This report covers a modified PSE Sensor Heater circuit increasing total power dissipation from 2.5 watts to 5.5 watts principally by replacing existing components with components of higher power ratings.

Particular attention was paid to the current control circuit, which required a special analytical approach, test verification, and thermal control to establish the reliability of the circuit at an acceptable level of confidence.

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Attachments:

Appendix A - Calculation of Q24 & Q25 Failure Rates
Appendix B - Parts Application Analysis
Appendix C - Failure Modes & Effects Analysis

1. INTRODUCTION

The purpose of the PSE Sensor Heater Modification is to increase the maximum power dissipation of the PSE Sensor Heaters from 2.5 watts to 5.5 watts. The requirement for the modification was established as a result of anomaly studies conducted on Flight 2 (Apollo 12) data.

The power increase was attained by the substitution of parts with similar characteristics but higher ratings to accommodate the increase in power dissipated by the heaters. The basic characteristics of the circuit are otherwise unchanged.

Extreme space limitations and the desirability of minimizing rework on circuit boards resulted in the use of parts in parallel where the choice of a single large part might have been preferred.

2. REFERENCES

A. SSED-R-57(d), "Investigation of PSE Anomalies Apollo 12 Mission" 28 May 1970.

B. ATM 887, "Apollo 12 PSE Thermal Anomaly Final Report", 5 June 1970.

3. DESCRIPTION OF CIRCUIT CHANGES

Modifications incorporated to increase heater power may be readily noted by reference to Figure 1. Additional comments are as follows:

a. Q18 & Q21 Substitutions

2N3499 NPN silicon transistors were substituted for 2N2222A's to obtain increased power dissipation capability. The two transistors are functionally similar and the substitution does not significantly affect the operating characteristics of the circuit. The main difference is in the heat transfer characteristics in that the 2N3499 is encased in a To-5 can while the 2N2222A is encased in a To-18 can. The only reason for changing Q21, which operates at a very low power level in either circuit, is to maintain a matched pair in the Darlington connection.

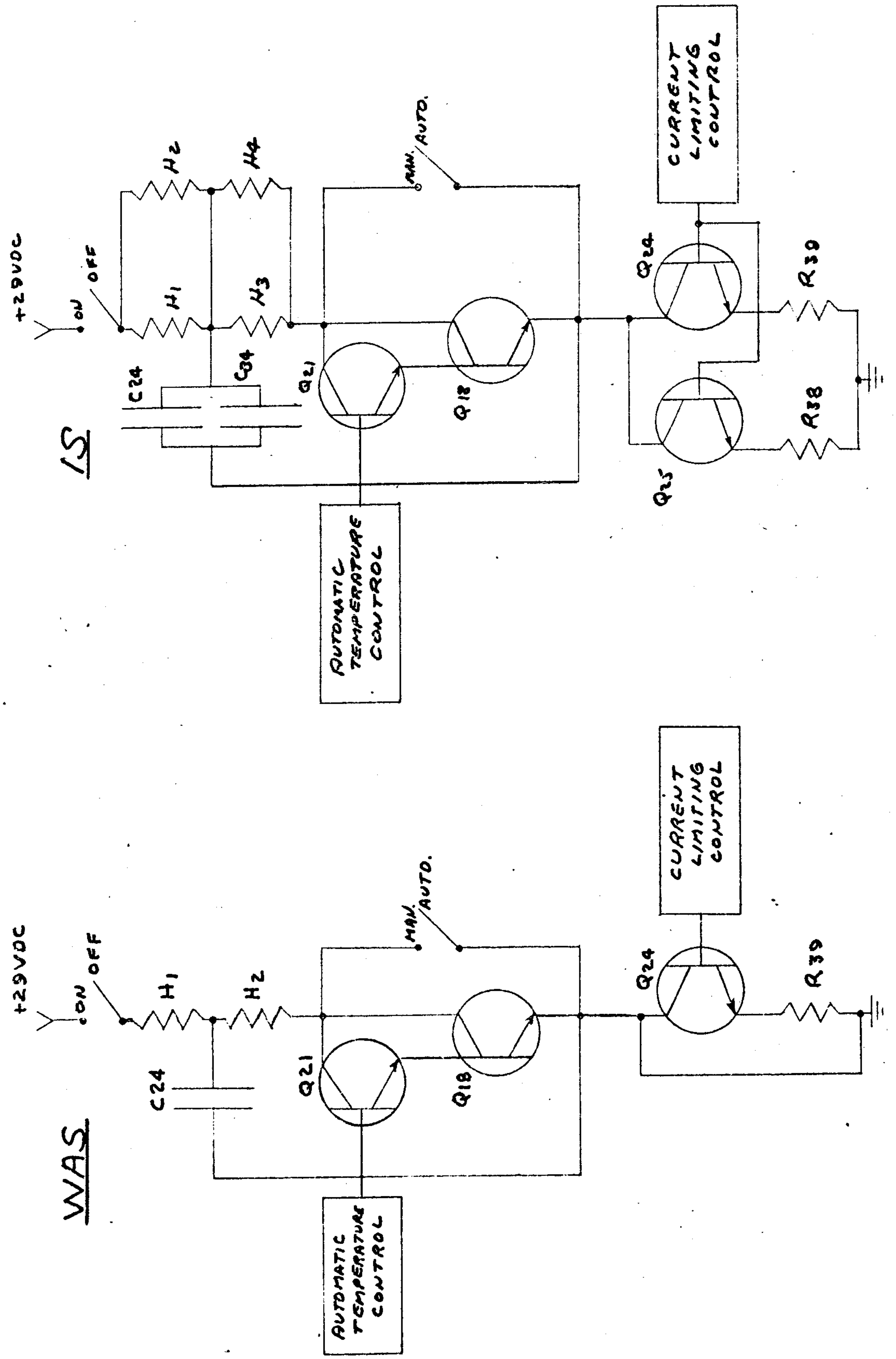

FIGURE 1 - HEATER CONTROL CIRCUIT MODIFICATION

b. Addition of C34

The increased resistance in the circuit as a result of the addition of H2 and H3 necessitated a change in the capacitance of C24 in order to control the ripple voltage within the circuit and to assure that the turn on transient voltage would not be of sufficient magnitude to open the circuit breaker protecting the central station power distribution network. The requirements for this change and the resulting parametric conditions are discussed in detail in Reference A.

Constraints of circuit board layout and available space prevented and increase of size in C24 to attain the required additional capacitance. The solution was to add C34 in parallel with the original C24.

c. Addition of H3 and H4

Replacement of heater strips H1 and H2 with strips of the required new resistance would have necessitated a special order with delivery date incompatible with the modification schedule for existing sensors and would have increased the amount of rework required on each sensor. Therefore stock items were selected which could be wired in to obtain the same net results but which avoided these problems.

It is expected that in future procurement two heater strips of the correct resistance value will be specified.

d. Addition of Q25 and Removal of Jumper Around Q24

The greatest difficulty in attaining an acceptable level of reliability in this modification was experienced in increasing the power handling capability of Q24. Lack of space on the circuit board, among other considerations, necessitated the utilization of a second 2N2102 transistor, Q25, in parallel with Q24. It was noted that, by utilizing the ATM-605 approach of calculating failure rates assuming connective heat transfer to air, it would be impossible to take advantage of the 5 watt junction-to-case rating of the 2N2102, or the even superior characteristics of other candidate transistors. This is due to the fact that all transistors encased in To-5 cans have a 1 watt case-to-air rating regardless of their junction-to-case rating.

Results of thermal vacuum tests conceived to establish a reasonable overall junction to ambient coefficient of thermal resistance for Q24 and Q25 operating in their true lunar environment revealed that the conductive path to the PSE outer shell was insufficient to permit operation, in the worst case condition of manual control of the heater circuit with K2 closed, within the desired temperature limit of 100°C or 50% of maximum rated junction temperature.

This situation, in turn, led to the development and testing of the conductive heat paths which are described in reference B and on which the parts applications analysis data in this report are based.

Previous engineering action resulted in the installation of a short circuit around Q24 prior to the development of this modification presumably due to lack of confidence in Q24 as it was, prior to the introduction of Q25, a single point failure which would cause the loss of the heater circuit and the leveling drive motors (not shown in Figure 1). Special test conditions were introduced during the thermal vacuum runs to evaluate the effect of open or short failures of Q24 and Q25. These data are also presented in reference B and a special computation of the failure rate of the survivor following the worst case failure (from a reliability viewpoint) of the other is included in Appendix A.

4. SINGLE POINT FAILURE SUMMARY

No single thread failures have been introduced as a result of this modification.

The single thread failure previously existing at Q24 has been eliminated by the introduction of Q25 in parallel and by demonstration of the ability of one to survive in the event of failure of the other.

APPENDIX A

CALCULATION OF Q24 & Q25 FAILURE RATES

Reading the junction temperature directly from reference B, Figure 5-11, the following equation from ATM-605 may be used directly:

$$T_n = \frac{T_j - T_s}{T_j(max) - T_s}$$

where:

T_n = normalized junction temperature

T_j = junction temperature

$T_{j(max)}$ = maximum rated junction temperature

T_s = temperature at which derating begins

For Q24 & Q25:

T_j = 92°C (@ .8 watts)

$T_{j(max)}$ = 200°C } Manufacturer's Data

T_s = 25°C }

and $T_n = \frac{92 - 25}{200 - 25} = .383^{\circ}C$

As the design goal constant ambient temperature of 52°C within the PSE sensor was used in deriving the reference B data, Figure 4 of ATM-605 may be entered directly and, by interpolation, the failure rate read out as:

$$\lambda\,(T_n = .383) = .00618 \text{ Failures}/10^5 \text{ hours}$$

(NPN, > 1 watt)

APPENDIX A

For the failure mode condition Q25 failed open

T_j (Q24) = 135°C (@ 1.88 watts)

$$T_n = \frac{135-25}{200-25} = .63°C$$

and λ (T_n = .63) = .01068 Failures/10^5 hours

PARTS APPLICATION ANALYSIS

(SEMICONDUCTORS)

(Semiconductors)

PROJECT: ALSEP

DATE: 2 July 1970

ASSEMBLY: PSE Sensor

SUB ASSEMBLY: Modified Heater Power Circuit

SCHEMATIC NO:

CKT SYM NO. (1)	TYPE DESIGNATION, SEMICONDUCTOR, POLARITY (2)	MANUFACTURER (3)	MAX. TEMP °C: AMBIENT ACTUAL T_A (4)	MAX. TEMP °C: RATED JUNCTION T_J (5)	MAX. TEMP °C: ACTUAL CASE HOT SPOT T_C (6)	AVG PWR DISSIPATION (mw): RATED AT 25°C: AMBIENT (7)	AVG PWR DISSIPATION (mw): RATED AT 25°C: CASE (8)	AVG PWR DISSIPATION (mw): RATED AT ACTUAL AMBIENT T_A (9)	AVG PWR DISSIPATION (mw): RATED AT ACTUAL CASE T_C (10)	AVG PWR DISSIPATION (mw): ACTUAL (11)	POWER RATIO: ACTUAL/RATED 25°C (Amb. or case) (12)	POWER RATIO: ACTUAL/RATED T_A or T_C (13)	MAXIMUM VOLTAGES: V_{CBO} RATED V (14)	MAXIMUM VOLTAGES: V_{CB} ACTUAL V (15)	MAXIMUM VOLTAGES: V_{CEO} RATED V (16)	MAXIMUM VOLTAGES: V_{CE} ACTUAL V (17)	DIODE PIV: RATED V (18)	DIODE PIV: ACTUAL V (19)	CIRCUIT FUNCTION or APPLICATION (20)	PART SPECIAL ENVIRONMENT (Define) (21)	FOR RELIABILITY USE ONLY: RATE (%/1000 HRS) (22)	FOR RELIABILITY USE ONLY: SOURCE (See below) (23)	FOR RELIABILITY USE ONLY: FAIL. RATE MULTIPLIER (24)	FOR RELIABILITY USE ONLY: FINAL FAIL. RATE (%/1000 HRS) (25)	FOR RELIABILITY USE ONLY: TOTAL COUNT PER TYPE (26)	FOR RELIABILITY USE ONLY: TOTAL FAILURE RATE (%/1000 HRS) (27)
Q18	2N3499		52	200		1000		875		252		T_A .288								Earth Ambient		A				.00662
Q21	2N3499		52	200		1000		875		4		T_A < .1								"		A				< .00434
Q24	2N2102		52	200		5000			4300	.943		219								Lunar Ambient		B				.00618
Q25	2N2102		52	200		5000			4300	.917		.213								"		B				.00618

28 FAILURE RATE SOURCE (See Column 23)

A ATM-605 C ______

B See Text D ______

29 NOTE: It is assumed the transient and peak power does not exceed the safe limit.

30 TOTAL FAILURE RATE ______ %/1000 HRS.

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PARTS APPLICATION ANALYSIS

CAPACITORS

PROJECT: ALSEP

DATE: 2 July 1970

ASSEMBLY: PSE SENSOR

SUBASSEMBLY: Modified Heater Power CKT

SCHEMATIC NO: ____

(Capacitors)

1 Circuit Symbol Number	2 Type Designation (MIL or MFR) and Construction	3 Manufacturer	4 Capacitance Value mfd	5 Tolerance %	6 Manufacturer's Rated Voltage	7 Operating Voltage DC	8 Operating Voltage Peak AC	9 Voltage Ratio, Operating/Rated	10 Maximum Duty Cycle	11 Bulk Air Temperature (°C)	12 Circuit Function or Application	13 Basic Failure Rate (%/1000 hrs) at __°C	14 Source (See Below)	15 Special Environment (Define)	15A Failure Rate Multiplier	16 Final Failure Rate	17 Total Capacitor Count per Type	18 Total Failure Rate (%/1000 hrs)
C24	CSR13F476K2552		47	±10	35	29		.83		52	Ripple Filter	.1	A		P			.01895
C34	CSR13F476K2552		47	±10	35	29		.83		52	Ripple Filter	.1	A		P			.01895

FOR USE OF RELIABILITY DEPT

20 FAILURE RATE SOURCES (FOR COLUMN #14)

A ATM-605 B ____

C ____ D ____

21 CALCULATED MTBF ____ HRS

22 TOTAL FAILURE RATE ____ % 1000 HRS

PARTS APPLICATION ANALYSIS

RESISTORS

PROJECT: ALSEP **DATE:** 2 July 1970

ASSEMBLY: PSE Sensor **SUB ASSEMBLY:** Modified Heater Power Ckt. **SCHEMATIC NO:**

(Resistors)

1 Circuit Symbol Number	2 Type Designation (MIL or MFR) and Construction	3 Manufacturer	4 Resistance Value (Ohms)	5 Tolerance (%)	6 Power Rating (Watts)	7 Maximum Operating Power (Watts)	8 Power Ratio Operating/Rated	9 Maximum Duty Cycle	10 Bulk Air Temperature °C	11 Circuit Function or Application	12 Basic Failure Rate (%/1000 HRS) at __°C	13 Source (See Below)	For Use of Reliability Dept	14 Special Environments (Define)	15 Failure Rate Multiplier	16 Final Failure Rate (%/1000 HRS)	17 Total Resistor Count per Type	18 Total Failure Rate (%/1000 HRS)
H1	238047-2	MINCO	145	±5.0	2.5				N/A △1	Case Stripheater-Sensor	.01	B						.01
H2	"	"	145	±5.0	2.5				"	"	.01	B						.01
H3	2344709-1	"	64	±5.0	2.5				"	"	.01	C						.01
H4	2344709-1	"	64	±5.0	2.5				"	"	.01	C						.01
R38	RWR81SXXXXFR	△2	5.9	±1.0	1.0	.4	.4			Q25 Emitter Resistor	.01	A						.00026
R39	"	△2	5.9	±1.0	1.0	.4	.4			Q24 Emitter Resistor	.01	A						.00026

NOTES

△1 No derating to 125°C

△2 Selected value - nominal value used for analysis

19 **FAILURE RATE SOURCES (FOR COLUMN #14)**

A ATM 605 B Teledyne SCD238047

C BxA SCD2344709 D

20 **CALCULATED MTBF** ________ **HRS**

21 **TOTAL FAILURE RATE** ________ **%/1000 HRS**

FORM 8881

BS-321A

APPENDIX C

PSE HEATER MODIFICATION ΔFMEA

CKT Symbol	Failure Mode	Failure Effect	Comments
Q18	Open	Automatic heater control inoperative	Manual mode may be selected for temperature control
	Short	Automatic and manual heater controls overriden and heater circuit at 100% duty cycle	Circuit must be turned off and on (K1) to control temperature
Q21	Same as Q18		
Q24 or Q25	Open	Parallel transistor would carry full current load	Operating conditions (worst case) for surviving transistor would be: $T_j = 135^oC$ $\lambda = .01068\%$ Failures/10^3 hours
	Short	Current limiter circuit inoperative	Danger of overloading PDU circuit breaker when turning circuit on and off. This may be minimized by assuming that power is selected sequentially from zero to "survival" to "normal"

APPENDIX C

PSE HEATER MODIFICATION △FMEA

CKT Symbol	Failure Mode	Failure Effect	Comments
H1 thru H4	Open	Maximum heat dissipation would be less than design requirement	Additional heat could be dissipated thru '2' motor, if required
	Short	1. Maximum heat dissipation would be in excess of design requirement 2. Circuit components would be overstressed and premature failures could result	1. Automatic control circuit would respond to temperature increase and tend to limit effect of failure 2. Time lag in manual response would be more deleterious 3. Probability of this failure mode occurring is very small.
R38 or R39	Open	Overload on transistor in parallel branch	Same as open failure on Q24 and Q25
	Short	Current limiter circuit inoperative	Same as short failure on Q24 and Q25
C24 or C34	Open	Increased ripple on 29V common line	Degrades seismometer data
	Short	1. Same as Q18 Short 2. H3 and H4 bypassed, increasing current draw and increasing power dissipation in Q24 and Q25	Same as Q18 Short