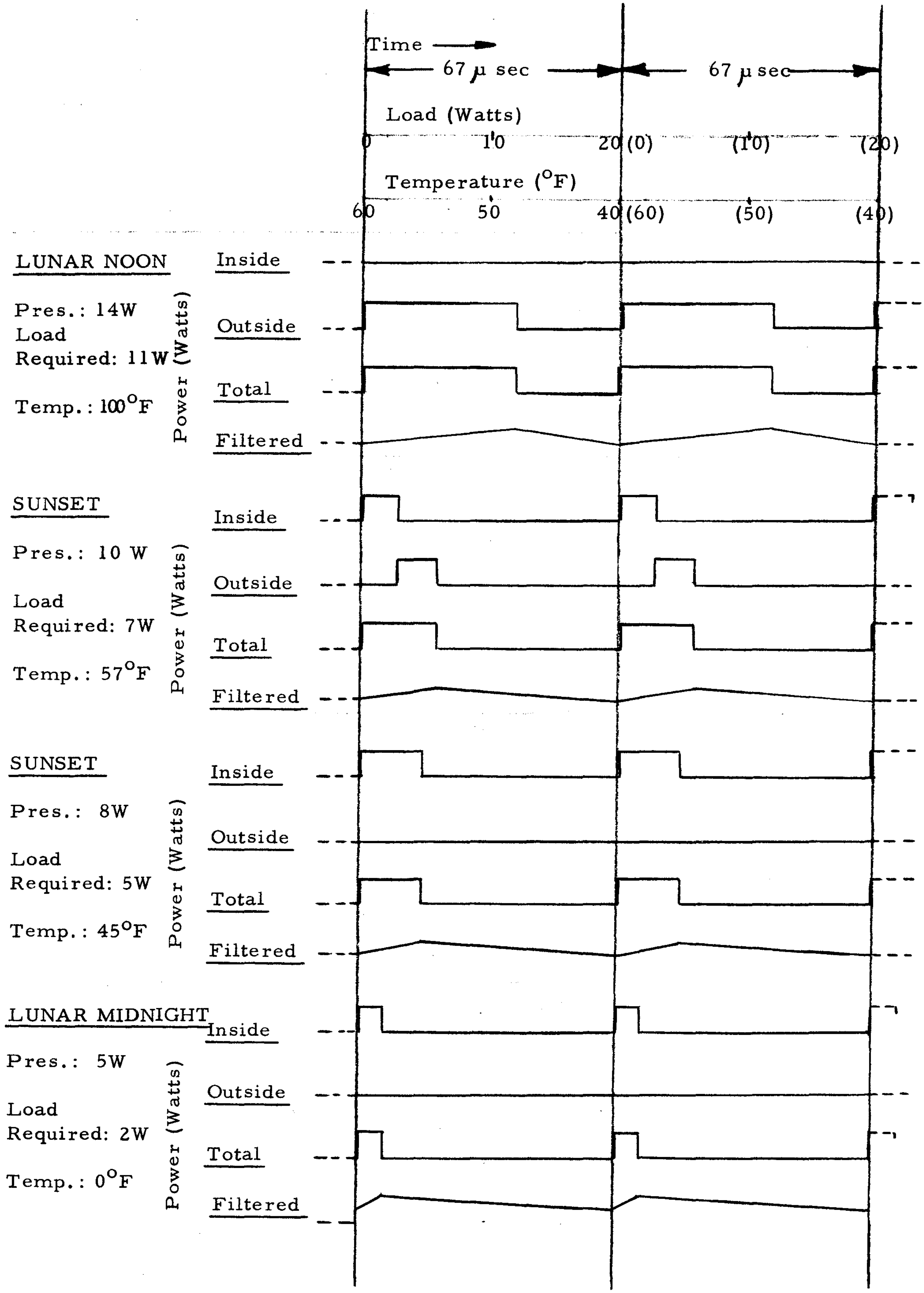
In summary, two servo loops establish the level of added 29 volt load current. One selects the external load at a thermal plate temperature of 60°F and above, the internal load at a thermal plate temperature of 40°F and below and proportionally distributes the load between internal and external between 40°F and 60°F. The second loop establishes the amount of power which can be supplied to the 29 volt loads by sensing reserve power in the PCU regulator and maintaining it at a level of 3 watts when the total available reserve power is within the range of 3 to 23 watts.

This dynamic load controller circuit can be packaged in the PDU in place of the dust detector electronics card as discussed under concepts I and II. Modification would be required changing the PDU mother board to accommodate additional input/output requirements. The central station harness would also require modification to remove dust detector wiring, add the regulator resistors and possibly delete other resistors on the thermal plate. The output switching transistors may require special heat sink consideration. This could be satisfied by mounting in such a manner that there is a low thermal resistance to the thermal plate. An alternative packaging scheme is to locate this circuit in a separate module mounted directly on the thermal plate. As mentioned for concept I and II, a problem of space allocation would arise on Flight System IV if this method of mounting were used.



DYNAMIC LOAD CONTROLLER
Figure 4.17

Figure 4.18 - Dynamic Load Timing Diagram



4.4.2 Reliability Considerations

The Dynamic Load Controller, unlike the other thermal control concepts, does not function as an integral part of the PCU regulator. It operates independent of the regulator and interfaces only to the extent that it loads the PCU output in proportion to reserve power. This becomes significant from the reliability standpoint when considering the effect of possible failures on the system. Table IX documents the failure modes of the dynamic load controller circuit, and the resultant effects on the regulator assembly and the system. The most significant feature is that in no case is a failure of this circuit catastrophic in nature (i.e., to render the system inoperable).

Basically, there are two failure categories which could affect system operational capabilities. These are:

1. Increased ripple on the +29v supply.

2. Depletion of the PCU reserve power, causing one or more experiments to be rippled off.

In both cases, a commandable inhibit function is provided to disable the dynamic load controller circuit.[1]

A third category of failure pertains to reduced thermal control capability. In this category, the dynamic load controller becomes inoperable or its functional capability is reduced. In either case, the system capability is not affected. The Central Station thermal control will revert to the present design capability.

The major disadvantage of the dynamic load controller design concept is that it is considerably more complex relative to the differential and proportional controller concepts. Therefore, from a probability of success standpoint, this system is inherently less reliable. However, in this text, the criticality of the failed function has not been taken into consideration. That is, a failure catastrophic in nature is weighted much heavier than a failure with minimal or limited degradational effects. However, in order to be consistent with the ALSEP design philosophy, utilization of redundancy should be employed.

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[1] If the load switching transistor fails or is biased in the ON mode, the inhibit function becomes ineffective. Refer to failure modes 5.1 and 5.3 of Table IX.

TABLE IX
FAILURE MODES ANALYSIS OF DYNAMIC LOAD CONTROLLER CIRCUIT

Component/ Part	Failure Mode	Failure Cause	Probability of Occurrance	Failure Effect		Remarks
				Assembly	System	
1.0 Central Station Temperature Sensing Circuit	1.1 Sensing circuit erroneously indicate high central station temperature.	1.1 Part failure causing the Op-Amp output voltage to swing positive.	.00010172	1.1 Proportional to the voltage level, more power will be dissipated outside the Central Station.	1.1 Degradation of C/S thermal control during lunar night.	
	1.2 Sensing circuit erroneously indicates low central station temperature	1.2 Part failure causing the Op-Amp. output voltage to swing negative.	.00034020	1.2 Same as 1.1 except power dissipation will be inside the Central Station.	1.2 Degradation of C/S thermla control during lunar day. (i.e. C/S temp. will increase).	
	1.3 Sensing circuit becomes unstable. Op-Amp goes into oscillation.	1.3 Failure of the Op Amp's Frequency compensation and/or feedback circuit.	.00013163	1.3 The amplifier will switch with no hysteresis.	1.3 Negligible effect.	
2.0 Oscillator/ Inverter Amplifier Circuit	2.1 The oscillator fails, the output voltage remains either positive or negative.	2.1 Part failure causing the unijunction to remain in the off-mode or on-mode.	.00027353	2.1 The load controller will function similar to a Differential controller circuit, switching to the internal or external PDL depending on the lunar temperature.	2.1 The reserve power sensor circuit will be switching the PDL on and off. This will increase the ripple on the 29v supply.	
	2.2 The oscillator frequency increases.	2.2 Shift in basic RC Time constant of the oscillator.	.00001838	2.2 Increase switching rate Inside/Outside power dump loads. Possible increase dissipation in the switching transistors.	2.2 Negligible Effect unless frequency increase becomes significant.	
	2.3 The oscillator frequency decreases.	2.3 Same as 2.3.	.00001838	2.3 Decrease switching rate of Inside/Outside power dump loads.	2.3 The 29v supply will be subjected to more ripple voltage.	
	2.4 The inverter amp fails, the output voltage remains positive.	2.4 Part failure causing the transistor to remain in the off-mode.	.00016113	2.4 The reserve power monitor and power dissipation inhibit function is disabled.	2.4 If the reserve power in the PCU is depleted, the Exp. pwr. ripple-off function will occur.	2.4 A command inhibit function is provided to override this anomaly.

TABLE IX(Continued)

Component/ Part	Failure Mode	Failure Cause	Probability of Occurrance	Failure Effect		Remarks
				Assembly	System	
Oscillator/Inverter Amplifier Circuit (Continued)	2.6 The inverter amp. fails--the output voltage remains negative.	2.6 Part failure causing the transistor to remain in the on-mode.	.00012437	2.6 Cannot maintain constant load to the PCU.	2.6 Same as 2.1.	
3.0 Reserve Power Monitor Circuit	3.1 Sensing circuit erroneously indicates adequate power reserve in PCU.	3.1 Part failure causing the Op-Amp output voltage to swing positive.	.00010172	3.1 Cannot detect when excessive power demand on PCU occurs.	3.1 If the reserve power in the PCU is depleted, the Exp. Pwr. Ripple-off function will occur. Note: For normal power demands, ripple-off will not occur.	3.1 A commandable inhibit function is provided to override this anomaly.
	3.2 Sensing circuit erroneously indicates low PCU power reserve.	3.2 Part failure causing the Op-Amp output voltage to swing negative.	.00006496	3.2 Proportional to the error of the Op-Amp output voltage, power dissipation in the Pwr. Dump Loads will be inhibited.	3.2 The Power dissipation in the PCU will increase proportionately Degradation of the C/S thermal control will occur during the lunar day.	3.2 Same as 3.1.
	3.3 Sensing circuit becomes unstable. Op-Amp goes into oscillation.	3.3 Failure of the Op-Amp Frequency compensation and/or feedback circuit.	.00013164	3.3 Loss of a reliable power monitor sensing signal.	3.3 The load control for the PCU will become erratic and probably go into oscillation.	3.3 Same as 3.1.
4.0 Comparator/ Logic Control Circuit	4.1 Control signal for the External PDL remains continuously positive.	4.1 Part failure causing the output gate to be locked in the Logic "1" state.	.00005257	4.1 Cannot control External power dissipation. (e.g. cannot turn external PDL on).	4.1 The reserve power dissipated will be shared between the internal PDL and the PCU. The C/S temperature will increase during the lunar day.	
	4.2 Control signal for the External PDL remains continuously negative.	4.2 Part failure causing the output gate to be locked in the Logic "0" state.	.00005257	4.2 Cannot inhibit power dissipation in the External PDL.	4.2 As PCU reserve power decreases first the internal PDL will be proportionately inhibited. If this is not sufficient to maintain minimum PCU reserve power, the Exp. Pwr. ripple-off function will occur. C/S temp. will decrease during Lunar Night.	

TABLE IX (Continued)

Component/ Part	Failure Mode	Failure Cause	Probability of Occurrance	Failure Effect: Assembly	Failure Effect: System	Remarks
Comparator/Logic Control Circuit (Continued)	4.3 Control signal for the internal PDL remains continuously positive.	4.3 Part failure causing the output gate to be locked in the Logic "1" state.	.00003932	4.3 Cannot control internal power dissipation (i.e. cannot turn internal PDL "on").	4.3 Power normally dissipated by the internal PDL will be dissipated in the PCU. If below 50°F the external PDL will be off (normal operation). If above 50°F the external PDL phases on giving reasonable C/S thermal control.	
	4.4 Control signal for the internal PDL remains continuously negative.	4.4 Part failure causing the output gate to be locked in the Logic "0" state.	.00001325	4.4 Cannot inhibit power dissipation in the internal PDL.	4.4 20W of pwr. will be continuously dissipated in the internal PDL. The C/S will operate hotter during the Lunar Day. If reserve pwr. in PCU decreases below 20W, the Exp. Pwr. ripple-off function will occur.	
	4.5 Continuous presence of inhibit command to internal/external PDL control gates.	4.5 Presence of grd. signal to input of control gates.	.00007821	4.5 Cannot maintain constant load to PCU.	4.5 Reserve power will be dissipated by the PCU. The C/S temperature will increase during Lunar Day.	4.5 Operates similar to existing design.
	4.6 Continuous presence of control signal to turn External PDL on and Internal PDL off.	4.6 Comparator for Temperature Sensing circuit erroneously indicates maximum C/S temperature.	.00006496	4.6 Reserve Power Monitor circuit can override External PDL "on" command.	4.6 C/S temperature will decrease during Lunar Night. If PCU reserve pwr. decreases below 20W the power dissipation in the Ext. PDL will be decreased proportionately.	4.6 Commandable inhibit function is available.
	4.7 Continuous presence of control signal to turn Internal PDL on and External PDL off.	4.7 Comparator for Temperature Sensing circuit erroneously indicates minimum C/S temp.	.00005257	4.7 Loss of capability to dump reserve power outside the C/S.	4.7 C/S Temperature will increase during Lunar Day. If the PCU reserve pwr. decreases below 20W, the pwr. dissipation in the PDL will be decreased proportionately.	4.7 Same as 4.6.

Component/ Part	Failure Mode	Failure Cause	Probability of Occurrance	Failure Effect		Remarks
				Assembly	System	
5.0 Reserve Power Dump Control Switch	5.1 Internal Pwr. Dump control switch is continuously turned ON.	5.1 Switching transistor is shorted or driven into saturation.	.00023677	5.1 Loss of control relative to amount of pwr dissipated in the Internal PDL.	5.1 C/S temperature will increase during the Lunar Day. If greater than 20W reserve pwr. is available the additional pwr. will be dissipated in the External PDL. If less than 20W Exp. Ripple-off will occur.	
	5.2 Internal Pwr. Dump control switch is continuously turned OFF.	5.2 Switching transistor is open or cut-off.	.00024874	5.2 Cannot dissipate power in Internal PDL.	5.2 Excess power will be dissipated by the PCU.	5.2 Operation similar to existing design.
	5.3 External power Dump control switch is continuously turned ON.	5.3 Same as 5.1.	.00023677	5.3 Loss of control relative to amount of power dissipated in the External PDL.	5.3 C/S temperature will decrease during Lunar Night. If reserve pwr. decreases to less than 20W, the Exp. Pwr. Ripple-off function will occur.	
	5.4 External Pwr. Dump Control Switch is continuously turned OFF.	5.4 Same as 5.2.	.00024874	5.4 Cannot dissipate power in External PDL.	5.4 C/S temperature will increase during the Lunar Day. Excess power will be dissipated by the PCU.	
6.0 Power Dissipation Load (Internal)	6.1 The equivalent PDL resistive impedance increases.	6.1 Any one of four power resistors open.	.00062399	6.1 The equivalent load impedance approximately doubles. The power dissipation capability is halved.	6.1 The additional power will be absorbed by the PCU. The 29v supply will see additional ripple.	
	6.2 The equivalent PDL resistive impedance decreases.	6.2 Any one of two filter capacitors short circuit.	.00005599	6.2 The equivalent load impedance decreases approximately 1/3. The power dissipation capability increases proportionately.	6.2 The External PDL duty cycle will increase to offset the additional power dissipated by the Internal PDL. The impact on the C/S thermal control will be minimal.	6.2 Sizing of the PDL resistor (i.e., wattage rating) is important to allow for this operational contingency.
	6.3 Degradation of PDL filtering capability	6.3 Any one of two filter capacitors open.	.00001410	6.3 The 29v filtering capability is degraded.	6.3 The ripple on the 29v line will increase.	

TABLE IX (Continued)

Component/ Part	Failure Mode	Failure Cause	Probability of Occurrance	Failure Effect		Remarks
				Assembly	System	
7.0 Power Dissipation Load (External)	7.1 The equivalent PDL resistive impedance increases.	7.1 Any one of four power resistors open.	.00062399	7.1 The equivalent load impedance approximately doubles. The power dissipation capability is halved.	7.1 The C/S temp. will increase during Lunar Day. Up to 10W of reserve power will have to be absorbed by the PCU.	
	7.2 The equivalent PDL resistive impedance decreases.	7.2 Any one of two filter capacitors short circuit.	.00005599	7.2 The equivalent load impedance decreases approximately 1/3. The power dissipation capability increases proportionately.	7.2 The internal PDL duty cycle will increase to offset the additional power dissipated by the Ext. PDL. The C/S thermal control impact will be minimal. The 29v ripple increases.	7.2 Sizing of the PDL resistor (i.e., wattage rating) is important to allow for this operational contingency
	7.3 Degradation of PDL filtering capability.	7.3 Any one of two filter capacitors open.	.00001410	7.3 The 29v filtering capability is degraded.	7.3 The ripple on the 29v line will increase.	

Two methods for mechanizing redundancy were evaluated for reliability. These are documented in the following sections.

Method A

This method would utilize the PCU Regulator's switching relay. (Refer to Figure 4.19.) Each thermal controller operates with its respective PCU Regulator. The controllers are totally redundant except for the resistive Power Dump Loads (PDL). Note, the PDL filtering capacitors are redundant, each coupled to their respective regulator's ground. The objective is to protect against the short failure mode of the capacitor (refer to failure mode 7.2, Table IX). Similarly, redundant switching transistors are isolated via the ground return. This technique protects against the second failure category described above in addition to maximizing the effectiveness of the "Inhibit Command" function.

Method B

Method B is essentially the same as A, except, instead of using an existing relay for redundant switchover, an independent relay and associated drive circuit is utilized. (See Figure 4.20.) The primary advantage of this method is that additional flexibility is provided. That is, either load controller circuit can function with either regulator. For this technique, switchover is accomplished via appropriate ground commands. The PCU #1 select and PCU #2 Select Commands could be used, however, some flexibility would be lost.

Comparison of Method A vs. Method B

The significant feature of both techniques is that the switchover is accomplished in the ground loop. This is important if "short circuit" isolation is to be achieved.

Since either method is compatible with the reliability objectives, then the system most compatible with existing packaging constraints should be selected.

From a comparative reliability standpoint, method B has a slight edge due to the added flexibility.

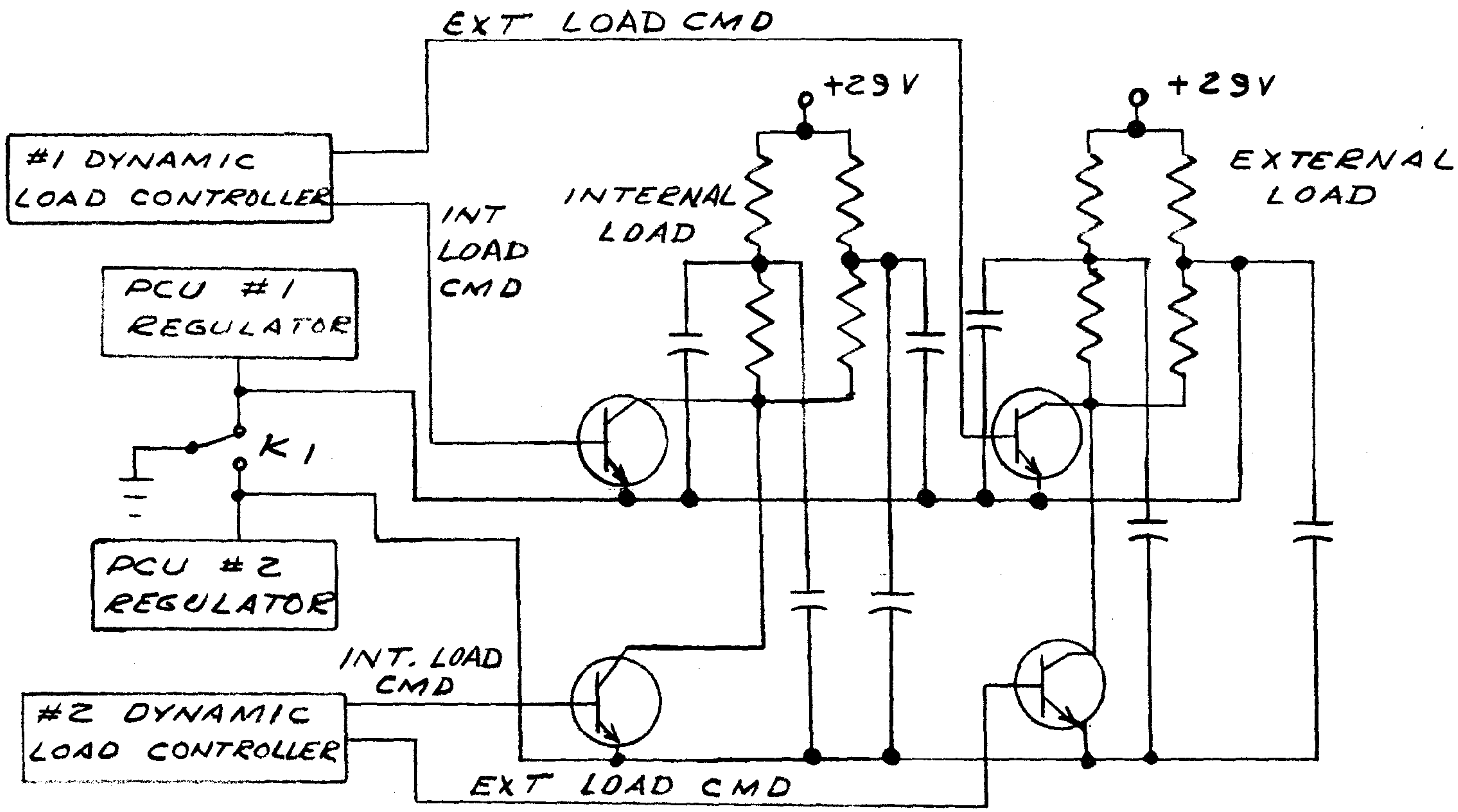

Figure 4.19.

METHOD A - REDUNDANT MECHANIZATION OF DYNAMIC LOAD CONTROLLER

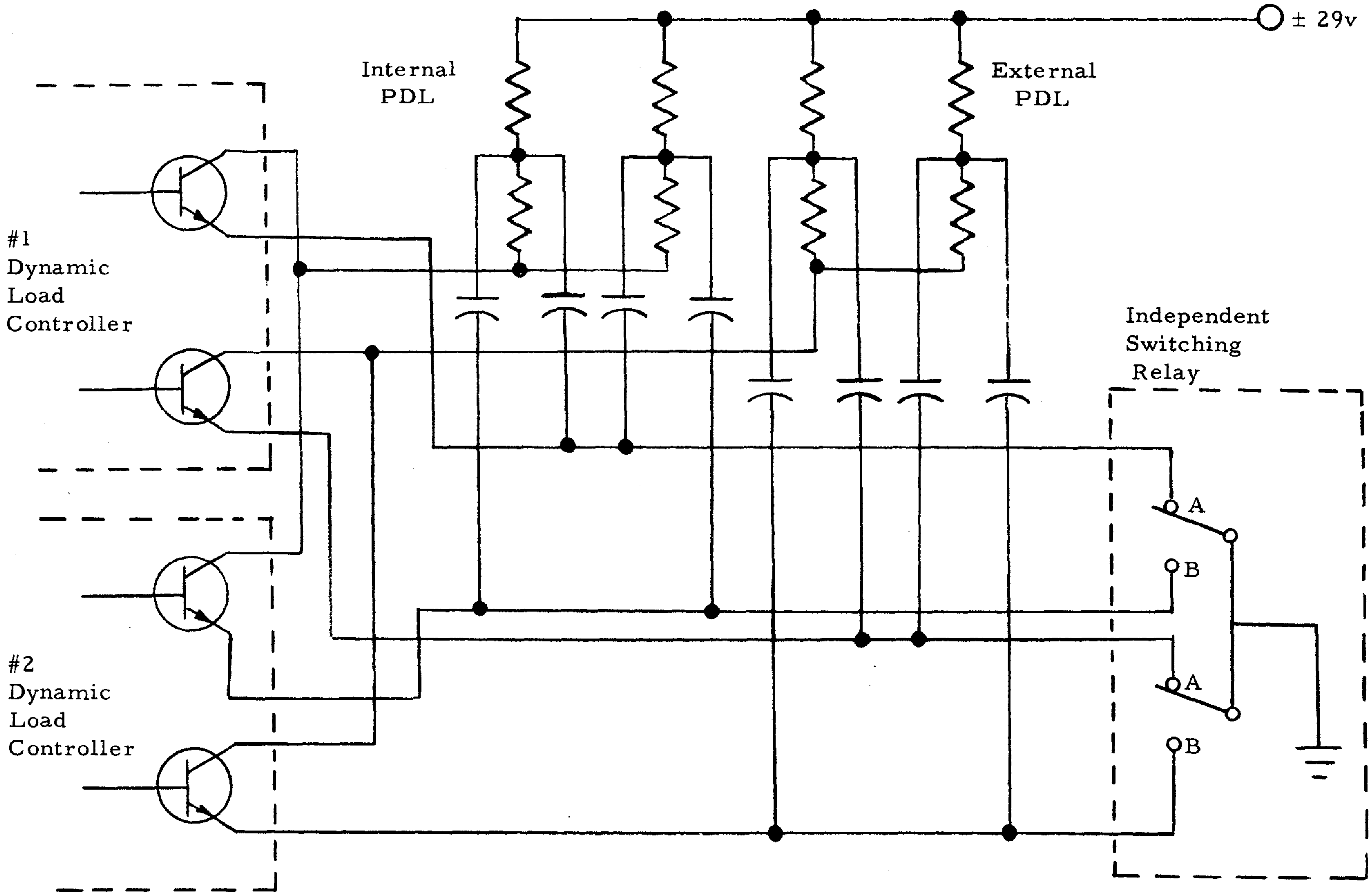

Figure 4.20

Method B - Redundant Mechanization of Dynamic Load Controller

4.4.3 Thermal Performance

Of all the units mounted in the central station electronics bay, the only one in which the power dissipation changes appreciably is the PCU. This is due to the reserve power in the transistor element of the shunt regulator. If concept IV is implemented, the dynamic load controller maintains a constant 3 watts dissipation in the regulator circuit and hence, the PCU dissipation becomes essentially constant. This assumes a reserve power within the limits of 3 and 23 watts. A preliminary analysis of the temperature swing of the thermal plate was made assuming, for daytime operation, this minimum steady dissipation and, for nighttime operation, the thermal heating provided by the inboard resistor load. The results of this analysis are presented in Table X for each ALSEP flight system and power inputs representative of first month (68 watts) and twelfth month (63 watts) operation. For purposes of comparison, the temperature ranges under similar mission conditions are presented for the central station (a) as determined by its physical design (passive), (b) if it is assumed that the mission controller inserts the various commandable loads at the right time (manual), and (c) with the automatic use of reserve power by the circuits of concept IV.

TABLE X
THERMAL PLATE TEMPERATURE VS INPUT POWER

Flight Model	Central Station Input Power (Watts)	Temperature Range, (°F) Passive Control	Manual Control	Automatic Control
Flights 1, 2	63	148	131	131
	68	139	124	112
Flight 3	63	142	111	111
	68	134	101	97
Flight 4	63	136	107	106
	68	130	91	85

As reflected in the Table, concept IV improves the temperature range from 0°F to a maximum of 12°F for Flights 1 to 4 when compared with the present method of manual control.

The Flight 1 and 2 temperature swing for a 68 watt RTG input is decreased from 139°F to 124°F through the use of the 14W power dump command during lunar noon and the 5 watt commandable heater at night. The automatic regulation of the PCU load further reduces the temperature swing to 112°F. The 12°F temperature difference (124°F versus 112°F) between the automatic and manual operating modes of the control station is due to the automatic sensing system selecting a daytime dump load which is optimum for the reserve power available together with the internal utilization of resistor power at night. The temperature swings shown above for Flight Systems I and II were determined using the power dissipation values listed in Table XI. The manual selection of daytime dump loads is limited to 14 watts (the reserve power in the central station is approximately 20 watts) since the initiation of a 21 watt dump command would result in the "rippling-off" of Experiment 4. The automatic dynamic load, while always ensuring 3 watts of minimum reserve power, results in an overall net decrease in central station thermal dissipation of approximately 4.0 watts (8°F) as compared to the manual operating case.

Although the above confirms an important thermal advantage provided by the automatic dynamic load, another advantage of perhaps equal or greater importance is the automation of optimum usage of reserve power and therefore the elimination of dependence on the command link availability and near real time monitoring for power management.

TABLE XI
CENTRAL STATION DISSIPATION

Mission Condition		Total C/S Dissipation with Manual Control, (watts)	Total C/S Dissipation with Automatic Control, (watts)
Time	Input Power (watts)		
Day	63	30.0	30.0
Day	68	34.0	30.0
Night	63	30.3	30.1
Night	68	34.6	35.4

As indicated in Table XI, the improvement in the central station thermal performance is due to the overall reduction in central station thermal dissipation from 34 to 30 watts with the automatic load control during lunar noon and the increase in nighttime internal dissipation from 34.6 to 35.4. The total improvement in the day to night power dissipation is approximately 5 watts, and results in an overall day to night temperature range improvement of $12^{o}F$.

5.0 SUMMARY EVALUATION

The results of the analyses made under this study of the four concepts described above are presented in summary form in Table XII.

Concept IV rated highest in net improvement to central station temperature control and in reliability. In addition, it was estimated to be no more difficult to integrate into the system than any of the other concepts. The power consumption of the control electronics would be higher for concept IV than for the others, but might not be noticeable if the dust detector were deleted.

Hence, Concept IV clearly meets the objectives established for the study and, by removing the dependence of central station thermal control on the availability of the command network, was ranked the most effective of the selected concepts.

Thus, the study effort authorized by CCP 90 has resulted in the initial development of a concept which enhances central station thermal control and eliminates the need for reserve power monitoring and command link availability for power management. A significant improvement in System operation is conceivable if the operation and design of the Automatic dynamic load can be verified and then incorporated into the System Design. To take advantage of the work already completed under CCP 90, the following activities are recommended as a logical follow-on.

a) Breadboard and test: The circuit designs completed to date are paper designs only and must be verified by fabricating the circuits and performing tests as appropriate.

TABLE XII
EVALUATION OF SELECTED CONCEPTS

Concept	Reduction in Central Station Temperature Range	Integration Requirements	System Weight Change	Additional Power Required	Effect on Reliability	Resultant Ranking
I	8° F	-Replacement of Dust Detector card. -Mount new items.	0 ± 0.5 pound	0 ± 0.2 watt	Reduces PCU Reliability	3
II	8° F	-Replacement of Dust Detector card. -Mount new items.	0 ± 0.5 pound	0 ± 0.2 watt	Reduces PCU Reliability	2
III	-3°F to -7°F	-New deployment item. -New cable/connector. -Rework radiator	3 ± 1 pounds	0 watt	Increase in Possible EMI	4
IV	17° F (RTG = 63 watts) 27°F (RTG = 68 watts)	-Replacement of Dust Detector electr. card. -Minor cable changes -Mount new items.	0 ± 0.5 pound	1 ± 0.2 watt	No critical failure modes	1

b) Packaging: Once the circuit designs are confirmed, packaging in a suitable location can be accomplished. A second model will then be built and evaluated. Drawings will then be completed and parts selections confirmed to document the design.

c) Thermal Analyses: The test data obtained must be used to confirm the completed thermal analysis. Therefore, a minimal amount of additional thermal analysis is required.

d) Reliability: Complete a reliability analysis with an assessment of the affects on System reliability.

e) Integration into Hardware: Evaluate the impact of integration into flight hardware. Prepare schedules for integration.

f) Report: Prepare a final report including design drawings, parts and materials list, test results and planning for incorporation into flight hardware. This report to include a section with schedules, costs and tasks by MCP.

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