TECHNICAL ADVISEMENT MEMORANDUM NO. 106-9

RELIABILITY ASSESSMENT OF THE GEOS A POWER SUPPLY

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TECHNICAL ADVISEMENT MEMORANDUM NO. 106-9

To: Program Manager, Geodetic Satellite Physics and Astronomy Programs, Office of Space Science and Applications, NASA Headquarters

From: PRC GEOS Reliability Assessment Team

Subject: Reliability Assessment of the GEOS A Power Supply

1. Introduction

Exhibit 1 is the diagram of the power supply that will be used for modeling purposes. The blocks labeled $U_{i,j}$ represent particular collections of electronic parts, and the circles labeled $W_{i,j}$ represent particular "output" points of interest.

The GEOS power supply system comprises three subsystems: (1) the main power supply, (2) the optical power supply, and (3) the transponder power supply. As shown in Exhibit 1, two outputs, W_{22} and W_{52}, are ORed together so that the loads connected to these points will have a higher probability of receiving their required power. The three power subsystems are designed to supply their respective loads within the operational constraints of the spacecraft system. The main solar array, for example, can supply power to all loads connected to it without the aid of the main battery. The battery, in this case, is provided for eclipse operation. The optical and transponder solar arrays, however, require the help of batteries to supply the peak current demands of the loads which the solar cells alone cannot furnish.

In the case of the transponder power supply, the SECOR transponder will require 32.8 watts of power when in the transmit mode. The range and range rate transponder requires 15.3 watts in the transmit mode. The transponder solar array is capable of providing only 11.6 watts. Furthermore, the optical beacon flash assembly requires peak currents of approximately 13.5 amperes for short durations. The optical solar array is capable of only 1.2 amperes when at an optimum sun angle. In both cases, batteries are required for proper operation. Thus, failure of the battery in these subsystems results in failure of the primary function of the associated subsystem.

Several commands are provided for increased flexibility of operation. The transponder and optical supplies are each provided with a system of power dump resistors, the purpose of which is to prevent overcharging, and consequent overheating, of the batteries. These are normally switched in and out automatically by thermostatic switches that sense battery temperature. However, the power dump resistors can be manually controlled from the ground via commands in the event of malfunction or if additional control is required.

The main battery can be switched in or out as required by use of commands 10a and 10b. This gives protection against battery failure and also provides a means of protecting the battery from overheating if most of the "main" loads happen to be disconnected. During normal operation, however, the main power supply load demand is expected to be nearly constant, thus eliminating the need for power dump protection of this battery. The main and memory d-c/d-c converters are operated in switchable standby redundancy. The command converter, of necessity, is operated in active redundancy. The use of redundant circuits--plus the availability of various commands for the power supply system that permit switching, isolating, and bypassing--has provided a flexible overall design.

Those failure effects of the prime power system which can occur as a result of component failures are tabulated in the appendix to this TAM. The probability of occurrence of these failure effects is shown in the following analysis to be low.

The models were developed with three tasks in mind. The first was to allow the calculation of the probability of having the proper output at each of the 19 output points at the end of one year. The second was to allow the calculation of particular combinations of outputs of interest (e.g., the probability that the power supply will provide sufficient

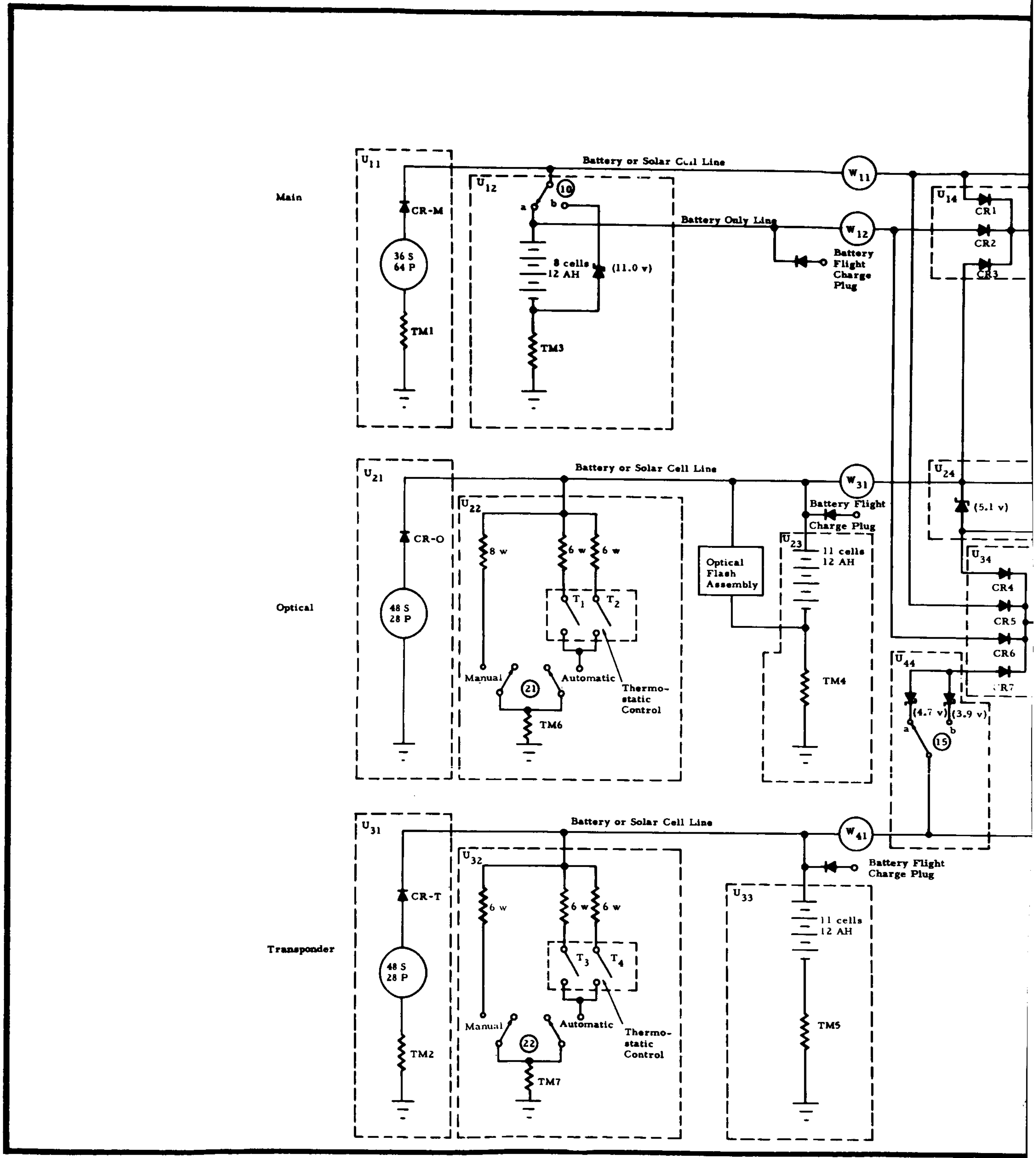

EXHIBIT 1 - DIAGRAM OF

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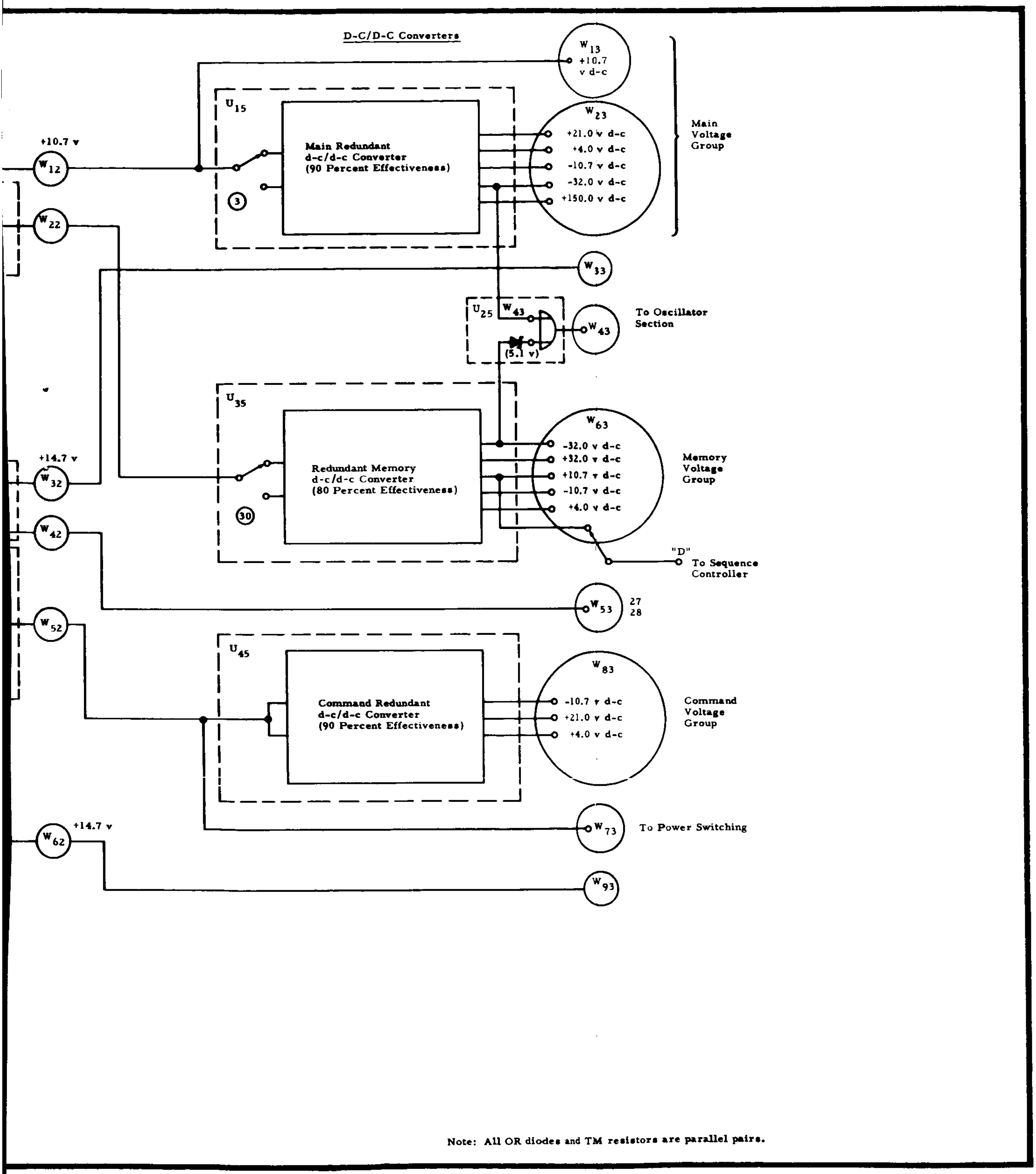

GEOS A POWER SUPPLY

outputs for operation of the beacon experiment). The third was to allow the calculation of an overall figure of merit (FOM) for the power supply system.

The first task is satisfied by the following set of equations:

$$P(W_{11}) = P(U_{11}) [1 - Q_s(U_{12})] \tag{1}$$

$$P(W_{21}) = P(U_{11}) P(U_{12}) \tag{2}$$

$$P(W_{31}) = P(U_{21}) [1 - Q_s(U_{22})] P(U_{23}) \tag{3}$$

$$P(W_{41}) = P(U_{31}) [1 - Q_s(U_{32})] P(U_{33}) \tag{4}$$

$$P(W_{12}) = P(W_{11}) \tag{5}$$

$$P(W_{22}) = P(U_{14}) [1 - Q(W_{11})Q(W_{21})Q(W_{31})] \tag{6}$$

$$P(W_{32}) = P(W_{31}) \tag{7}$$

$$P(W_{42}) = P(U_{24}) P(W_{31}) \tag{8}$$

$$P(W_{52}) = P(U_{34}) \left\{1 - Q(W_{42})Q(W_{11})Q(W_{21}) [1 - P(W_{41}) P(U_{44})]\right\} \tag{9}$$

$$P(W_{62}) = P(W_{41}) \tag{10}$$

$$P(W_{13}) = P(W_{12}) \tag{11}$$

$$P(W_{23}) = P(U_{15}) P(W_{12}) \tag{12}$$

$$P(W_{33}) = P(W_{32}) \tag{13}$$

$$P(W_{43}) = P(U_{25}) \left\{1 - [1 - P(U_{15}) P(W_{12})] [1 - P(U_{35}) P(W_{22})]\right\} \tag{14}$$

$$P(W_{53}) = P(W_{42}) \tag{15}$$

$$P(W_{63}) = P(U_{35}) P(W_{22}) \tag{16}$$

$$P(W_{73}) = P(W_{52}) \tag{17}$$

$$P(W_{83}) = P(U_{45}) P(W_{52}) \tag{18}$$

$$P(W_{93}) = P(W_{62}) \tag{19}$$

where $P(U_{i,j})$ = probability that the (i, j)th unit is operable

$P(W_{i,j})$ = probability that the (i, j)th output is available

$Q(X_{i,j}) = 1 - P(X_{i,j})$ where $X_{i,j}$ stands for $U_{i,j}$ or $W_{i,j}$

$Q_s(U_{i,j})$ = probability that the unit $U_{i,j}$ is shorted

All of the above equations are a function of time, but, since they will be evaluated only at the end of one year, the time notation is suppressed.

Achievement of the second task will, in general, require additional input information. However, anticipating the requirement for the probability of adequate power for the optical beacon, the following equations will satisfy. Let P(OP) be the probability of being able to provide sufficient power for the optical beacon, assuming that, if necessary, the other experiments will be sacrificed. Then,

$$P(OP) = P(W_{31})\, P(U_{14})\, P(U_{35})\, P(U_{25})\, P(U_{24})\, P(U_{34})\, P(U_{45}) \; . \qquad (20)$$

Equation (20) follows from Exhibit 1 and from the fact that the optical power source is both necessary and sufficient for the beacon experiment.

The third task is accomplished as follows: The power supply, as a distinct entity, is considered to be in one of 2^n possible states (i. e., each having a different combination of the n units shown in Exhibit 1 operating, with the remainder failed). To each of these states, a value is assigned in terms of the effect on the experimental payload. The desired figure of merit is then defined as

$$FOM = \sum_{k=1}^{2^n} P(S_k)\, V(S_k) \qquad (21)$$

where S_k represents the kth state, $P(S_k)$ is the probability of being in the kth state, and $V(S_k)$ is the relative value of the kth state. The vast majority of possible states will effectively[1] drop out of the

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[1] Dependent on number of decimal places carried.

expression because of either insignificant value or insignificant probability.

2. Unit Probability Calculations

The prerequisites for the calculation of any of the above tasks are the various unit probabilities. The following subsections will therefore be devoted to deriving these probabilities.

a. Solar Arrays: U_{11}, U_{21}, U_{31}

Exhibit 2 presents the configurations of the GEOS solar cell panels and blocking diodes. In addition, the main and transponder arrays contain a parallel pair of resistors for telemetry purposes, as indicated in Exhibit 1. Failure of an array is assumed to occur if (1) both telemetry resistors fail open, (2) the number of blocking diode pairs failing open is sufficient to cause significant reduction of the available power output, or (3) the number of failed solar cells is sufficient to cause significant reduction of the available power output.

The probability of occurrence of the first event is readily shown to be insignificant; it may be expressed as

$$\left[k\left(1 - e^{-\lambda_R t}\right)\right]^2$$

where λ_R is the resistor failure rate and k is the proportion of failures that are "opens." Utilizing the failure rates and open/short ratio presented in TAM No. 106-6,[1] this probability is seen to be less than 3×10^{-6}, which, for all practical purposes, can be neglected.

The probability of occurrence of the second event is determined as follows: The probability of a single pair of diodes failing open is

$$\left[k\left(1 - e^{-\lambda_D t}\right)\right]^2 ,$$

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[1] Component Part Failure Rate Assignments for Reliability Assessment of the GEOS Satellite, Technical Advisement Memorandum No. 106-6 (PRC D-1027), 8 June 1965.

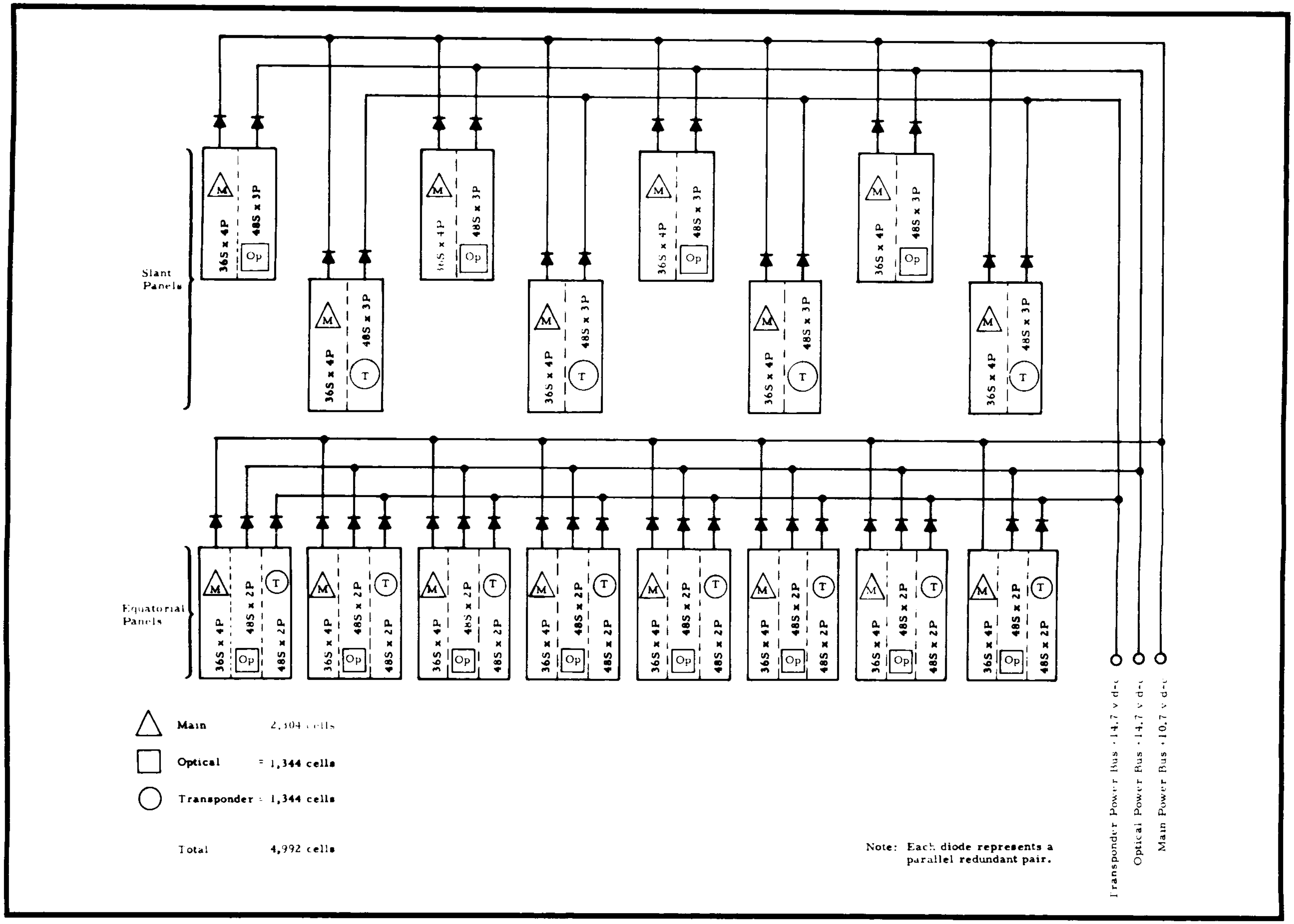


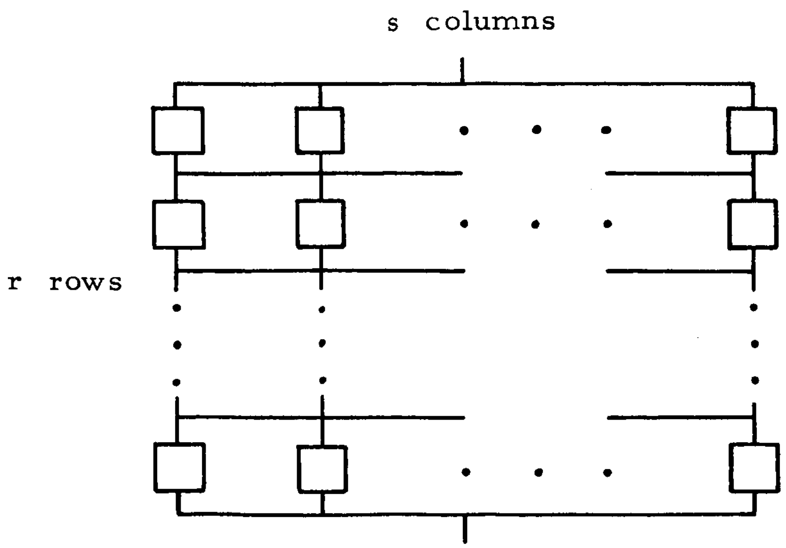
EXHIBIT 2 - GEOS SOLAR CELL PANEL CONFIGURATION

which is $\cong 3 \times 10^{-7}$, utilizing a k of 1/2 and a λ_D of 0.13×10^{-6}. If k is assumed to be unity for the sake of conservatism, the probability of failure of a redundant pair of diodes is $\cong 1.3 \times 10^{-6}$. The probability of n such failures in an array is given by $\binom{N}{n}p^n q^{N-n}$ where N is the number of redundant diode pairs in the array and p is, say, 1.3×10^{-6} and $q = 1 - p$. The following table summarizes these probabilities for the three arrays being considered.

Number of Redundant Blocking Diode Pairs Failed	Main Power Supply	Optical Beacon and Transponder Power Supplies
0	$1 - (21 \times 10^{-6})$	$1 - (16 \times 10^{-6})$
≥1	21×10^{-6}	16×10^{-6}

Again, the probability of failure due to the blocking diodes is seen to be negligible.

The third event is somewhat more difficult to evaluate. The approach is as follows: Define a group of solar cells to consist of those cells on one panel which contribute their output to one of the three prime power sources. Thus, there are 16 main solar array groups and 12 each for the transponder and optical solar arrays, as shown in Exhibit 2. Each group consists of a fully interconnected matrix of solar cells containing r rows and s columns as shown in the sketch below.



Failure of a group is assumed to be solely the result of open solar cells, and the latter are assumed to occur at a rate of 0.1 failures per million hours.

"Failure" in this context means loss of current output of the group. Taking the maximum available current output (no failed solar cells) as I, the current output with solar cells failed is assumed to be $I\left(1 - \frac{m}{s}\right)$ where m is the maximum number of failed cells in the r rows of the group. That is, if in all rows of the group there is at most one failure, the relative current output is $1 - \frac{1}{s}$, whereas, if at least one row has s failures, there is zero current out of that group.

For a one-year period, the probability of failure of a single solar cell is approximately 0.001. The probability of exactly m failures in a particular row is

$$P(m) = \binom{s}{m} (0.001)^m (0.999)^{s-m} \quad . \tag{22}$$

It is clear that $P(m)$ is negligible for $m \geq 2$ for the cases under consideration, and hence each row may be treated as a two-stated device. Thus, the probability that a particular group will have its maximum available output current is simply the probability that there are no failures in the r rows, i.e.,

$$P(I) = (0.999)^{rs} \quad , \tag{23}$$

and the probability of having a relative current output of $I\left(1 - \frac{1}{s}\right)$ from a particular group is $1 - P(I)$.

Finally, the probability that exactly g groups of a particular type are "failed" is given by

$$P(g) = \binom{G}{g} [1 - P(I)]^g \, P(I)^{G-g} \tag{24}$$

where G is the total number of groups of a particular type.

Letting M denote the main array,

$$P_M(g) = \binom{16}{g} (0.1342)^g (0.8658)^{16-g} \tag{25}$$

and the expected available current is given by

$$\begin{aligned} I_e(M) = \frac{64}{4} I \left[P_M(0)\right] + \frac{63}{4} I \left[P_M(1)\right] + \frac{62}{4} I \left[P_M(2)\right] \\ + \cdots + \frac{48}{4} I \left[P_M(16)\right] \quad . \end{aligned} \tag{26}$$

Evaluating Equations (25) and (26) yields an expected available current of 15.236 I. Thus, degradation of current due to catastrophic failures is $100\left(1 - \frac{15.236}{16}\right)$ percent, or approximately 4.5 percent.

The current degradation for the optical and transponder arrays is somewhat more difficult to arrive at because of the different configurations of the groups in the slant and equatorial panels. Since each array consists of 4 slant panels (3 columns, 48 rows) and 8 equatorial panels (2 columns, 48 rows),

$$\begin{aligned} I_e(O) = I_e(T) = \frac{12}{3} I_s \left[P_S(0)\right] + \frac{11}{3} I_S \left[P_S(1)\right] \\ + \cdots + \frac{8}{3} I_S \left[P_S(4)\right] + \frac{16}{2} I_E \left[P_E(0)\right] \\ + \frac{15}{2} I_E \left[P_E(1)\right] + \cdots + \frac{8}{2} I_E \left[P_E(8)\right] \end{aligned} \tag{27}$$

where $I_e(O)$ = expected available current of optical array
$I_e(T)$ = expected available current of transponder array
I_S = maximum available current of one slant group
I_E = maximum available current of one equatorial group
$P_S(g)$ = probability of g slant groups failing
$P_E(g)$ = probability of g equatorial groups failing

Utilizing Equation (24) in Equation (27) yields an expected available current of $3.83\ I_S + 7.66\ I_E$. The maximum available current of each array is $4\ I_S + 8\ I_E$. Assuming that current is directly proportional to the number of strings, the expected degradation of current due to catastrophic failures is $100\left[1 - \frac{3.83(3) + 7.66(2)}{4(3) + 8(2)}\right]$ percent, or, again, in the neighborhood of 4 percent.

The numerical values of expected available current output are so near the maximum available output that it is reasonable to assume a reliability equal to 1 for the solar arrays. Thus, $P(U_{11}) = P(U_{21}) = P(U_{31}) = 1$.

b. Main Battery: U_{12}

The main battery unit, shown schematically in Exhibit 1, consists of command relay 10, one zener diode, an 8-cell 12 AH battery, and a parallel redundant pair of resistors. The function of the relay is to provide the ability to select, on command, either the battery (command 10b) or the zener diode (command 10a, "solar only"). The function of the zener diode is to prevent an excessive rise of the main bus voltage under light load or low temperature conditions. It is anticipated that the functions of the relay and zener diode will be required only a small percentage of the time, primarily at the beginning of the mission. Hence, these two components are assumed to have a reliability equal to 1. As was pointed out in the previous subsection, the probability of catastrophic failure caused by the telemetry resistors is negligible. Thus, U_{12} reliability is dominated by the reliability of the battery. For the purposes of this analysis, batteries are assumed to fail open (only) at the rate of one failure per million hours per cell. Unit U_{12} then has a probability of successful operation of $\exp\left[-8(8{,}760) \times 10^{-6}\right] \cong 0.932$ and a probability of unsuccessful operation (losing the "battery only" line) of 0.068.

c. Power Dump Circuits: U_{22}, U_{32}

Exhibit 1 presents the power dump circuits schematically. There is no single component part failure that could be considered catastrophic, and the probability of catastrophic multiple failures is so small as to be negligible. These units are therefore assumed to have a reliability equal to 1.

d. Optical and Transponder Batteries: U_{23}, U_{33}

For the optical and transponder batteries, using arguments similar to those in subsection 2(b), $P(U_{23}) = P(U_{32}) = \exp[-11(8{,}760) \times 10^{-6}] \cong 0.907$.

e. OR Gates, Zener Diodes, Etc.: U_{14}, U_{24}, U_{34}, U_{44}

From Exhibit 1, it can be seen that units U_{14}, U_{24}, U_{34}, and U_{44}, considered together, consist of 14 gate diodes, 3 zener diodes, and 1 command relay. The probability of no failure whatsoever in these components is greater than 0.975. From the failure effect analysis, it is clear that only a small proportion of the "failure" probability (0.025) is catastrophic. It is also easy to demonstrate that each unit has a probability of failure (catastrophic and noncatastrophic) of less than 0.01. Therefore, each unit will be considered to have a reliability equal to 1; i.e., $P(U_{14}) = P(U_{24}) = P(U_{34}) = P(U_{44}) = 1$.

f. Converters: U_{15}, U_{35}, U_{45}

A "worst-case" analysis of each set of redundant converters results in the assumption of a reliability equal to 1 for all three units. This analysis proceeds as follows: Assume all converter units to be operable at all times (more severe than is actually the case). Since relay reliability is greater than 0.995 at one year, assume it to be 1. The reliability of each unit is then given by

$$1 - \left(1 - e^{-\lambda_c t}\right)^2$$

where λ_c is the failure rate for a single converter. The parts count, failure rate estimate, and worst-case reliability calculations are shown on the following page for each of the three units.

Part Type, i		Failure Rate, $\lambda_i \times 10^6$	Part Quantity		
			Main Converter, n_{1_i}	Memory Converter, n_{2_i}	Command Converter, n_{3_i}
1.	Transistors	0.26	3	10	2
2.	Diodes	0.13	29	29	7
3.	Resistors	0.18	18	24	8
4.	Capacitors	0.01	57	37	27
5.	Inductors	0.05	5	7	5
6.	Transformers	0.25	2	2	2

For U_{15}, $\sum_{i=1}^{6} n_{1_i}\lambda_i = 9.11$ $\quad \exp[-(9.11)(8{,}760) \times 10^{-6}] = 0.9233$

For U_{35}, $\sum_{i=1}^{6} n_{2_i}\lambda_i = 11.91$ $\quad \exp[-(11.91)(8{,}760) \times 10^{-6}] = 0.9010$

For U_{45}, $\sum_{i=1}^{6} n_{3_i}\lambda_i = 3.89$ $\quad \exp[-(3.89)(8{,}760) \times 10^{-6}] = 0.9657$

$$P(U_{15}) = 1 - (1 - 0.9233)^2 = 0.994$$
$$P(U_{35}) = 1 - (1 - 0.9010)^2 = 0.990$$
$$P(U_{45}) = 1 - (1 - 0.9657)^2 = 0.999$$

Again, since these reliabilities are so high (and in fact are lower than would be derived under a detailed analysis), it will be assumed that $P(U_{15}) = P(U_{35}) = P(U_{45}) = 1$.

g. OR Gate: U_{25}

Unit U_{25} is an OR gate to provide -32 volts to the oscillator section from either the main or the memory converter. Using the logic of the previous subsection, 1 is also a reasonable reliability prediction for this unit.

3. Output Probability Calculations

Exercising Equations (1) through (19) with the unit probabilities developed in subsection 2 yields the following predictions of one-year probabilities of having outputs $W_{i,j}$.

$P(W_{i,j})$ at One Year

j i	1	2	3
1	1	1	1
2	0.932	1	1
3	0.907	0.907	0.907
4	0.907	0.907	1
5		1	0.907
6		0.907	1
7			1
8			1
9			0.907

4. Reliability of Optical Beacon Power

From Equation (20), the probability that the optical beacon power is available is readily seen to be simply the probability that the optical battery is operable (i.e., 0.907).

5. Overall Power Supply Figure of Merit

From the preceding subsections, it is clear that, for all practical purposes, the power supply may be in one of eight possible states corresponding to the events of having or not having each of the three batteries. These eight states are represented below, where "1" indicates that the battery is operable and "0" indicates that the battery has failed (open).

State, S_i	Battery			Relative Value, V_i	Probability, P_i
	Main	Optical	Transponder		
S_1	1	1	1	1	0.767
S_2	1	1	0	0.750	0.079
S_3	1	0	1	0.583	0.079
S_4	1	0	0	0.333	0.008
S_5	0	1	1	0.933	0.056
S_6	0	1	0	0.683	0.006
S_7	0	0	1	0.516	0.006
S_8	0	0	0	0.266	0.001

From Equation (21), the overall power supply figure of merit is

$$\mathrm{FOM} = \sum_{i=1}^{8} P_i V_i \cong 0.935 \quad .$$

The state probabilities of the above table are readily derived, being simply the product of the reliabilities and unreliabilities of the batteries. The relative values are derived as follows: Information from NASA, as interpreted by PRC, yields the experiment relative values indicated on the following page.

Experiment	Relative Value	Normalized Relative Value
Optical beacon	5	5/12
Doppler	4	4/12
SECOR	2	2/12
Range and range rate	1	1/12

The normalized value is used to derive the relative mission loss associated with each experiment loss. The experiment losses are assumed to be independent and additive. Furthermore, loss of a particular battery results in a particular experiment loss, as shown below.

Battery Loss	Resultant Experiment Loss
Main battery	Doppler experiment during eclipse
Optical battery	Optical beacon experiment[1]
Transponder battery	SECOR and range and range rate experiments[1]

The numeric loss associated with loss of the main battery is taken to be the value associated with the doppler experiment multiplied by the expected proportion of time that the satellite is in eclipse. The former value is 4/12 and the latter is approximately 20 percent. Thus, the numerical loss is 0.067.

Numerical losses associated with the loss of the other two batteries are simply the numerical values associated with the experiments lost. For example, numerical loss of the optical battery is 5/12 = 0.417, and numerical loss of the transponder battery is 3/12 = 0.250.

Summing the losses associated with each state and subtracting from unity yields the state values, V_i.

6. Summary and Conclusions

The analysis presented above indicates that nearly all unit failure probabilities are negligible. This conclusion was based on an

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[1] This is due to the inability of the solar arrays to sustain the required load demand. Intermittent or sporadic operation during sunlight, while possible, is considered as failure.

extensive failure effect analysis of the unit in question, and all assumptions in the numerical analysis were made in the direction of conservatism.[1] The final result of a power supply figure of merit of 0.935 means that, on the basis of the analysis presented, at the end of one year the power supply is expected to perform 93.5 percent of the function required of it. The fact that MIL-HDBK-217 failure rates were used in the calculations leads one to believe that the estimate is conservative (low).

In conclusion, it seems clear that the power supply portion of the GEOS satellite is extremely well designed from a reliability point of view. Further efforts to increase its reliability seem unwarranted at this time. If such efforts were to be expended, then the batteries (particularly the optical and transponder batteries) would be the obvious focal point.

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[1] The model equations and approach are presented in detail so that, if further study is desired in any or all areas, it may be accomplished with a minimum of additional effort.

APPENDIX

GEOS PRIME POWER SYSTEM FAILURE EFFECTS

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GEOS PRIME POWER SYSTEM FAILURE EFFECTS

Failure Effect No. 1: Loss of Prime +10.7 v d-c W_{12}

Possible Causes:

a. A shorted main battery when in command 10b.

b. A shorted 11-volt zener diode when in command 10a.

c. A short to ground by a component within the selected main d-c/d-c converter; e.g., (1) 1 zener diode, (2) either of 2 transistors, or (3) 1 of 13 capacitors.

d. Loss of the entire solar array, which would cause eventual loss of the main battery; this might be caused by an open of both telemetry sensing resistors, TM1.

e. An open battery or an open in both telemetry sensing resistors, TM3, either producing the same effect (namely, failure of +10.7 v d-c during eclipse).

f. A short to ground developing in the +10.7 v d-c line connecting the telemetry time marker.

g. A short to ground in the boom squib and gravity-gradient attitude control unit.

h. A short to ground at output point W_{22}.

Failure Effect No. 1: Loss of Prime +10.7 v d-c W_{12}

Possible Causes:

i. A short to ground at output point W_{52}.

j. An open wire in the harness or main bus line.

Failure Effect No. 2: Loss of Output Voltage W_{22}

Possible Causes: A short to ground in the selected memory converter. This could be caused by one of four input capacitors shorting; in the switching regulator circuit, one of the following might produce a short in transistor Q103 that would produce a similar effect: (1) one of three capacitors failing short, (2) one diode failing short, or (3) one of two oscillator transistors in the converter failing short.

Failure Effect No. 3: Loss of Optical +14.7 v d-c W_{32}

Possible Causes:

a. A shorted optical battery.

b. A short to ground at point W_{22} (see 1. h).

c. A short to ground at point W_{52} (see 1. i).

d. An open battery or open telemetry sensing resistors, TM4, causing loss of +14.7 v d-c during eclipse and also failure of optical beacon.

e. Degradation of the solar array to the point where battery charge cannot be maintained.

Failure Effect No. 3: Loss of Optical +14.7 v d-c W_{32}

Possible Causes:

f. An open wire in the harness or +14.7 v d-c bus line.
g. A shorted 8-watt power dump resistor when in command 21b.
h. A shorted 6-watt (one of two) power dump resistor with its associated thermostatic switch closed.

Failure Effect No. 4: Loss of Output Voltage W_{42}

Possible Causes:

a. An open zener diode (5.1 v d-c).
b. Any of failure effects number 3.
c. A short to ground in the sequence controller when commands 27b and 28b are in effect.
d. A short to ground at output points W_{22} and W_{52}.

Failure Effect No. 5: Loss of Output Voltage W_{52}

Possible Causes:

a. A short to ground in the command converter.
b. A short to ground in the power switching unit.

Failure Effect No. 6: Loss of Transponder +14.7 v d-c W_{62}

Possible Causes:

a. A short to ground in SECOR with command 31a in effect.
b. A short to ground in the range and range rate transponder with command 31a in effect.
c. A short to ground in the SECOR regulator with command 31a in effect.

Failure Effect No. 6: Loss of Transponder +14.7 v d-c W_{62}

Possible Causes:

d. A short to ground in the voltage sensing cutoff with command 31b in effect.

e. A short to ground on output voltage W_{52}.

f. A shorted 6-watt (manual) power dump resistor when in command 22b.

g. A shorted 6-watt (automatic) power dump resistor with its associated thermostatic switch closed when in command 22a.

h. Two telemetry sensing resistors, TM2, open, causing loss of solar array leading to eventual loss of battery charge.

i. An open battery or an open in both telemetry sensing resistors, TM5, either producing the same effect (namely, failure of +14.7 v d-c during eclipse); the solar array, however, cannot support maximum load requirements without battery during sunlight.

j. A shorted transponder battery.