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Prepared for
Jet Propulsion Laboratory
Pasadena, California

PLANNING RESEARCH CORPORATION
LOS ANGELES, CALIFORNIA WASHINGTON, D. C.

[redacted]

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By
J. D. Andrew
E. E. Bean
N. E. Chudacoff

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[redacted]

FOREWORD

The success of the Venus space probe, Mariner R, in late 1962 demonstrated most dramatically the feasibility and great value of a well-organized planetary research venture. Another important step in the continuing schedule of scientific investigations of the solar system will be taken in the latter half of 1964 with the launching of the Mariner Mars spacecraft, which will follow a planned trajectory that assures a near-Mars encounter. This spacecraft will be equipped to collect scientific data in interplanetary space and in the vicinity of Mars, and will be provided with the capability of taking television pictures of this interesting planet. The Mariner projects constitute an important segment of the vast space research program being conducted by the Jet Propulsion Laboratory of Pasadena, California.

Reliability has been an important consideration in the design of the Mariner vehicles, and a formal reliability assessment of the Mariner Mars spacecraft was undertaken in March 1963 by Planning Research Corporation. The assessment was authorized under contract 950445 issued by Jet Propulsion Laboratory, and this report, which presents the findings of the assessment in numerical terms, completes the contract work.

Previous contractual associations of Planning Research Corporation and the Jet Propulsion Laboratory have been marked by a high degree of cooperation and mutual assistance. This spirit has continued throughout the period during which this assessment was conducted, and Dr. Elizabeth Baxter, of the Systems Design Section of JPL, has fulfilled the important function of project liaison--without which very little could have been accomplished. Cognizant engineering personnel from JPL supplied valuable assistance in the form of direct consultation both by telephone and in a number of conferences.

The authors are anxious to acknowledge the contributions to this work by other members of the PRC staff, including H. B. Battey, W. E. Faragher, J. P. Francis, R. J. Mulvihill, and R. G. Salter. Appreciation is expressed to G. E. Monroe for his helpful suggestions regarding the preparation of the report. Credit for the arduous computational work belongs to Mary E. Barrow and Joy K. Fort.

ABSTRACT

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The findings of a numerical exercise of the reliability model of the Mariner Mars spacecraft are presented along with detailed reliability representations of the spacecraft subsystems. Conclusions are drawn regarding pertinent aspects of the reliability of this complex system, which is scheduled for launch in late 1964. A set of carefully apportioned worth functions that quantitatively rank the project objectives is presented, and these are employed to weight, in a rational manner, the probabilities of successfully accomplishing the stated objectives. From this a reliability figure-of-merit is derived. Selected events and functions of particular interest and significance are separately investigated, and the corresponding classical reliabilities are computed. Complete data on failure rate estimates and parts complements are presented.

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I. INTRODUCTION

Calculation of the predicted reliability of a planetary spacecraft is a process which, in common with the design effort, must recognize the variety of objectives to be served during the course of the long and complex mission. The Mariner Mars (Mariner C) spacecraft to be launched in the latter half of 1964 will incorporate a number of interdependent functional subsystems that must remain operable through most or all of the spacecraft's mission time in order to achieve any significant success in fulfilling the program objectives. The reliability assessment described in this report constitutes an analytical approach to the prediction of the reliability, or probability of success, of the individual subsystems and of the total system.

A. Background

An important phase of a reliability assessment is the construction or formulation of a mathematical model of the system under study. The model is developed in such a way that the effects or consequences of component part failures are brought into evidence. To the greatest extent possible, the consequences of external perturbations to the system are also accounted for by the model. The formulation of a reliability model for the Mariner C spacecraft was accomplished in the first phase of this study effort, and the details of that model are fully described in PRC R-322, Interim Report on Reliability Model Formulation for the Mariner Mars Spacecraft. It will be necessary in the present report to make frequent reference to the model formulation results, and the term "interim report" will be used wherever that reference is intended.

The model presented in the interim report was based on a study of the available spacecraft design documents and a limited number of conferences with the cognizant design personnel. The study was initiated in early March 1963, at which time the details of subsystem design were reasonably well documented, at least for most subsystems. Design changes were subsequently introduced, however, and, following the

the publication of the interim report, a series of extended conferences was held with the engineering groups charged with the responsibility of the spacecraft design. In the course of these conferences, design changes were revealed and, more importantly, many details of the subsystem designs that had not previously been available were documented for incorporation into the model. Complete descriptions of some of the subsystem designs could not be obtained, and, in a few instances, approximations used in the model formulation could not be completely removed. Notable among these was the necessity for excluding the data automation system from the analysis, due to the fact that the design is of an advanced nature and had not been crystallized to the extent required for the model.

B. Approach to the Numerical Assessment

The exercising of a reliability model involves the establishment of a set of component part failure rates and the numerical definition of such symbolic quantities as event times on the mission profile and the probabilities of occurrence of external perturbations. In the model formulation, groups of component parts, called reliability units, were defined on the basis that these parts always function simultaneously to produce a given effect or series of related effects. The exercising of the model includes the computation of unit failure rates based on the failure rates of the constituent parts. These unit failure rates form the basis for the calculation of the probability of success or failure of any desired functional subsystem or any group of units that jointly effect the occurrence of a significant mission event. Thus, it is possible to develop a set of numerical results that represent the reliability of the spacecraft as the aggregate reliability of its important functions.

The model developed in the initial phases of the study was structured in a manner which would permit a more meaningful assessment of spacecraft reliability than could be provided by the classical reliability of its functions. The figure-of-merit technique,[1] by introducing the

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[1] For a more complete description see PRC R-293, Reliability Assessment of the Mariner Spacecraft, 17 December 1962.

concept of worth accrual as a function of time, affords a means of accounting for the partial success that might well be achieved in a mission where some degradation of performance has occurred because of an impairment which is not totally catastrophic. The approach to exercising a figure-of-merit model demands that primary mission objectives be clearly stated and that an assignment of worth be made to each objective. This was done for the Mariner C spacecraft by Jet Propulsion Laboratory, and these assigned worth functions have been appropriately integrated with equipment survival probabilities to produce a set of results that form the spacecraft figure-of-merit.

C. Report Organization

This report includes the information necessary to permit computation of the reliability of any significant spacecraft function using either a classical or a figure-of-merit approach. A summary of the more important results is presented in Section II, and the model representations of the spacecraft subsystems are discussed and diagrammed in Section III. Section IV describes the derivation of the results and contains full details of the numerical exercise. Section V discusses certain conclusions drawn as a consequence of the study. Complete failure rate and parts count information is given in two appendices.

D. Assumptions

It is in order at this point to state the explicit assumptions which have been necessary to place reasonable bounds on the scope of the study. Many assumptions are implicit in the model representations and can be identified in the descriptions of the subsystems. Certain general assumptions apply broadly to the entire study, however, and these are listed below:

1. Launch phase failure possibilities are not considered. All equipment and all piece parts required for the mission after injection are assumed to be operable throughout the launch phase, and no incipient failures have resulted from the launch stresses.

2. Scientific experiments are completely reliable. Except for certain hardware associated with the planet scanning function, it is assumed that none of the scientific experiments fail during the mission. Thus, loss of worth to be returned from these experiments is a consequence of equipment failure outside the experimental hardware or circuitry.

3. Engineering measurement transducers are completely reliable. This is similar to assumption 2, but refers to the equipments (such as temperature or position transducers) that provide the unconditioned signals for telemetry purposes.

4. The trajectory of the space probe after injection is correctible by midcourse maneuvers. The two cases which are disallowed by this assumption are, first, that the required correction is beyond the capability of the midcourse motor and, second, that injection was accomplished so accurately as to obviate the requirement for a midcourse correction.

5. The mission period is 6,213 hours. This variable, which depends to a large extent on the time of launching, has been fixed at 6,213 hours. This places the time of closest approach at 6,000 hours after injection.

6. Part failures are catastrophic. Degraded operation of piece parts is not considered. It is assumed that a failed part is completely inoperable and will remain inoperable from the time of failure throughout the balance of the mission.

7. Part failures are random in time. This assumption is predicated on the absence of "burn-in" or "wear-out" failure mechanisms, and allows the application of the exponential failure law and the exclusive use of random failure rates.

8. All parts are exposed to the same stress. The selected failure rates are based on the assumption that each piece part is stressed to 25 percent of its design rating and operates in an unchanging ambient temperature of 35°C.

With the foregoing assumptions as a background, the principal results of the study are summarized in the next section.

II. SUMMARY OF NUMERICAL RESULTS

An important task within the scope of this study is the selection for computation of those numerical results which will afford maximum insight into spacecraft reliability. It would be neither feasible nor desirable to attempt to present all of the corollary or intermediate results that are developed or could be developed in the course of the assessment.

The process of determining the specific class of results to be examined brings into evidence an apparent conflict that arises because of the varying viewpoints which can be adopted in ordering or ranking the importance of the many spacecraft functions. Emphasis on a large number of detailed results will tend to obscure the integrated or "big" picture, whereas overall results fail to show the interrelationships of the many factors which entered into them. It is believed that a judicious combination of results on interesting events and functions, together with a figure-of-merit approach to important objectives, constitutes the most satisfactory resolution of this conflict. The results selected for presentation here represent an effort to provide this kind of combination.

A. Summary of Classical Reliabilities

The term "classical reliability," in the sense employed here, implies that some minimum level of performance has been established as a criterion of success or failure. Reliability is then the probability that this minimum performance level will be equaled or exceeded for the applicable time periods within the mission. No gradations of operating characteristics are recognized between the extremes of "operable" and "failed," and the element of judgment is applied only to determining the complement of parts deemed necessary to achieve the functional performance selected for examination.

From this rather general explanation of classical reliability, it is possible to specify in somewhat more precise terms the functions or events that are considered to be of interest and that have a significant bearing on the total mission. A predicted reliability is given for each.

1. Solar array deployment: less than 1 failure in each 100,000 trials. Equipment considered for this event includes the redundant pyrotechnics for unlatching the panels, the hinges and spring actuators for unfolding them, and the hydraulic snubbers which limit their deployment velocity.

2. Power supply: 0.710 reliability for 6,213 hours. This includes the scheduled generation of 400-cps power as well as continuous production of 2.4-kc/s power for general spacecraft use and direct current for the radio power amplifiers.

3. Command capability: 0.340 reliability for 6,213 hours. This predicted reliability applies to the capability of executing a typical command, and includes the necessity for an operating radio receiver.

4. Radio functions:

   a. Receiver: 0.675 reliability for 6,213 hours. This does not include the ranging channel, but does encompass the antenna switching requirements.

   b. Transmitter: 0.970 reliability for 6,213 hours. This applies to the transmitter operating with either coherent or noncoherent excitation.

   c. Coherent transponder: 0.640 reliability for 6,213 hours. This figure covers the complete radio subsystem except for the ranging channel, with the auxiliary oscillator redundancy disallowed.

5. Central computer and sequencer:

   a. Maneuver signals: 0.948 reliability for 286.5 hours. Maneuver data registration and maneuver central functions are considered in this predicted reliability.

   b. Sequencing functions: 0.672 reliability for 6,213 hours. This is the probability of generating a typical master time signal through the end of the mission.

6. Attitude control:

   a. Sun acquisition and tracking: 0.767 reliability through 6,213 hours. This figure includes two scheduled reacquisitions and the probability of unscheduled reacquisitions.

b. Initial acquisition of Canopus: less than 5 failures in 10,000 trials. The probability of obtaining the prerequisite sun acquisition is included, and operating commands, needed redundantly, are calculated at their normal reliabilities.

c. Celestial reference acquisition and tracking: 0.635 reliability for 6,213 hours. This is the combined probability of acquiring and tracking Canopus as well as the sun.

d. Inertial roll control: 0.441 reliability for the final 263 hours of the mission. This predicted reliability applies to the specific case in which the inertial control is not invoked until 50 hours before encounter. Reliability of the radio subsystem has been included.

7. Trajectory correction: 0.961 probability of an adequate maneuver within 288 hours. All necessary spacecraft subsystems are incorporated in this calculation.

8. Data encoder:

a. Video data encoding: 0.626 reliability for 6,213 hours. This covers the unit complement needed for tape playback data only.

b. Cruise science data encoding: 0.557 reliability for 6,213 hours. This reliability prediction applies to the portions of the data encoder requisite for cruise science data.

c. High-rate engineering telemetry: 0.474 reliability for 6,000 hours. This is the probability of successfully encoding data through one typical high-rate analog channel.

d. Low-rate engineering telemetry: 0.392 reliability for 6,000 hours. This predicted reliability covers all equipment associated with the encoding of a typical low-rate analog channel.

9. Total system: 0.111 reliability for 6,213 hours. This is defined as the classical reliability of the system. It is the calculated probability of success of a mission which accomplishes all objectives except (possibly) the return of low-rate engineering telemetry and the functioning of a coherent radio receiver beyond the midcourse correction point.

B. Figure-of-Merit Summary

If the primary mission objectives can be quantitatively ranked, and an assignment of worth made to each of them, consideration can be given to the possible degradations in performance which, while not meeting the criterion established for total mission success, still provide the capability of at least partial fulfillment of mission objectives. This type of assessment, leading to a spacecraft figure-of-merit, has been pursued in this study.

The resultant figure-of-merit is 34.8 percent, which is to be compared with a figure of 100 percent for a perfect mission in which all objectives are achieved with complete reliability. The constituent elements of this figure-of-merit correspond to primary mission objectives. They are tabulated below together with the assigned worth for each objective.

Mission Objective	Assigned Worth	Expected[1] Worth
Cruise science	12.0	6.3
Engineering telemetry	3.5	2.0
Orbit determination	4.5	3.6
Star acquisition	1.0	0.9
Trajectory correction	2.0	1.9
Planet encounter	6.0	2.9
Encounter science	11.0	2.6
Tape playback	60.0	14.1
Total worth	100.0	34.3

The figure-of-merit has characteristics in common with all stochastic measures, and is not to be interpreted as the proportion of worth likely to be obtained from a single mission. Any single mission may well result in complete success or failure, particularly in view of the many "one-shot" objectives to be accomplished. The figure-of-merit provides insight into system reliability by predicting the average worth of a significantly large number of identically defined missions. No statistical measure can predict the degree of success of a single trial, but the figure-of-merit does offer a realistic assessment of system reliability.

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[1] Throughout this report, the words "expected" and "average" are used interchangeably to denote a statistical mean or expectation.

III. SUBSYSTEM REPRESENTATIONS

The reliability model of a subsystem is not a unique representation of the equipment because the assumptions that have been necessary will tend to emphasize particular aspects of subsystem operation. A model is based upon a reliability-oriented description of the subsystem, and such a description is usually clarified by more or less concise representations such as block diagrams and time profiles of the mission. These illustrate the manner in which the subsystem is viewed for its reliability aspects, and depict the introduction of many of the assumptions.

The interim report on the Mariner C reliability assessment contains a relatively complete description of the functions of each subsystem and the manner in which they are implemented. It is deemed unnecessary to repeat these descriptions here; however, the block diagram representations and the time profile for a normal mission are resubmitted so that the basis for the numerical assessment which follows will be absolutely clear and explicit.

It was observed in Section I that a limited number of changes in the reliability representatives have been necessary to ensure that the most current documentation would be reflected in the assessment. It is the purpose of this section to discuss these changes and to demonstrate that they have, in fact, been introduced into the subsystem representations. Accordingly, the descriptions that follow emphasize the difference between the subsystem representations as given in the interim report and those that are submitted here. To facilitate this discussion, a complete set of block diagrams is included for each subsystem with the exception of the science subsystem and the command detector and decoder. As has been explained in Section I, only a partial assessment of the science subsystem has been possible because of the somewhat fluid state of development of this equipment.

The implementation of each of the discrete commands is not reproduced here because of the similarities between them. The representation of a sufficient number of typical commands are presented so that no ambiguities will exist in any reconstruction of the numerical assessment procedure.

A. Science Subsystem

Data processing has been designated as the science subsystem for the purposes of this study. This includes the data automation system, together with the planetary instrument scan equipment and the tape recording and playback functions. The development of much of this equipment has not reached the stage that would permit its evaluation to the extent that other subsystems on the spacecraft have been analyzed. The interim report does not contain a model for this subsystem. Accordingly, no changes in the model development can be discussed, but the possibility of improving the accuracy of the study has been enhanced by the availability of a limited amount of information on some parts of this subsystem.

1. Data Automation System

The data automation system constitutes the largest and most complex portion of the science subsystem. The design of the data automation system involves the use of pelletized circuits, which is a departure from the design practices followed in the other subsystems of the spacecraft. Decisions regarding the complement of scientific instruments to be carried aboard the spacecraft have been delayed, and for this reason it has not been possible to include the data automation system in the subject study.

2. Planetary Instrument Scan System

Among the functions which have been grouped with the science subsystem is the planetary instrument scan system. The reliability of this system is depicted in Exhibit 1. It is seen that the initiation of the scan function is dependent primarily on a successful pyrotechnic event as shown by the presence of the pyro-firing circuits. These circuits are activated by the CC and S through signal MT-7, with the capability of redundant initiation through command DC-25. Parallel squibs are fired by redundant silicon-controlled rectifiers shown as units 930 and 931. The function of these squibs is to release the science cover latch unit 101. A hinge and actuating spring, unit 102, swing the science cover out of the way and open the optical view of the planetary instruments.

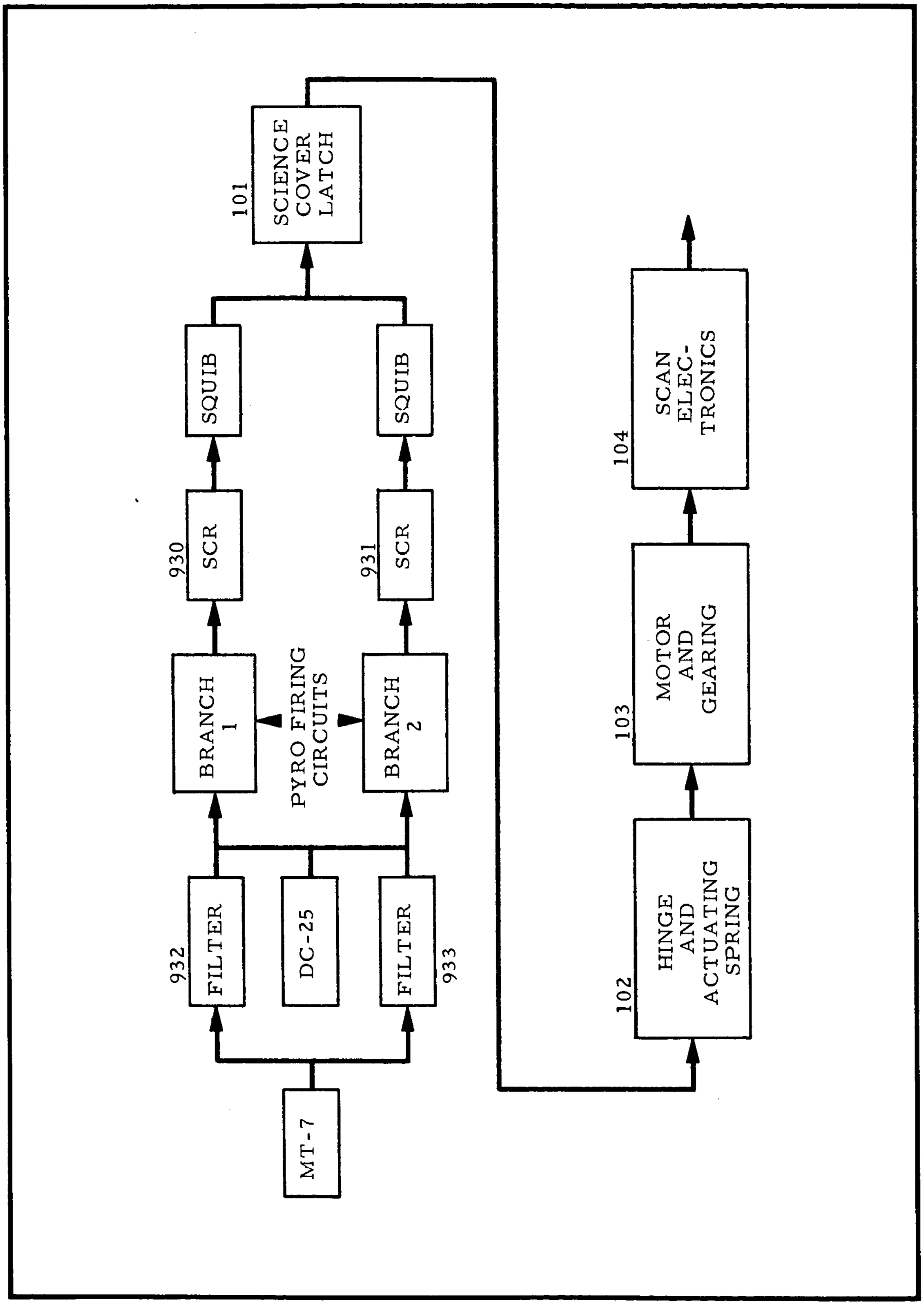


EXHIBIT 1 - PLANETARY INSTRUMENT SCAN

Units 103 and 104 constitute the scan gear motor and its control electronics. These units operate throughout the encounter phase to direct the view of the optical instruments. It will be noted that the only redundancy which has been accounted for is that which is available for the pyrotechnic event. Circuit diagrams of the scan electronics were not available for study, and it has been assumed that the entire parts complement is required for the success of the scan function.

3. Tape Recording/Playback Equipment

The taping of video data and its subsequent playback through the radio subsystem is a design responsibility separate from the data automation system. It has been included with the science subsystem, however, because of its close functional relationship with the equipment which is responsible for the processing of science data. Complete documentation on the design of the tape recorder became available late in the program and an accurate parts count of this equipment was thereby made possible. However, it was not possible to discern specialized failure modes, and, consequently, the parts complement was simply divided into those portions which are concerned with recording and those which are concerned with playback.

Exhibit 2 shows the reliability block diagram which resulted from this very straightforward approach to the tape recorder. The mechanical portions of the recorder are included in unit 105 and, as indicated, the record and playback electronics are split between units 106 and 107.

A number of CC and S signals are required at different times to effect the proper recording and playback of video data. These CC and S signals are shown in the diagram as MT-7, MT-8, and MT-9, and it will be seen that each signal is individually backed up by a discrete command.

It is assumed that both the record and playback functions must be successful if any worth is to be derived from the gathering of video data. For this reason, all units are placed in series from a reliability standpoint.

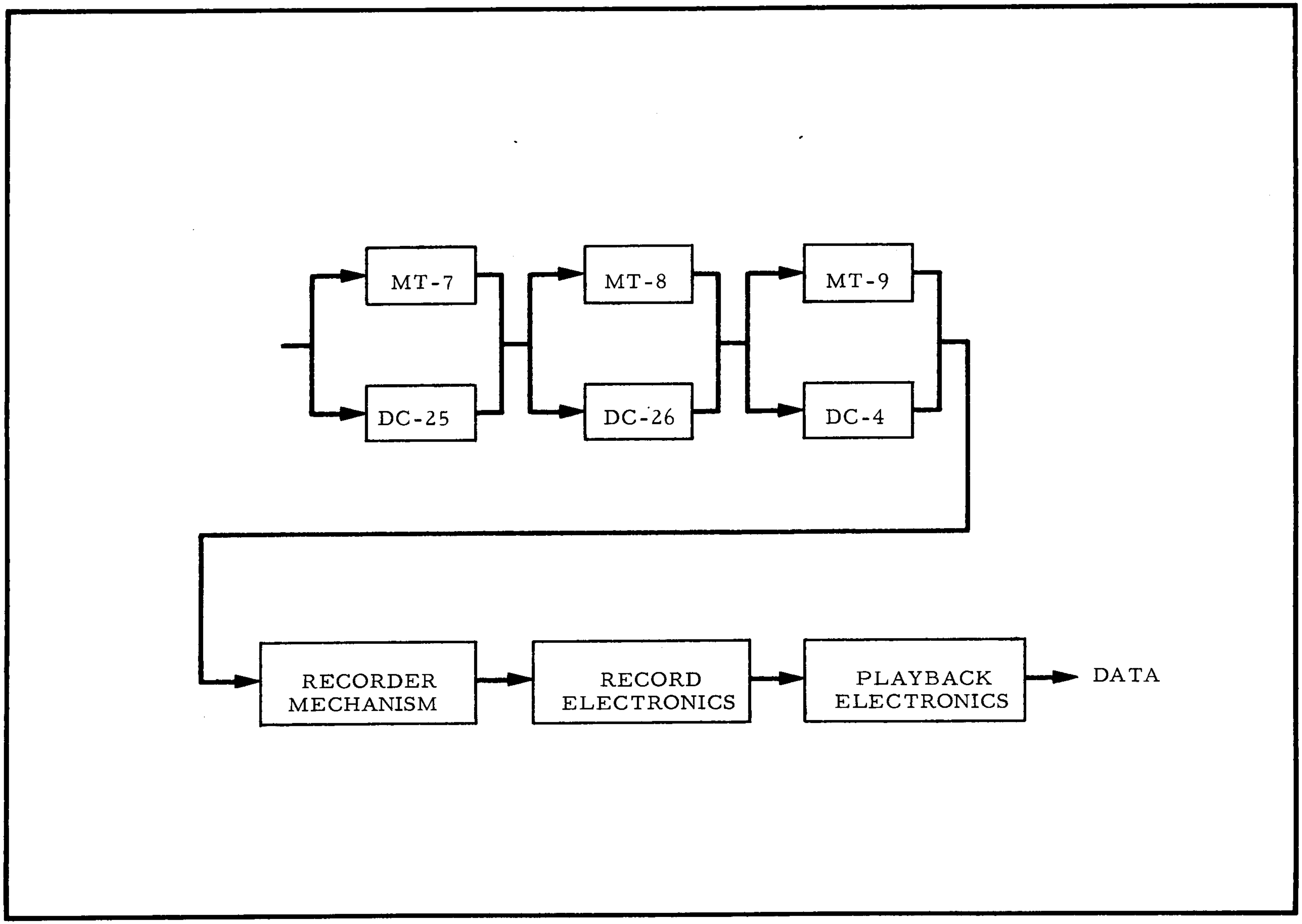


EXHIBIT 2 - VIDEO DATA RECORDING AND PLAYBACK

B. Data Encoder

1. Revised Representation

Further analysis of the data encoder, along with additional documentation and some specific requests from JPL personnel, resulted in significant changes to the model since issuance of the interim report. Because of the magnitude and quantity of changes in the data encoder, a new and revised set of exhibits (Exhibits 3-15) covering this subsystem is included in this report. Changes that have been included in the new set of diagrams are described in the remainder of this subsection.

In Exhibits 3 through 9, unit 2051, the initial commutation switch, continues to be composed of the same parts as the succeeding switches, units 2052 through 2107, with the exception of units 2100 and 2101. The latter two, which are double-pole switches, are now composed of the same parts as units 2109 through 2143, found in Exhibits 5, 7, and 10. None of the above units contains a switch driver as these have all been designed out of the subsystem. (Note that the number 2067 has not been assigned to any unit.) Units 2144 through 2149 (see Exhibits 3, 4, and 7 through 10) are identical single-pole switches and equivalent to such units as 2051.

Units 2029, 2032, and 2034 are no longer the same as units 2025 through 2028, 2030, 2031, and 2033. The former three unit numbers are now associated with three new bucking supplies identified in Exhibits 3, 4, and 8 respectively. The latter 7 unit numbers continue to represent the sequencers or shift registers, of which there are 7 instead of 10 as previously described in the interim report. In addition, dash numbers are now associated with these seven units, as can be seen in Exhibits 3 through 10. Each dash number represents a particular stage in the given unit; e.g., 2025-1, 2025-2, and 2025-3 represent the first, second, and third stages, respectively, of the given unit 2025. Blocks identified with more than one such unit dash number represent a series requirement for sequential portions of the shift register; e.g., a block identified by 2025-1. . . -7 denotes a requirement for the first seven stages of unit 2025. Note that the blocks are not independent and, in fact, contain some of the same parts.

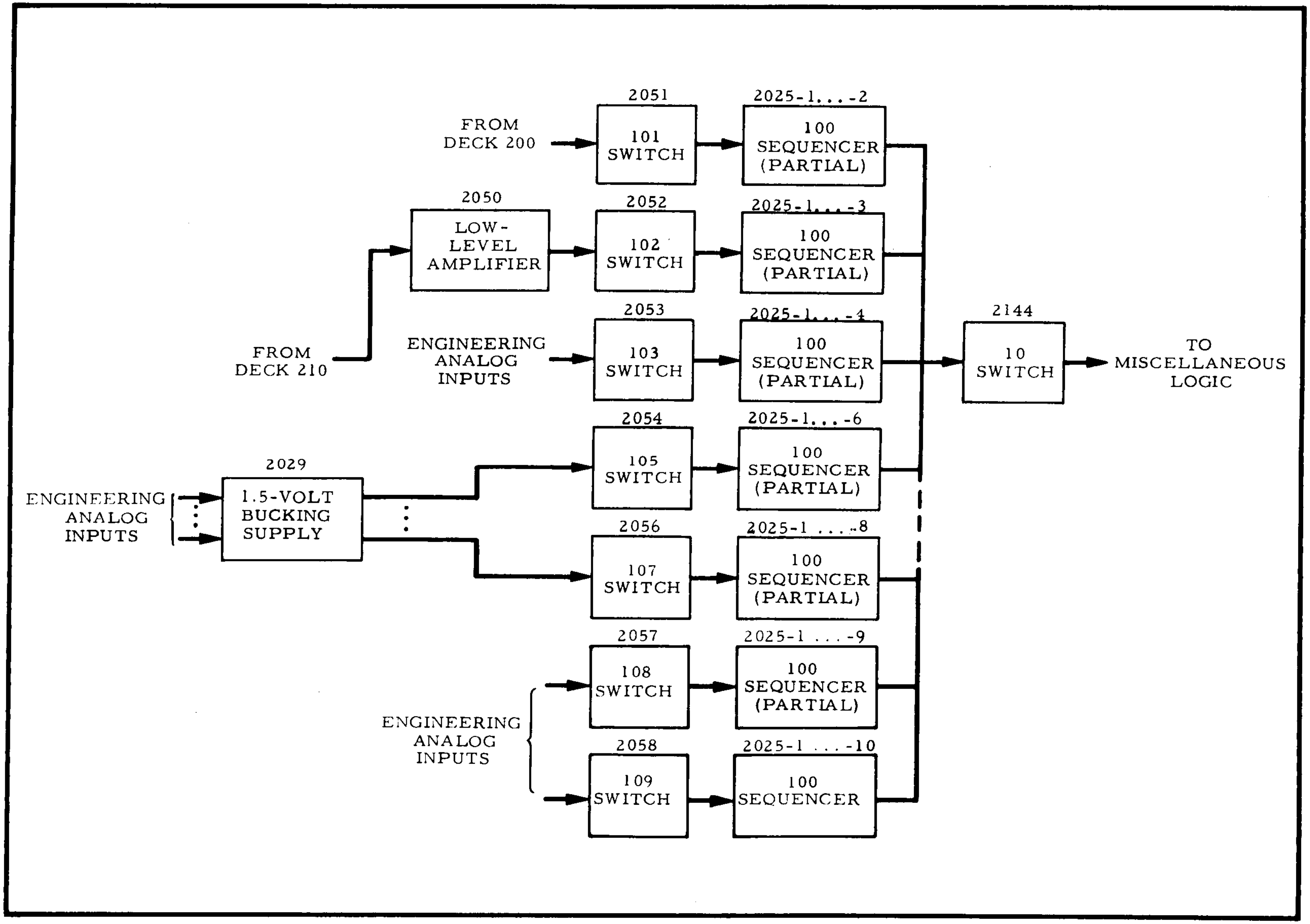


EXHIBIT 3 - DECK 100 ANALOG CHANNELS

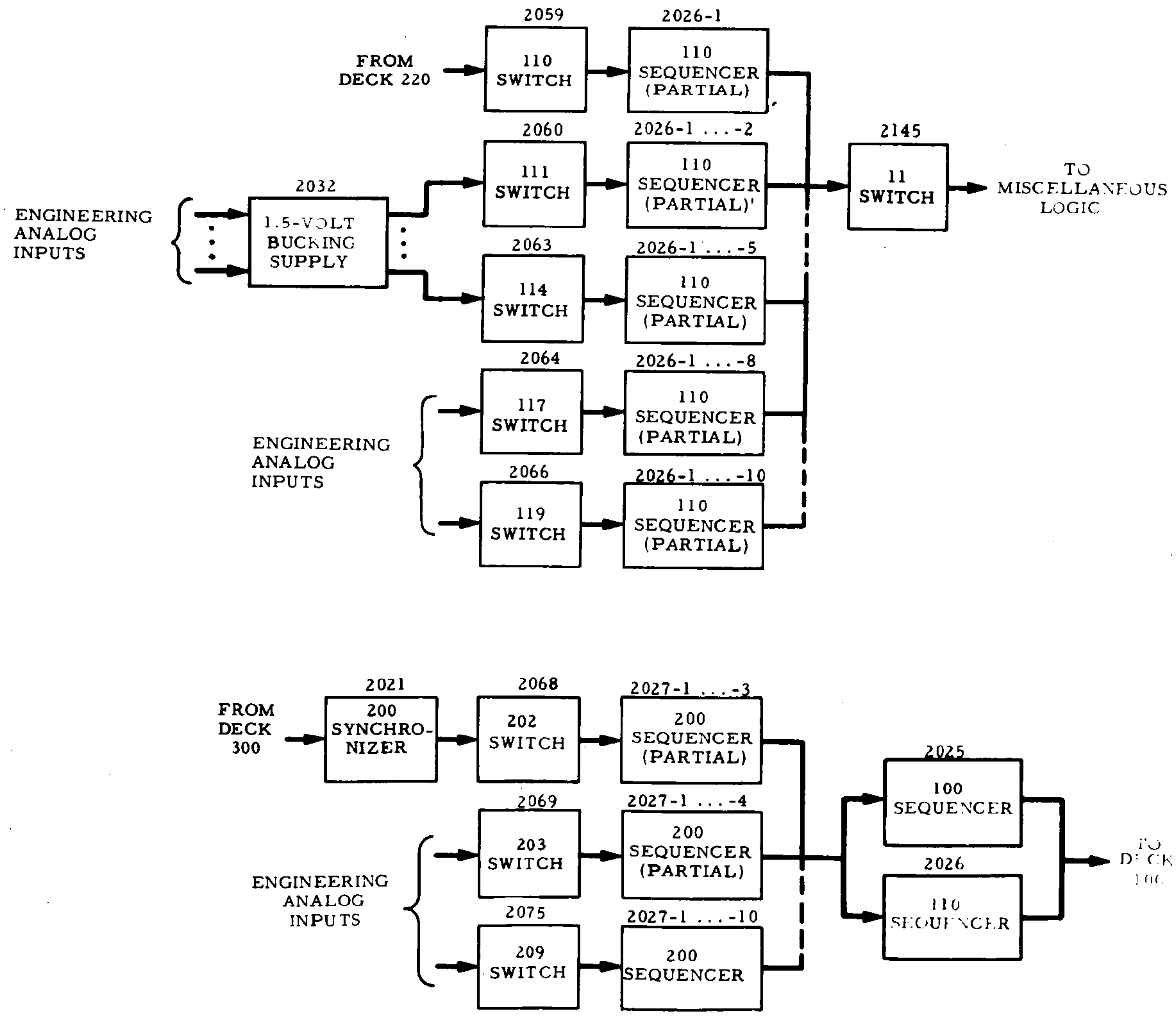


EXHIBIT 4 - DECKS 110 AND 200 ANALOG CHANNELS

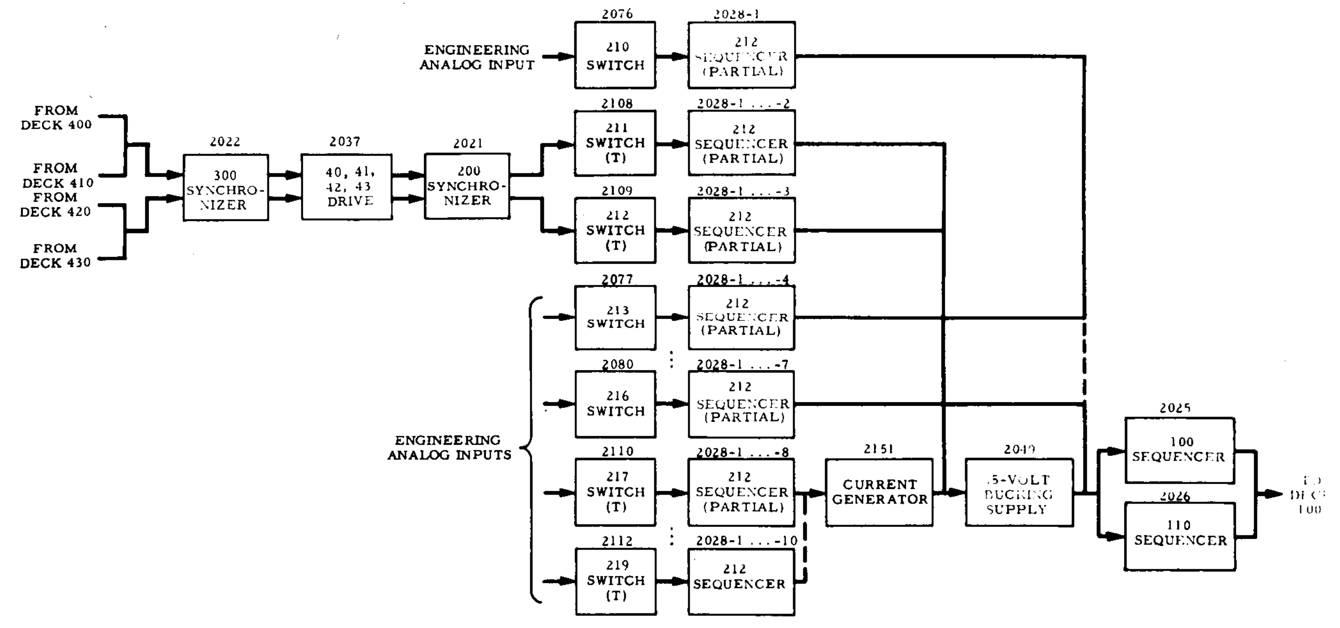


EXHIBIT 5 - DECK 210 ANALOG CHANNELS

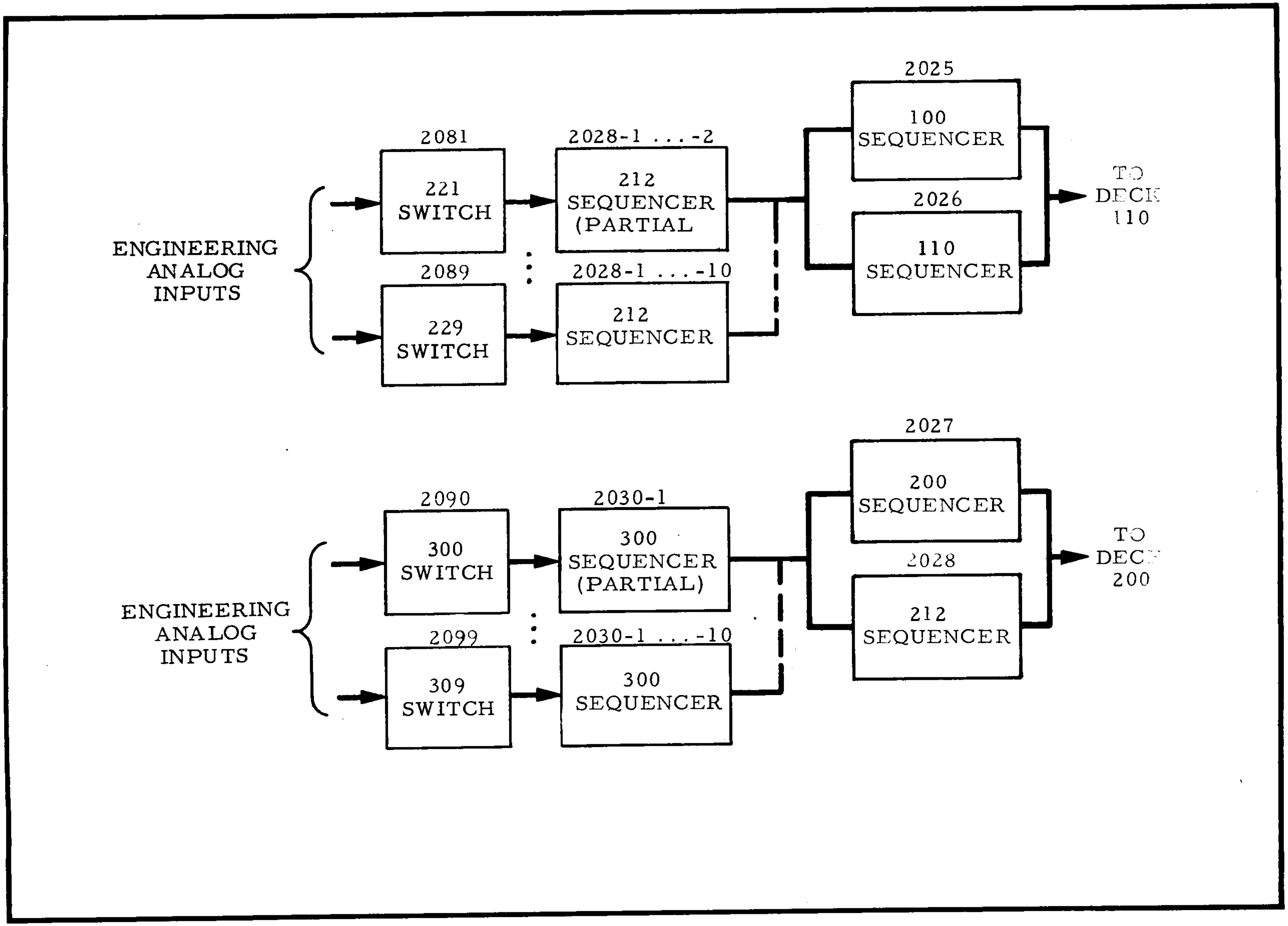


EXHIBIT 6 - DECKS 220 AND 300 ANALOG CHANNELS

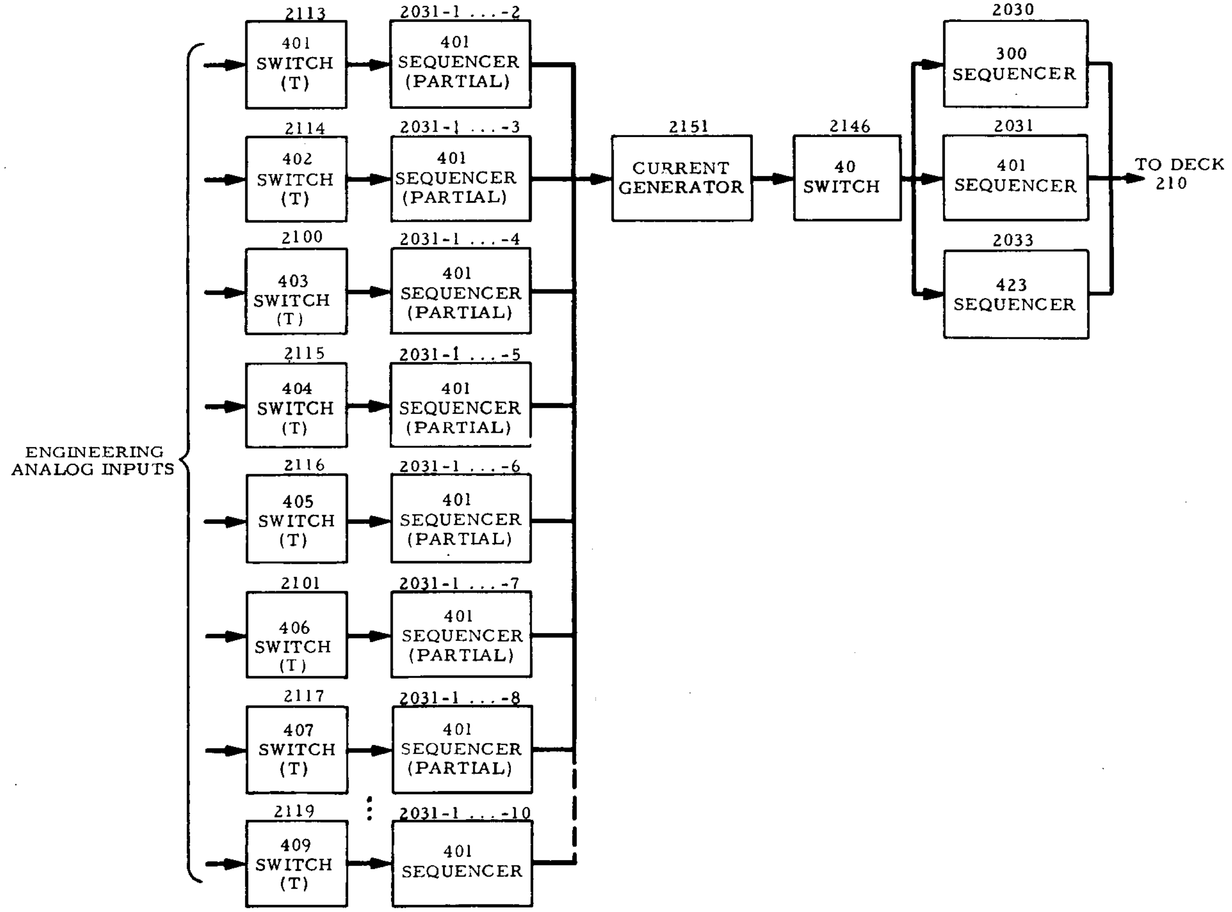


EXHIBIT 7 - DECK 400 ANALOG CHANNELS

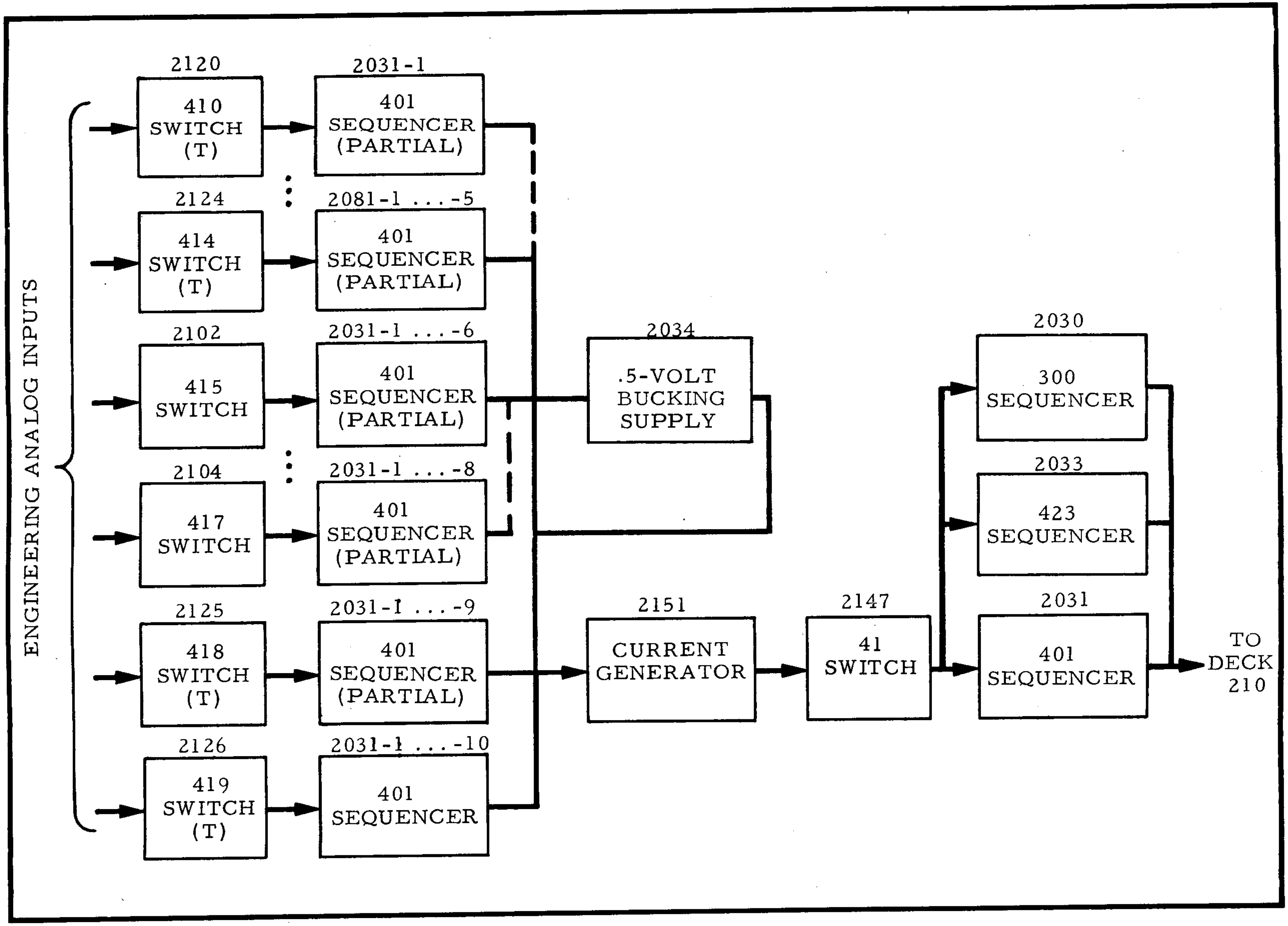


EXHIBIT 8 - DECK 410 ANALOG CHANNELS

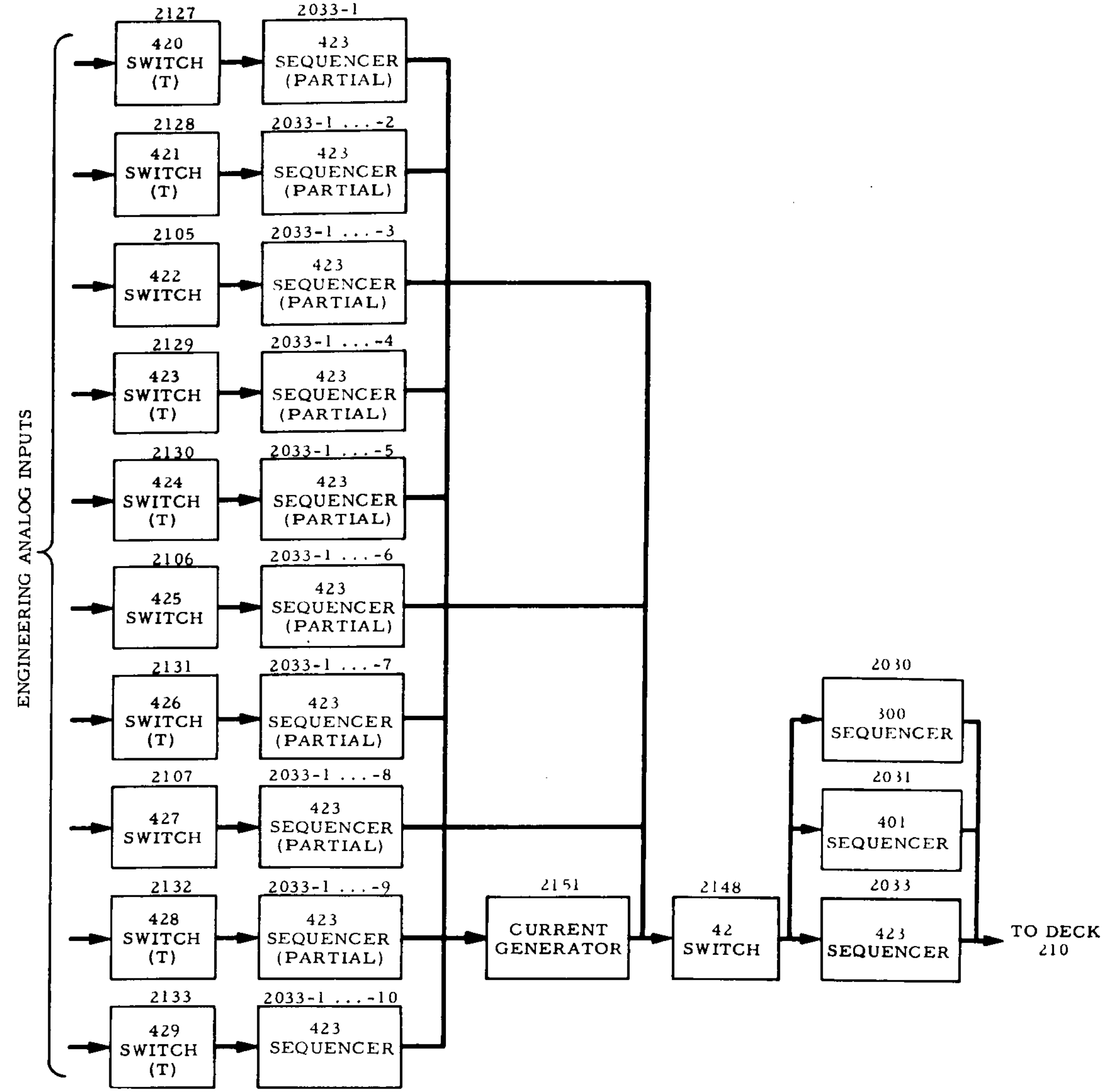


EXHIBIT 9 - DECK 420 ANALOG CHANNELS

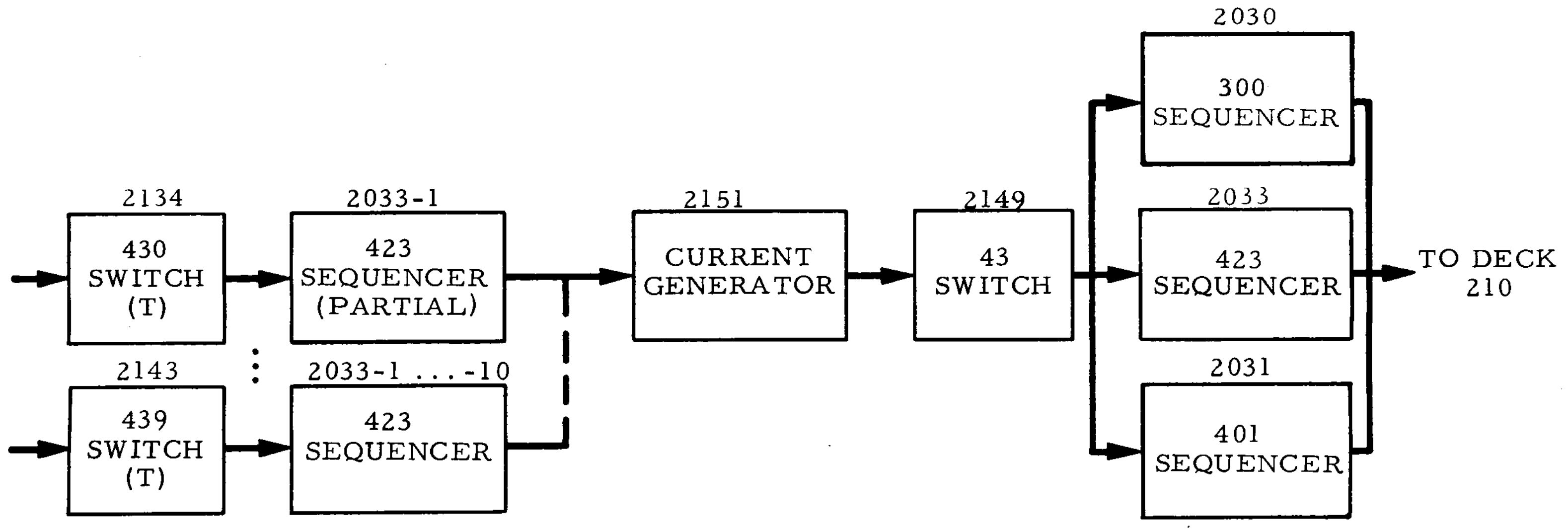


EXHIBIT 10 - DECK 430 ANALOG CHANNELS

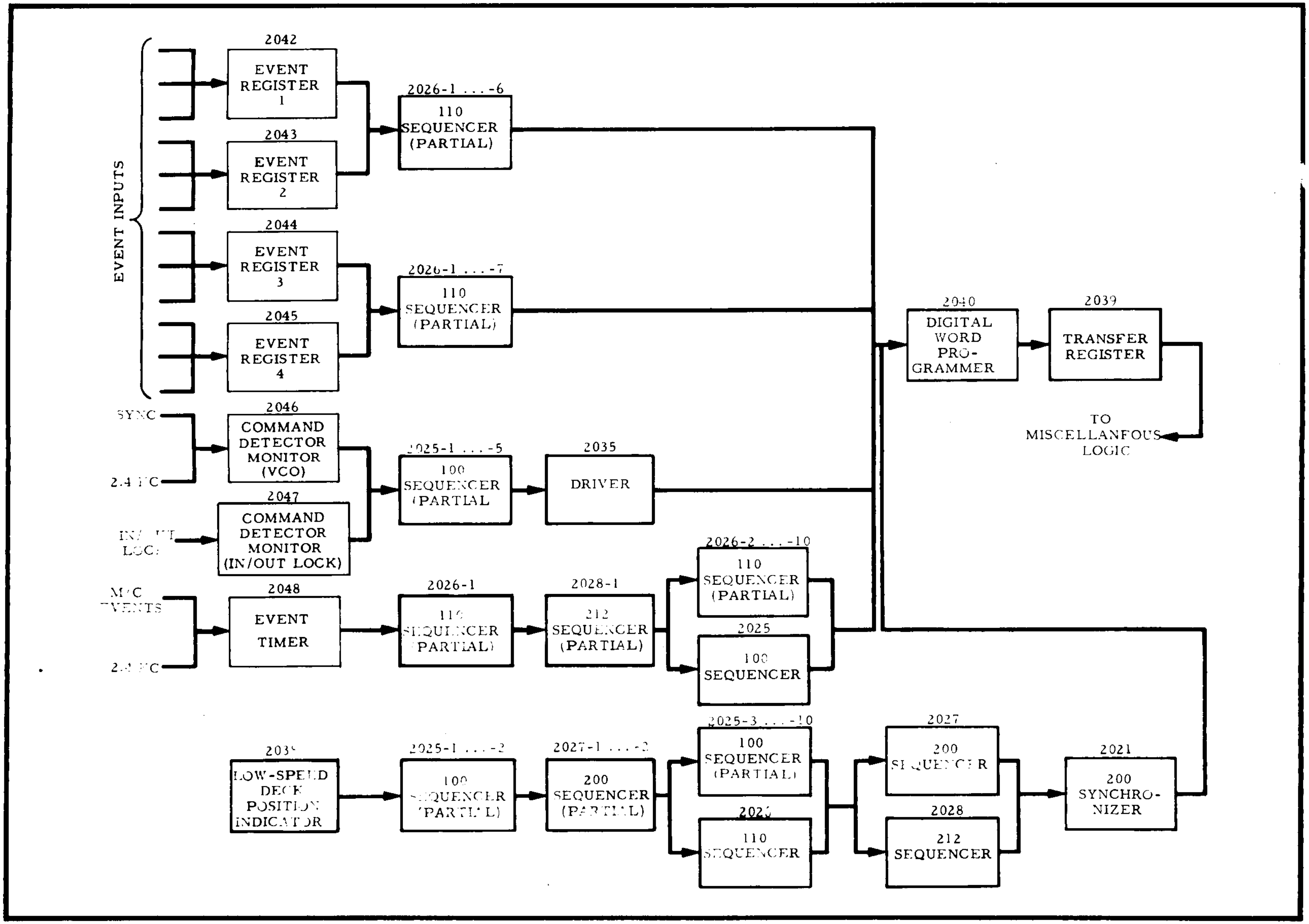


EXHIBIT 11 - DIGITAL ENGINEERING CHANNELS

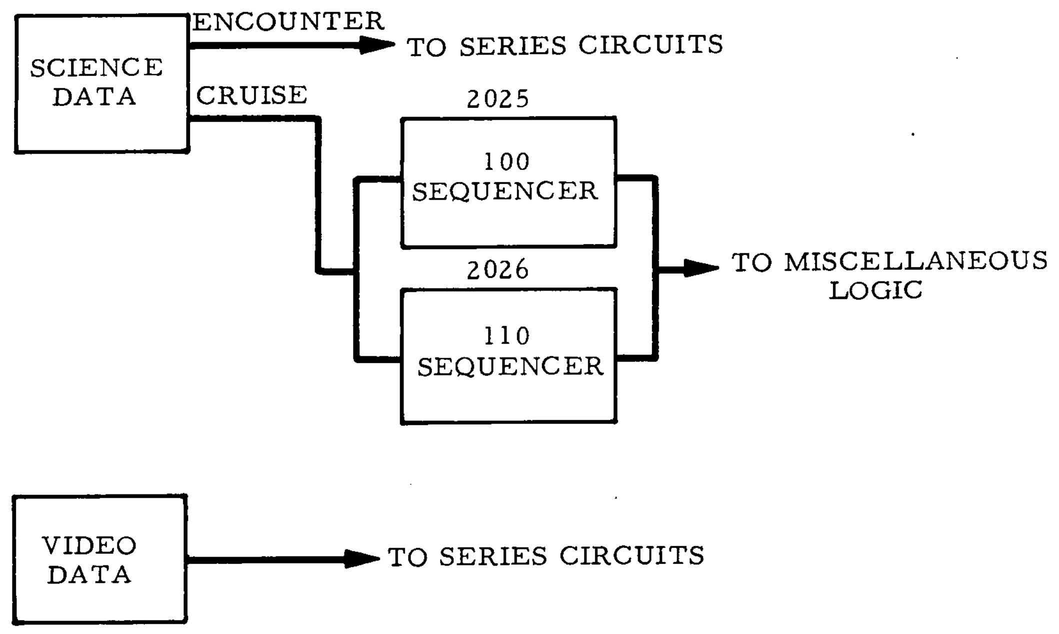


EXHIBIT 12 - SCIENCE AND VIDEO CHANNELS

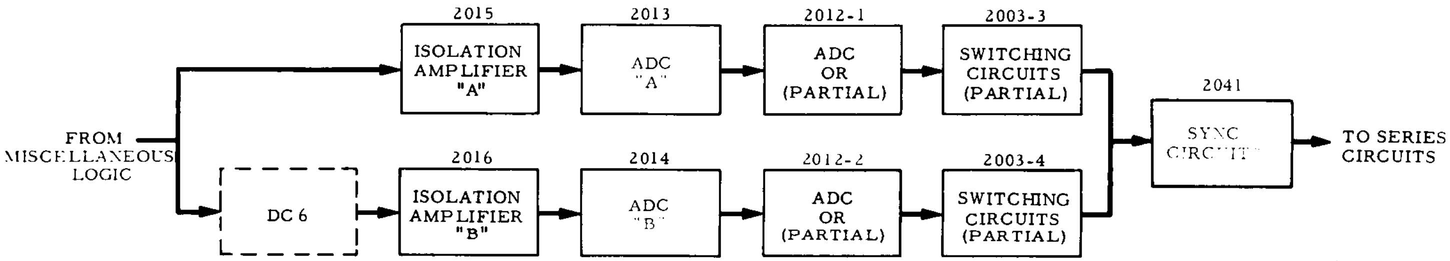


EXHIBIT 13 - ANALOG-TO-DIGITAL CONVERSION

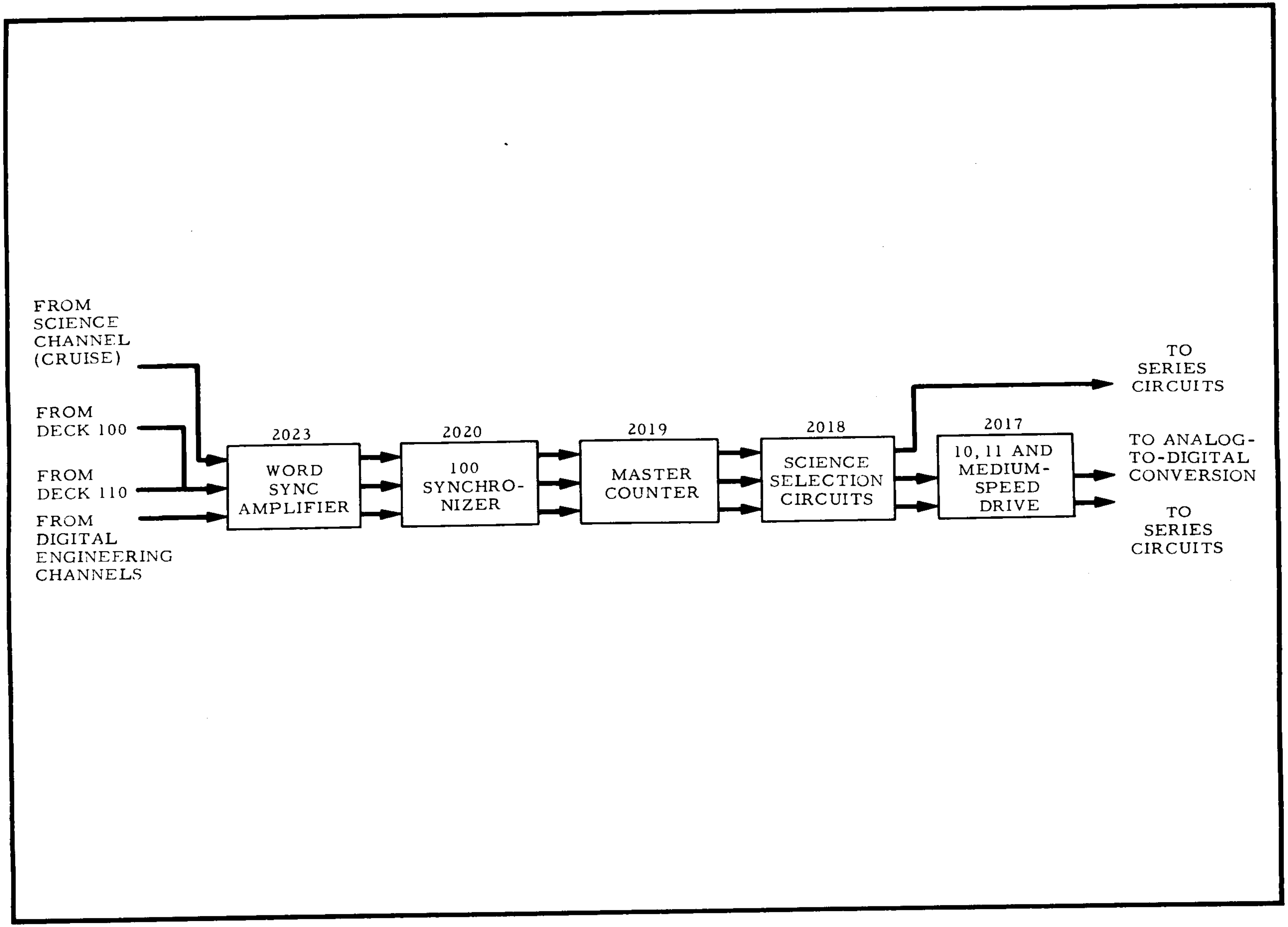


EXHIBIT 14 - MISCELLANEOUS LOGIC

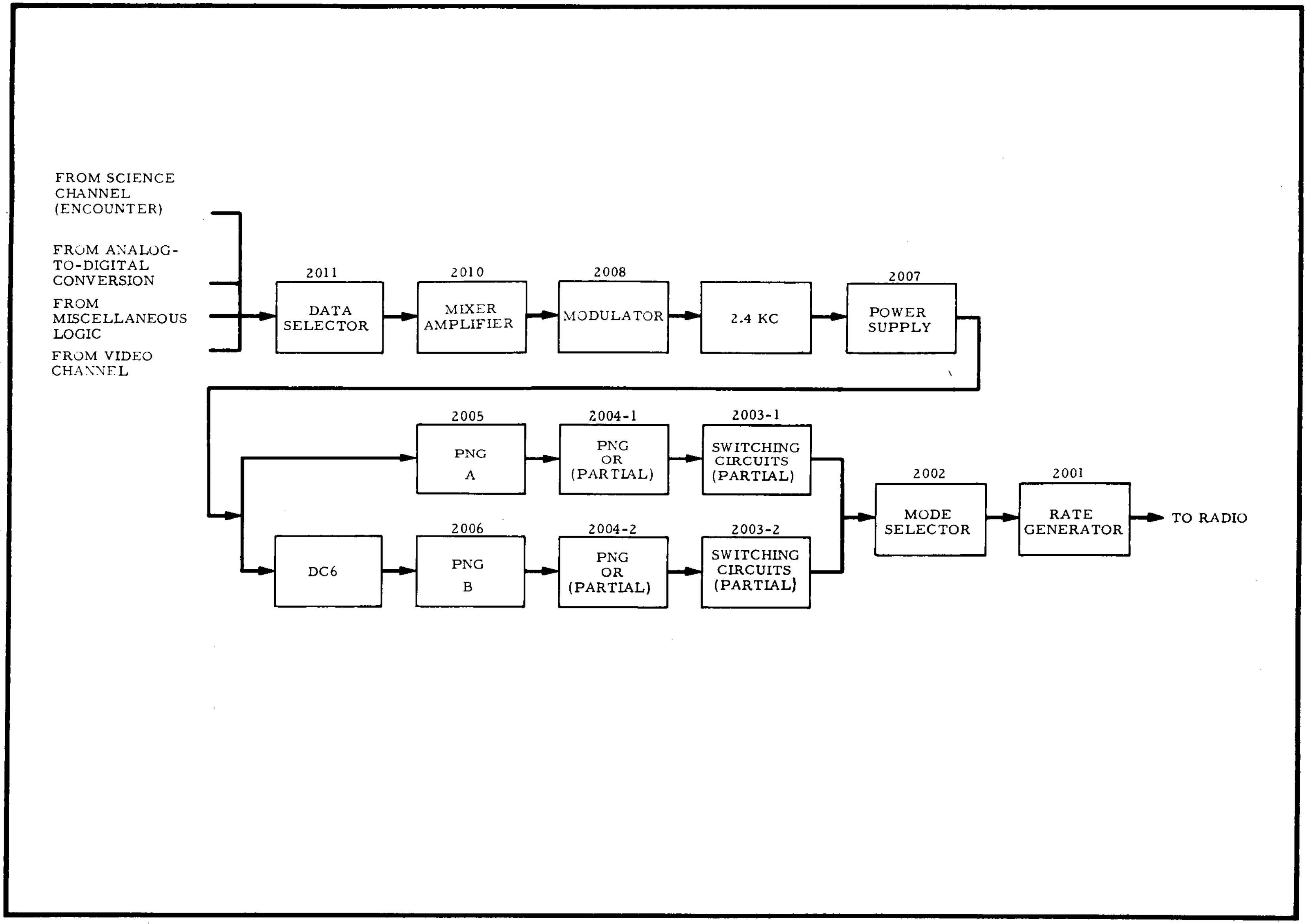


EXHIBIT 15 - SERIES CIRCUITS

In the previous representation, any failure in a sequencer constituted the loss of all channels dependent upon any part of that sequencer. In the new diagrams, the assumption is made that any failure in a particular sequencer results in some integral number of channels from 1 through 10 being unselectable, but that no failure will cause a continual selection of one particular channel.

Exhibits 4 through 12 have also been changed with respect to the complete sequencer units. Each of these exhibits can be seen to include two or three paralleled sequencers in series with each deck. Referring to Exhibit 4, note that in Deck 110, failure of unit 2026-1 causes the loss of channel 110 only and not the remainder of the deck, but such a failure also diminishes the probability of getting the Deck 200 channels since failure of 2026-1 means failure of 2026 which is in parallel with 2025, the combination being in series with the Deck 200 channels. Other consequences have been accounted for as can be determined by further examination of the exhibits.

Some of these consequences can be observed in Exhibit 11. Although this exhibit has been completely rediagrammed, there are no additional subtleties beyond those already described. Thus, the digital engineering channels are dependent on the same sequencers and sequencer stages as are the analog engineering channels, and in an identical manner.

Exhibit 12 has been changed to account for both cruise science and encounter science. The change involving video data is one of bookkeeping only, since the unit removed was actually the data selector indicated in Exhibit 15.

Exhibit 13 was changed by adding the sync circuits in series with the analog-to-digital conversion function. Exhibit 14 was changed by making all of the indicated data inputs dependent on the high rate synchronizer, unit 2020, while Exhibit 15 was changed by eliminating the possible degraded path resulting from loss of the sync subcarrier and adding the power supply.

2. Identification of Unit Parts

In order to calculate a truly representative failure rate for each unit, it has been necessary to determine exactly how many component parts are associated with it and whether any of the parts are used redundantly. Until late in the study, the documentation available for analysis provided no indication of component redundancy. Subsequently, additional documentation was received which was found to indicate that extra gate inputs to NAND type circuits were being utilized in a redundant manner. Although time constraints precluded a searching review of all of the new documentation, the information was used to correct the significant misrepresentations which had arisen because of alterations in design philosophy.

The detailed component part listing, including quantities and failure rates, can be found in Appendix A. It is the purpose of the remainder of this subsection to clarify exactly what the group of parts in Appendix A actually represents with respect to the documentation. Referring to the diagrams (or to Appendix A where the units are numerically ordered) it is evident that many of the units do not require further clarification other than to state that they are composed of individually well defined functional parts of the system. Included in this category are the following units: 2005 through 2008, 2010, 2011, 2013 through 2023, 2029, 2032, 2034, 2038, 2039, 2049 through 2149, and 2151. Part redundancy has been accounted for where applicable in units 2005 and 2006, the PN generator. Unit 2001, the rate generator, includes the switching circuits and the four-flip-flop toggled binary counter. Assembly drawing bills of material were used to determine the parts complement of the circuit modules used in these units, and their part redundancies are accounted for.

Unit 2002 comprises all of the circuitry for changing modes. It includes the capacitor bank with its series-parallel arrangement for operating the relays. The bank itself is in series, and, therefore, could have been included in unit 2001.

Unit 2003-1 contains six latching relay contact sets because this is all that must be operable for the "A" PN generator to operate successfully.

Unit 2003-2 contains the remainder of the switching circuits (with part redundancy accounted for) because they must all be operable to change to the "B" PN generator. Since switching of the "A" A-D converter requires the same parts as the switching of PN generator "A", and, similarly, A-D converter "B" switching requires the same parts as switching PN generator "B," units 2003-3 and 2003-4 are given failure rates of zero to avoid double counting of the parts. Note that the results would not be the same (in fact, they would be in error) if, instead, the parts were accounted for in the A-D converter circuits and not in the PN generator circuits.

The same failure rate has been given to the PN generator OR circuits, denoted as units 2004-1 and 2004-2. Their total failure rate is taken as the failure rate of any of the circuits handling signals derived from the PN generator, including the PN code, and the interrogate, $2f_s$, bit sync and word sync signals. Here, also, part redundancy has been taken into account.

Units 2012-1 and 2012-2, the A-D converter OR circuits, have also been given the same failure rates. Their total failure rate is taken as the sum of the failure rates of the appropriate NAND and NOR circuits handling the data through the A-D converter.

Units 2025 through 2028, 2030, 2031, and 2033 are denoted as the sequencers and each includes two individually well defined functional parts of the system. These are a clock driver and a 10-stage sequencer. The -1 portion of each includes a clock driver, the first stage of the sequencer, and the sequencer parts that are common to all 10 stages. Each of the other dash numbers, -2 through -10, represents a particular sequencer stage other than the first. Each is identical with respect to parts complement.

Unit 2035 is the module circuit that functions as a common driver for both portions of the command detector monitor, while unit 2037 includes one flip-flop and two drivers.

Unit 2040 contains all of the functional digital word programmer with the exception of the sync circuits, which are contained in unit 2041.

Units 2042 through 2045, which accept the event inputs, each include two functional parts of the system, an event register and an input conditioning circuit.

Unit 2046 is composed of that portion of the command detector monitor associated with the command detector VCO only. Unit 2047, which develops the state-of-lock signal, and unit 2035 (mentioned above) constitute the remainder of the command detector monitor.

Unit 2048 includes the event timer circuitry in addition to an input conditioning circuit.

In all units, the parts complement for circuit modules and other assemblies and/or subassemblies was obtained from the appropriate high-speed or low-speed assembly drawing bill of material. Extra diode inputs were considered as redundant if known to be so, or not counted at all if the redundancy was not evident.

C. Command Detector and Decoder

1. Revised Representation

Continued analysis of the decoder portion of this subsystem since issuance of the interim report has resulted in some minor bookkeeping revisions to the block diagrams. The changes do not affect the model because of the general nature of the equations. Due to the simplicity of the diagram changes, only revised exhibits necessary to typify the changes have been included in this report. Changes that have been indicated in the typical diagrams included in this report are described in the remainder of this subsection.

Exhibit 16 shows the implementation of the series and miscellaneous circuits to which there have been no changes. Exhibit 17 indicates the implementation of DC-1. It is typical, with the exception of the unit numbers, for DC-4 through DC-8. It is to be noted that there have been no diagram changes associated with these commands. However, DC-4 no longer goes to the power subsystem, but only to the data encoder; DC-7 and DC-8 do not go to the data encoder, but instead go to the radio subsystem.

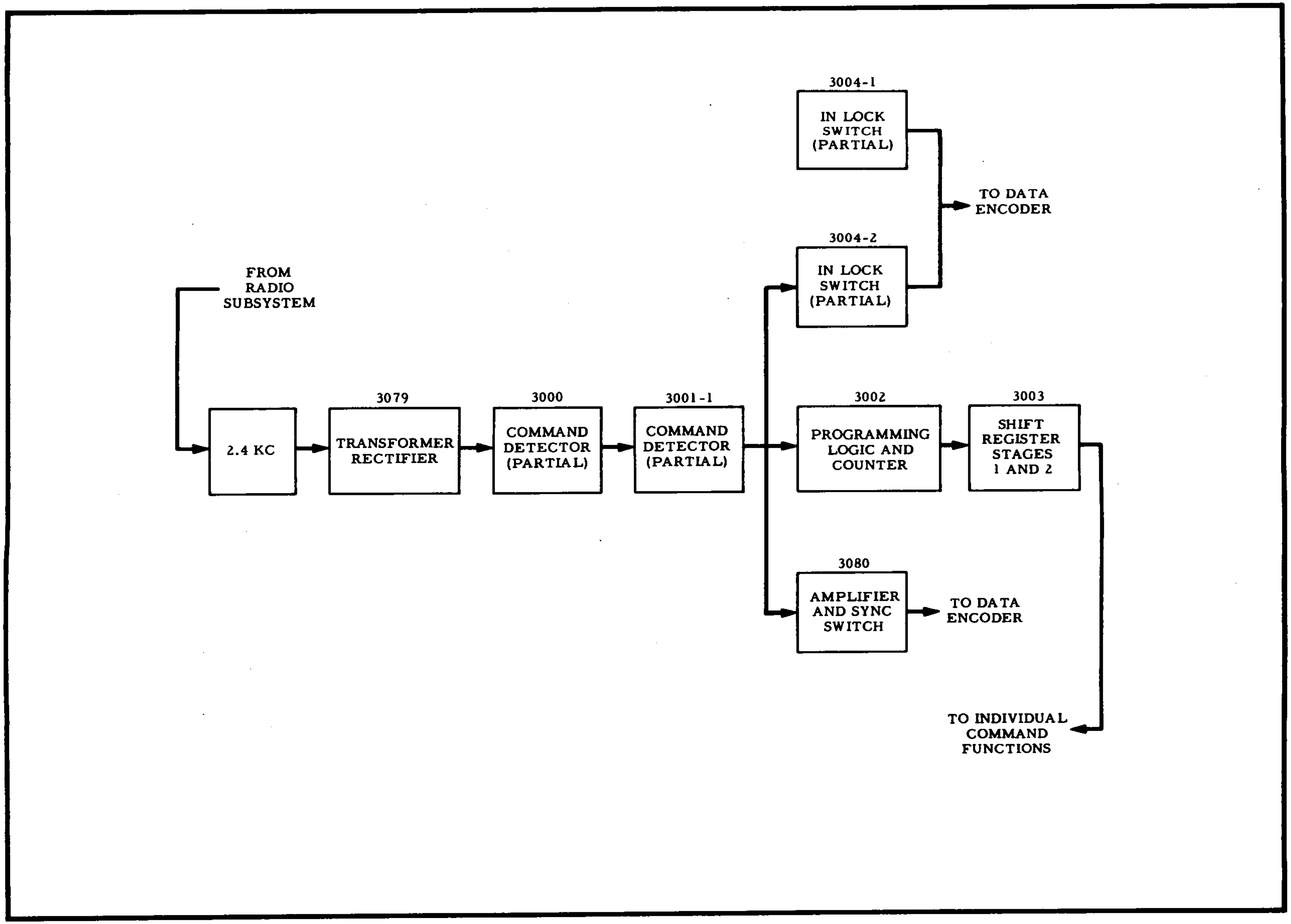


EXHIBIT 16 - SERIES AND MISCELLANEOUS CIRCUITS

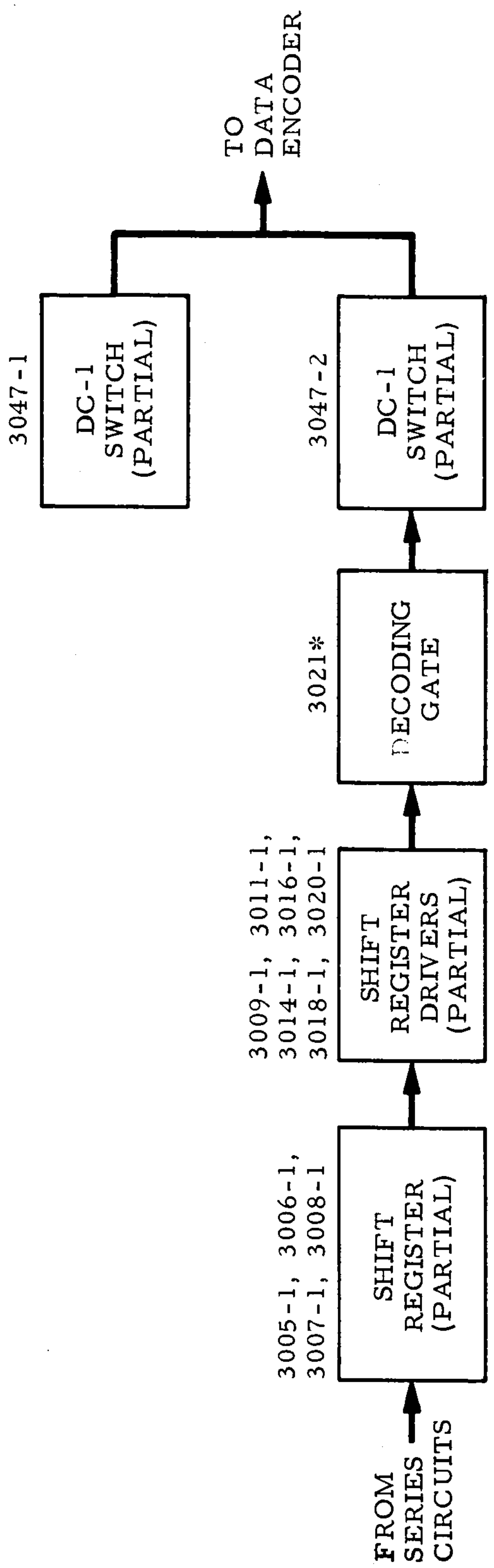


EXHIBIT 17 - DISCRETE COMMAND 1

Exhibit 18 shows the implementation of DC-2. The implication of the added unit A1 is that the active portion of the decoding gate can fail in a mode resulting in the same consequence as failure of 3054-1. Moreover, such a failure would also have as a consequence the inability to execute DC-2 to the data encoder. The new diagram illustrates these consequences.

With the exception of the unit numbers, Exhibit 19 is typical of DC-3, DC-9 through DC-12, DC-15 through DC-24, DC-26, and DC-27. The result of the change to the diagrammatic portrayal of these commands is that the decoding gate failures are now associated with more than one unit. However, since the added block is only involved in one path, it is not given a unit number and its failure rate is included with the adjoining series unit, i. e., 3055-1 in the illustrated diagram. The exact composition of this unit and the others will be indicated further in the following subsection and in Appendix A. It is to be noted that DC-3, DC-16, and DC-24 go to the data automation subsystem, DC-9 through DC-12 to the radio subsystem, DC-15 and DC-17 through DC-21 to the attitude control subsystem, DC-23 to the pyrotechnics subsystem, DC-26 to the power subsystem, and DC-27 to the central computer and sequencer.

Exhibits 20 and 21 now represent the implementation of DC-13 and DC-14, respectively. The implication of the added units, A2 and A3 is that the active portion of the decoding gate can fail in a mode resulting in the same consequence as failure of the -1 units. Note that the consequences of failure of these "A" units are different from A1 associated with DC-2. The reason for this is that failure of the "A" units has a different effect on IS switches than on IP switches. Actually, the consequences of failure of A2 and A3 are the same as for the unnumbered unit of Exhibit 19. However, both are common to more than one path and are therefore given a unit number to assure that they are not counted more than once. Exhibit 21 is also typical of DC-25 with the exception of the unit numbers and the fact that DC-25 goes to the power and pyrotechnics subsystems.

Exhibit 22 shows the implementation of the quantitative command circuits. There have been no changes in this diagram.

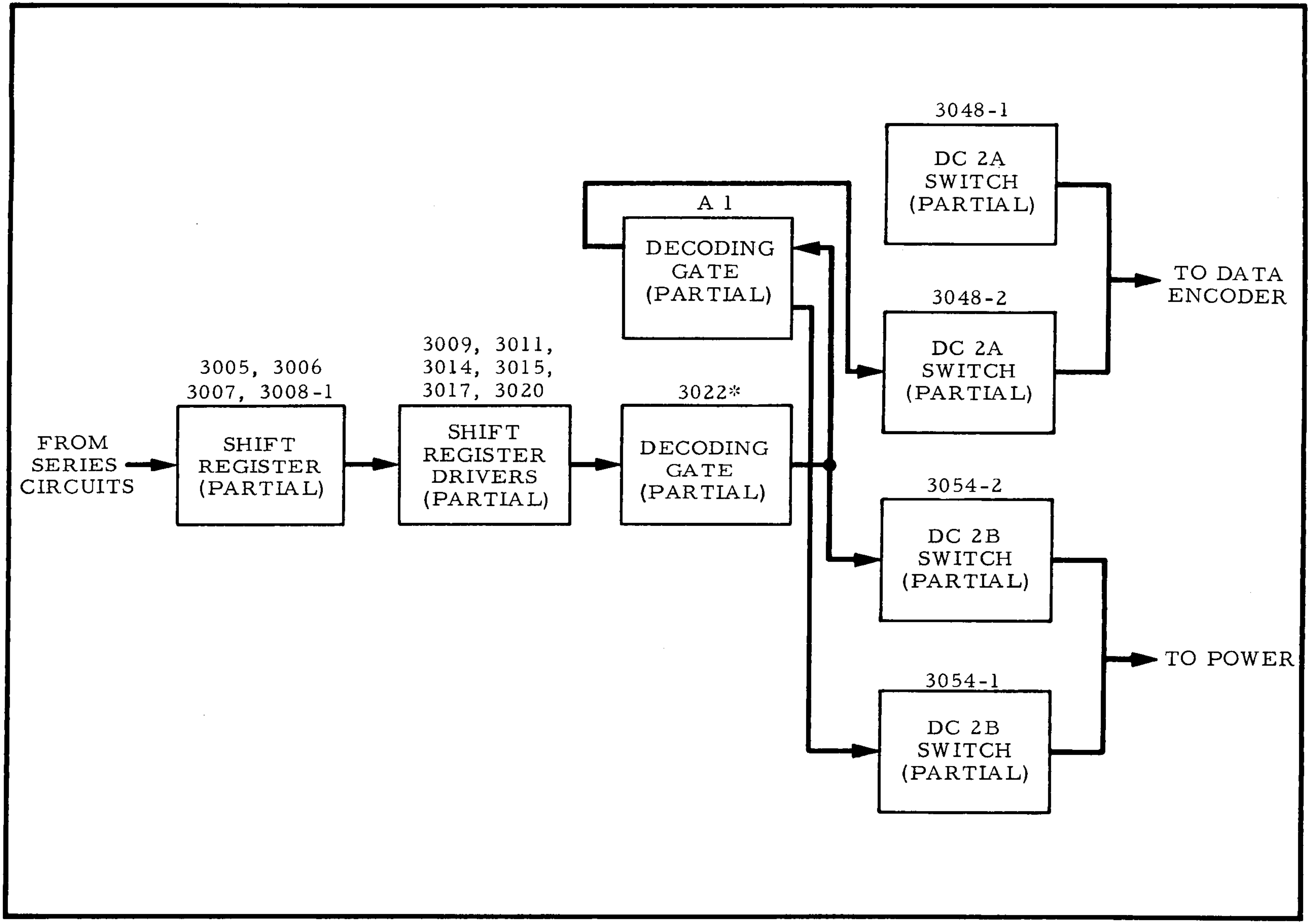


EXHIBIT 18 - DISCRETE COMMAND 2

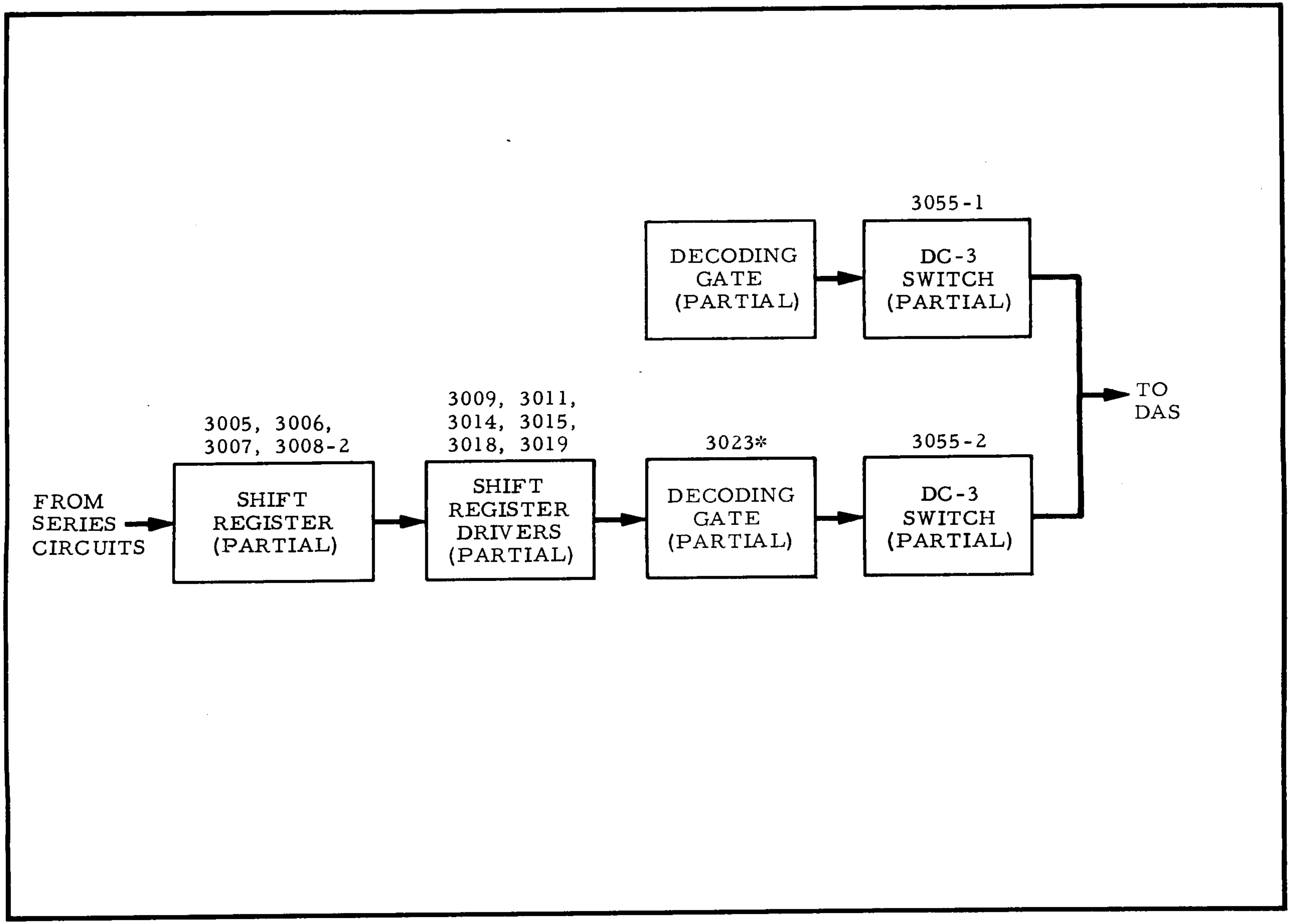


EXHIBIT 19 - DISCRETE COMMAND 3

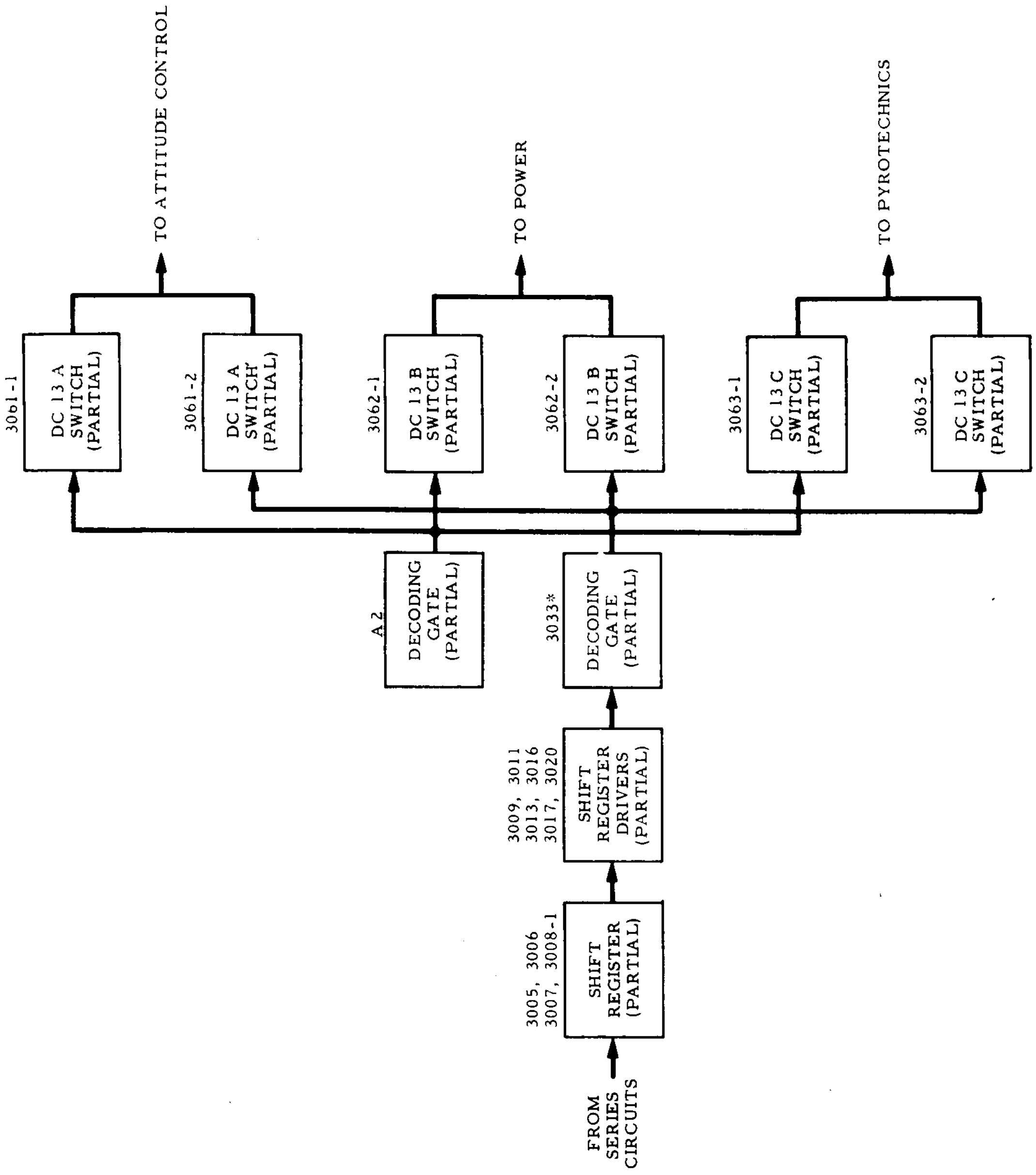


EXHIBIT 20 - DISCRETE COMMAND 13

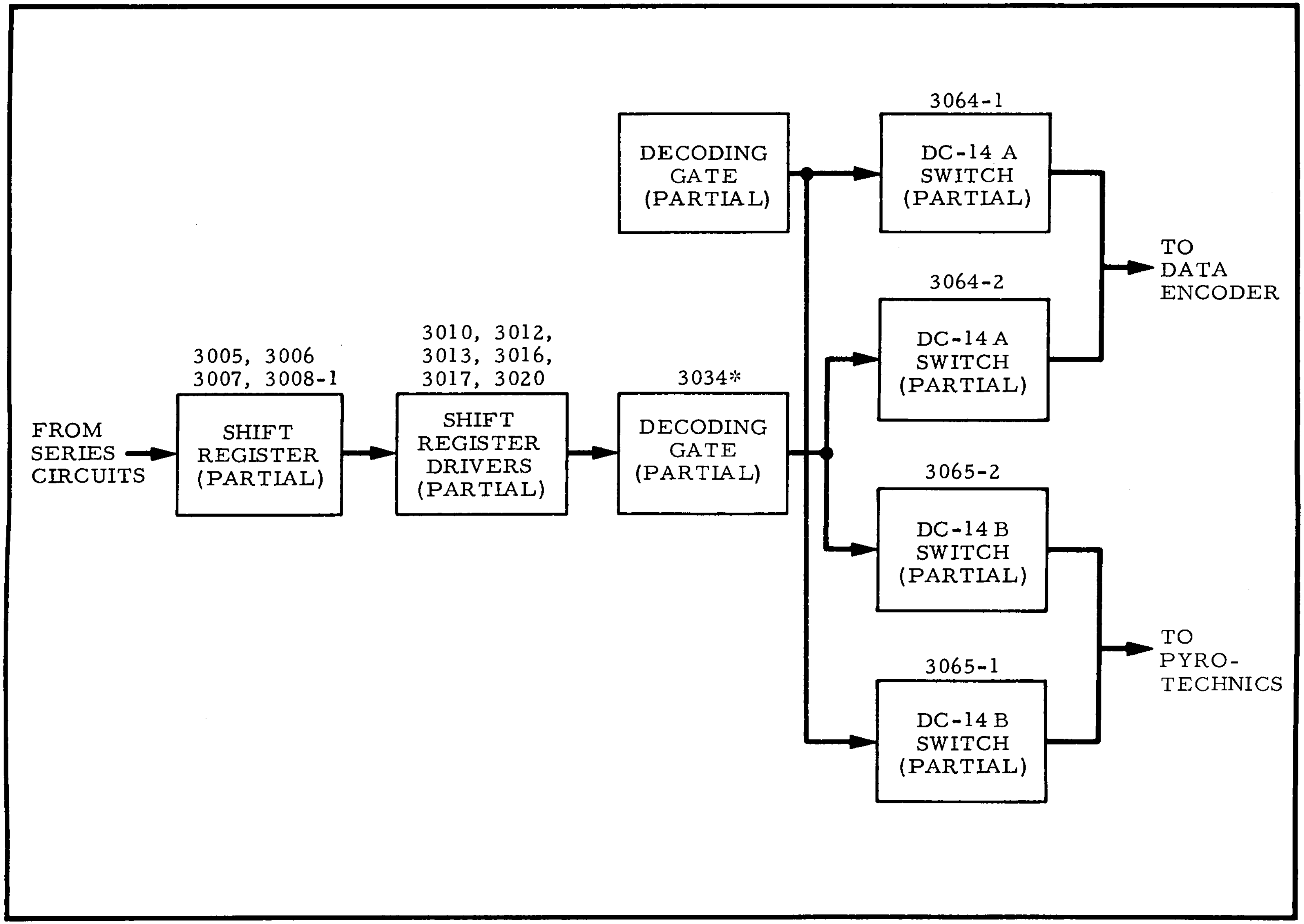


EXHIBIT 21 - DISCRETE COMMAND 14

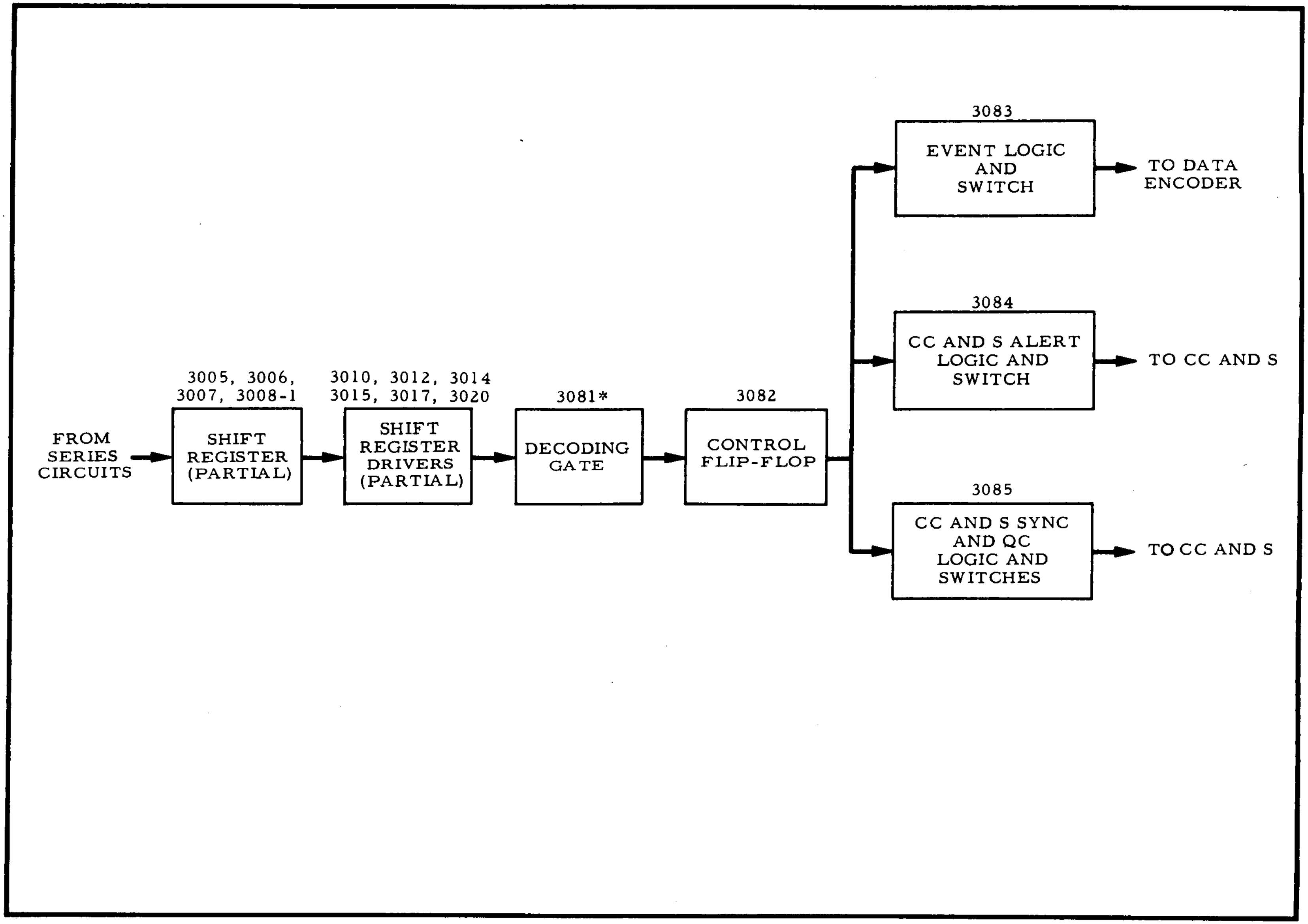


EXHIBIT 22 - QUANTITATIVE COMMAND

2. Unit Failure Rate Definition

As in the data encoder (and other subsystems as well), in order to calculate a truly representative failure rate for each unit of the command detector and decoder, it is necessary to accurately determine the component parts associated with it and whether any of the parts are used redundantly. No component redundancy was noted within the command subsystem. The detailed component part listing, including quantity and failure rate, can be found in Appendix A. It is the purpose of the remainder of this subsection to clarify exactly what the group of parts in Appendix A represents with respect to the documentation.

Referring to the diagrams and/or Appendix A where the units are numerically ordered, unit 3000 includes all of the command detector except the following circuits: one flip-flop, one inverter, one matched filter amplifier, one dump circuit, two capacitors, and one resistor. Schematic diagrams were used to determine the parts complement of the circuit modules used in the unit.

Unit 3001-1 concerns those command detector circuits listed in the preceding paragraph. These circuits are contained wholly within the sync channel portion of the detector. Their failure, by virtue of their digital nature, would cause either a continuous indication of in-lock or a continuous indication of out-of-lock, depending on the particular mode of failure. In general, the circuits used to implement this function have an equal probability of failing true or false (on or off). On a single failure basis, then, the unit has equal probability of failing with one continuous indication as with the other. Failure in-lock would only reduce the probability of executing a false command that had been received via the radio subsystem, and this is considered inconsequential. Failure out-of-lock would completely disable the command subsystem and would not allow the execution of any further commands. Therefore, only half of the total failure rate for the group of parts is included in unit 3001-1. (See interim report for further comments regarding this area.)

Unit 3002 contains all of the decoder program control circuits (except for the shift register) and their output amplifiers. The first two flip-flops of the shift register compose unit 3003.

A limited failure effects analysis was made on the IS and IP switches, and NAND decoding gates, and the shift register output amplifier-inverters. Certain failures cause these circuits to assume an "on" state while other failures cause them to assume an "off" state. The consequence of some failures is indeterminate. For want of a better alternative, the failure rate for the indeterminate occurrences has been divided evenly between the "on" and "off" states. The details of the calculations can be found in Appendix A.

Unit 3004 consists of an IS switch. Unit 3004-1 has a failure rate associated with it, where failure results in the consequence that there is a continuous in-lock indication to the data encoder (failure "on"). Unit 3004-2 has a failure rate associated with it where the consequence is no indication of in-lock (failure "off").

Units 3005 through 3008 and units 3009 through 3020 represent the last four flip-flop stages of the shift register and all of the shift register output driver-inverters, respectively. The reader is directed to subsection II. B. 2 of the interim report for a discussion of the significance of the dash numbers associated with these units. The driver-inverters are handled as described earlier in this subsection. For the flip-flops, it is assumed by symmetry that the failure rate "on" is equal to the failure rate "off," and that the sum of failures "on" and "off" constitutes all of the flip-flop failures.

In the interim report, it was shown that the reliability of a decoding gate is given as

$$R_{DG} = R_S \left[R_{DO}^6 + 6R_{DO}^5 (1-R_{DO}) \right] ,$$

where R_S is the reliability of components in series and R_{DO} is the probability that a diode does not fail open. Here $R_S = e^{-\lambda_s}$ and the failure rate, λ_s, of the series component is determined as described earlier in this section (by failure effects analysis) for units 3021* through 3046*. Appendix A provides the necessary details.

The units A1 through A4 represent the second failure mode of the decoding gates in some cases. In the remainder of the cases where this failure mode is of consequence, the failure rate is combined with the -1 portion of the switches as described in subsection III. C. 1. Thus, the failure rates for the following units are a combination of failure rates associated with the decoding gate and the switch as determined from the failure effects analysis: 3055-1, 3057-1 through 3060-1, 3066-1 through 3074-1, 3077-1, and 3078-1. The -2 portion (failure "off") of these units concerns switch failure "off" only.

Units 3047 through 3054, 3061 through 3065, 3075, and 3076, by means of their respective dash numbers, include only the failure rates for the switch failing "on" (-1) or "off" (-2) as described previously and also as indicated in Appendix A.

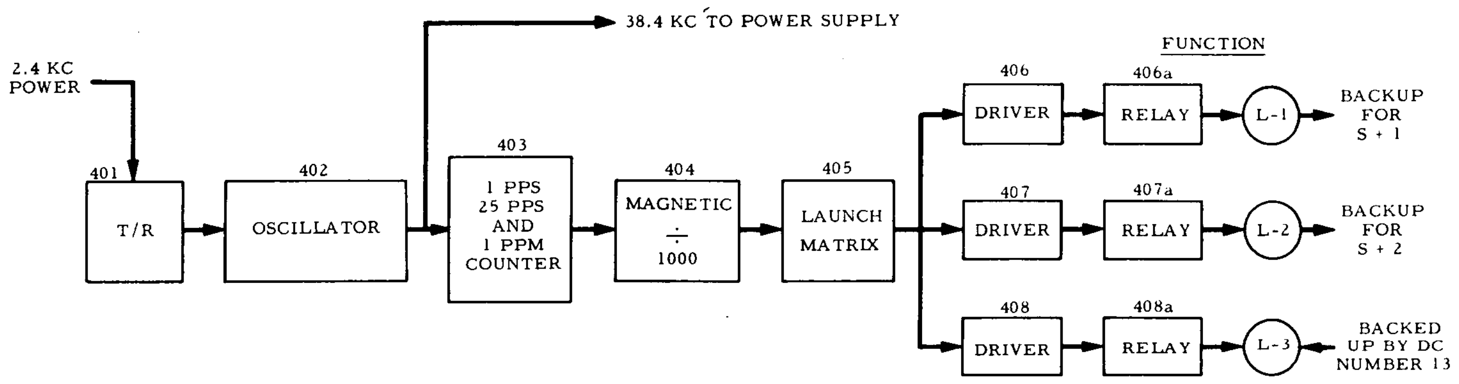
Unit 3079 is composed of the transformer-rectifier, as titled, while unit 3080 is composed of one NAND gate and one switch.

Unit 3081 is a complete decoding gate, unit 3082 is a single flip-flop, and units 3083 through 3085 include two NAND's and a switch, one NAND and a switch, and two NAND's and two switches, respectively.

D. Central Computer and Sequencer

The representation of the CC and S has not been altered significantly from that which was presented in the interim report. Exhibit 23 shows the configuration of the parts of the CC and S which are used during launch and acquisition. During this time, the CC and S functions principally as a clock with specific times being decoded by the launch matrix shown in unit 405. The three launch commands, L-1, L-2, and L-3, are derived from this matrix.

Prior to each maneuver, the CC and S performs the function of storing the quantitative commands. Exhibit 24 depicts the manner in which these commands are routed into the CC and S and are decoded and registered. Equipment concerned with the registration of the pitch command only has been separated into units 412 and 413 as shown. Similarly, units 414 and 415 comprise equipment which is concerned with the roll command only. In a comparable fashion, unit 416 singles out that equipment which is responsible for the proper registration of the velocity increment command. Separate reliability calculations for each of these



TIME (T = TIME OF LIFTOFF)	CC AND S EVENT	OPERATION	BACKED UP BY
T + 50 MIN	L - 1	DEPLOY SOLAR PANELS AND SOLAR PRESSURE STABILIZATION SYSTEM	BACKUP FOR S + 1
T + 52 MIN	L - 2	TURN ON ATTITUDE CONTROL	BACKUP FOR S + 2
T + 16-2/3 HOURS	L - 3	TURN ON SOLAR PRESSURE STABILIZATION SYSTEM	DC NUMBER 13
CONTINUOUS		38.4 SYNC. TO POWER SUPPLY	NONE

EXHIBIT 23 - CC AND S DURING LAUNCH AND ACQUISITION

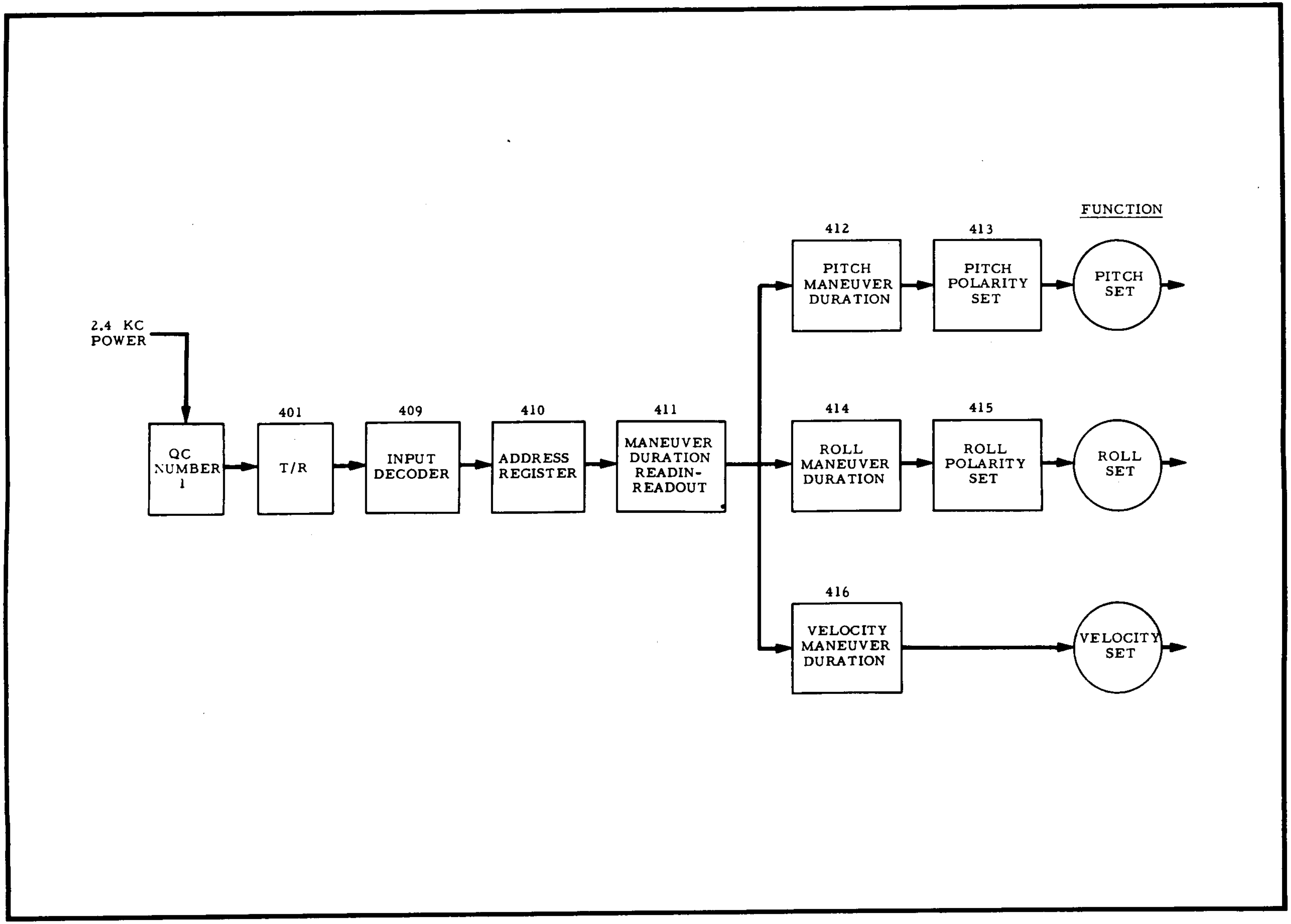


EXHIBIT 24 - CC AND S DURING DATA INSERTION

data insertion functions are not of interest inasmuch as all of them must be operable if a successful maneuver is to be performed.

Execution of each of the maneuvers demands a large complement of CC and S parts as illustrated in Exhibit 25. A number of parallel functions must be served in order to generate the sequence of signals which are utilized by the other subsystems during performance of a maneuver. These signals are identified as M-1 through M-7 and their complements, and consist of relay closures. The basic CC and S clock is indicated by the presence of units 402 and 403, and a special maneuver clock is shown in unit 417.

The principal change in this representation is in the elimination of unit 423, which has been previously shown in series with units 424 and 444. Unit 423 was labeled "Pitch and Roll Start Duration Logic" and an examination of the circuit diagrams reveals that this logic was actually incorporated into other units. For the most part, all of these signals and their complements are required for a successful maneuver; however, from the standpoint of the total maneuver sequence, signals $\overline{\text{M-1}}$ and $\overline{\text{M-2}}$ and the turnoff of the maneuver clock are required only after the second maneuver.

For the major part of its operating time, the CC and S will be configured as in Exhibit 26. Clock functions are provided by the oscillator 402 and the countdown circuits shown in units 403, 404, and 425. The unique states of the clock are decoded by the master time matrix, unit 426, and signals from the matrix are converted to relay closures as indicated by signals MT-1 through MT-6. A cyclic signal, denoted as CY-1, is derived every 33.3 hours directly from the countdown circuitry. This cyclic signal had previously been shown as emanating from the master time matrix, and the representation has been altered to correct this misinterpretation.

The configuration of the CC and S does not change during the encounter phase; however, the particular signals associated with this phase are shown separately in Exhibit 27. These signals are denoted as MT-7, MT-8, and MT-9. They function to control the encounter science and data recording. As with most of the master time signals, these CC and S events consist of relay closures.

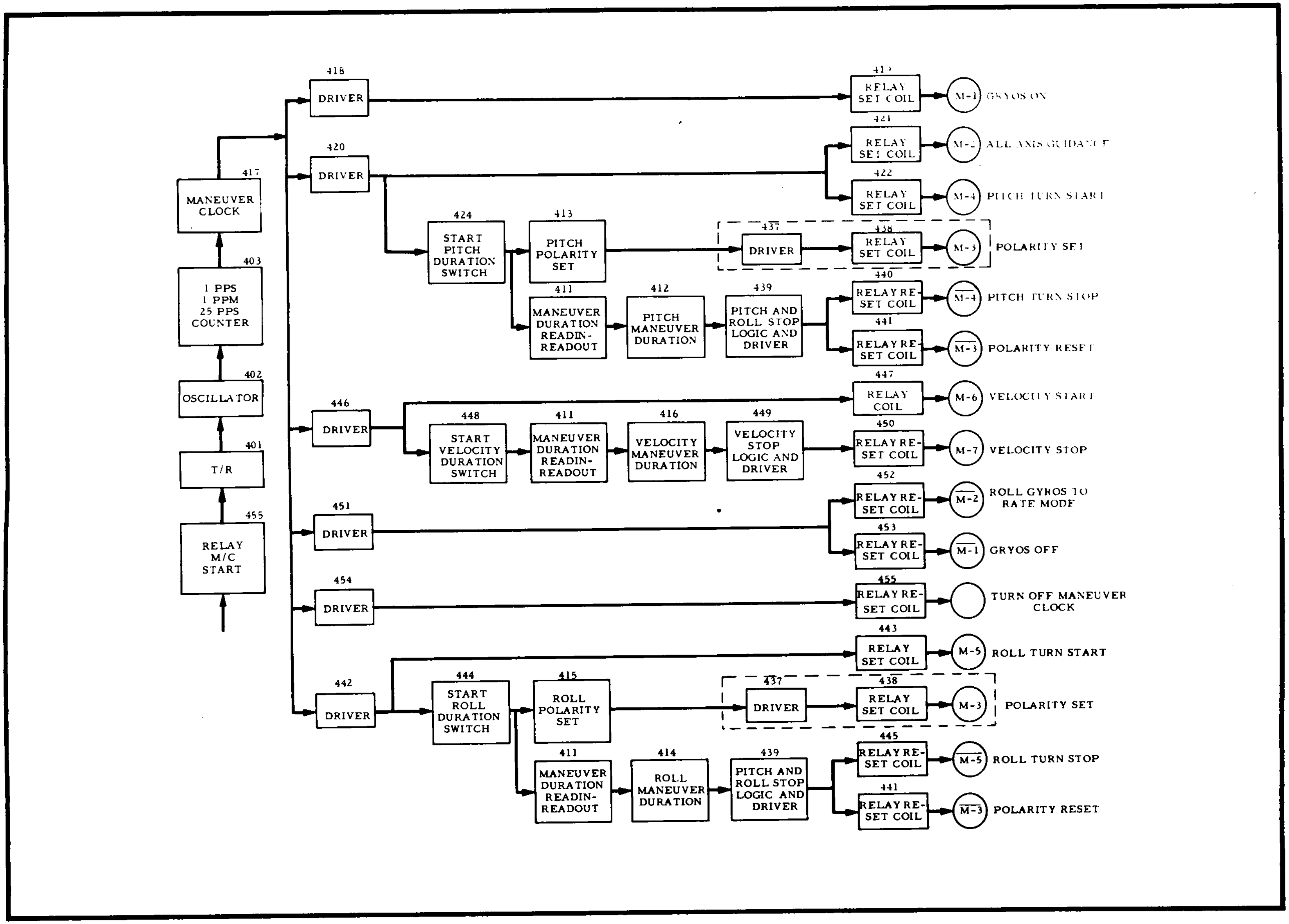
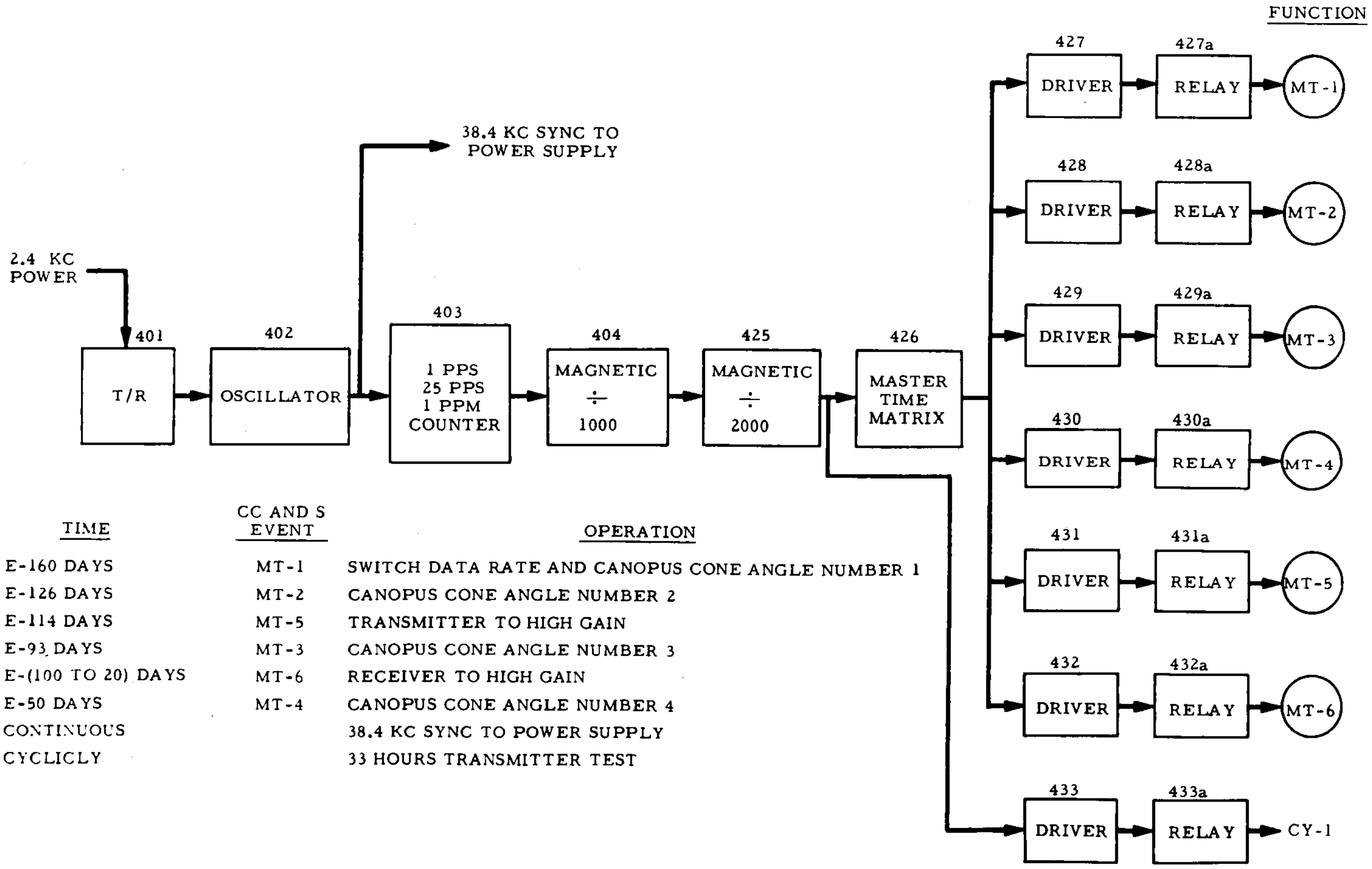
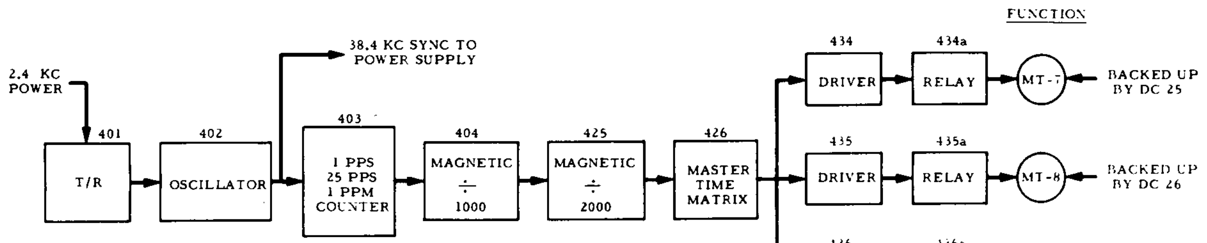


EXHIBIT 25 - CC AND S DURING MANEUVER



TIME	CC AND S EVENT	OPERATION
E-160 DAYS	MT-1	SWITCH DATA RATE AND CANOPUS CONE ANGLE NUMBER 1
E-126 DAYS	MT-2	CANOPUS CONE ANGLE NUMBER 2
E-114 DAYS	MT-5	TRANSMITTER TO HIGH GAIN
E-93 DAYS	MT-3	CANOPUS CONE ANGLE NUMBER 3
E-(100 TO 20) DAYS	MT-6	RECEIVER TO HIGH GAIN
E-50 DAYS	MT-4	CANOPUS CONE ANGLE NUMBER 4
CONTINUOUS		38.4 KC SYNC TO POWER SUPPLY
CYCLICLY		33 HOURS TRANSMITTER TEST

EXHIBIT 26 - CC AND S DURING CRUISE



TIME	CC AND S EVENT	OPERATION	BACKED UP BY
E-6-2/3 HOURS	MT-7	ENCOUNTER SCIENCE ON REMOVE SCIENCE COVER	DC 25
E - 6-2/3 HOURS	MT-8	ENCOUNTER SCIENCE OFF	DC 26
E - 13-1/3 HOURS	MT-9	SWITCH TO DATA MODE NUMBER 4 (POST ENCOUNTER)	DC 4
CONTINUOUS		38.4 KC SYNC TO POWER SUPPLY	NONE

EXHIBIT 27 - CC AND S DURING ENCOUNTER

E. Power Supply

Alterations in the implementation of the power supply have required a number of revisions in the reliability block diagrams that have been used to represent this subsystem. The power supply, as configured for the acquisition and maneuver phases, now is as illustrated in Exhibit 28.

The illumination of the solar panels is potentially insufficient during maneuvers, and the battery, unit 502, must be relied upon as the principal source of energy. The battery charger, unit 503, is not actually required during the acquisition and maneuver phases; however, it is shown in the diagram to indicate that it must have been operable during a prior phase if an adequately charged battery is to be available. This unit, 503, also serves as a load sharing protector, but this function is considered to be unnecessary until the encounter phase.

Units 516 and 517 have been added to the diagram in order to make more explicit the representation of the synchronizing source. The crystal oscillator within the CC and S provides the primary synchronizing signal at 38.4 kc/s but a redundant L-C oscillator within the power supply can take over this function with no serious degradation.

Unit 505 comprises the countdown circuitry which generates the basic 2.4-kc/s spacecraft frequency. Despite its all-inclusive title, unit 504 contains only those circuits which are common to the distribution and switching functions or which are responsible for the control of other units within the power supply itself.

The use of two booster regulators was recognized in previous representations of the power supply; however, no redundancy had existed between these regulators during the maneuver or acquisition phases. A change in the design of booster regulator number 2 now makes it possible to introduce unit 515 which indicates a one-way redundancy whereby booster regulator number 2 can take over the main inverter loads in the event of a failure of regulator number 1. The redundancy is one-way in the sense that regulator number 1 is not capable of supplying the maneuver loads.

During the cruise and post-encounter phases, the spacecraft will normally be oriented so that the solar panels will be illuminated by the

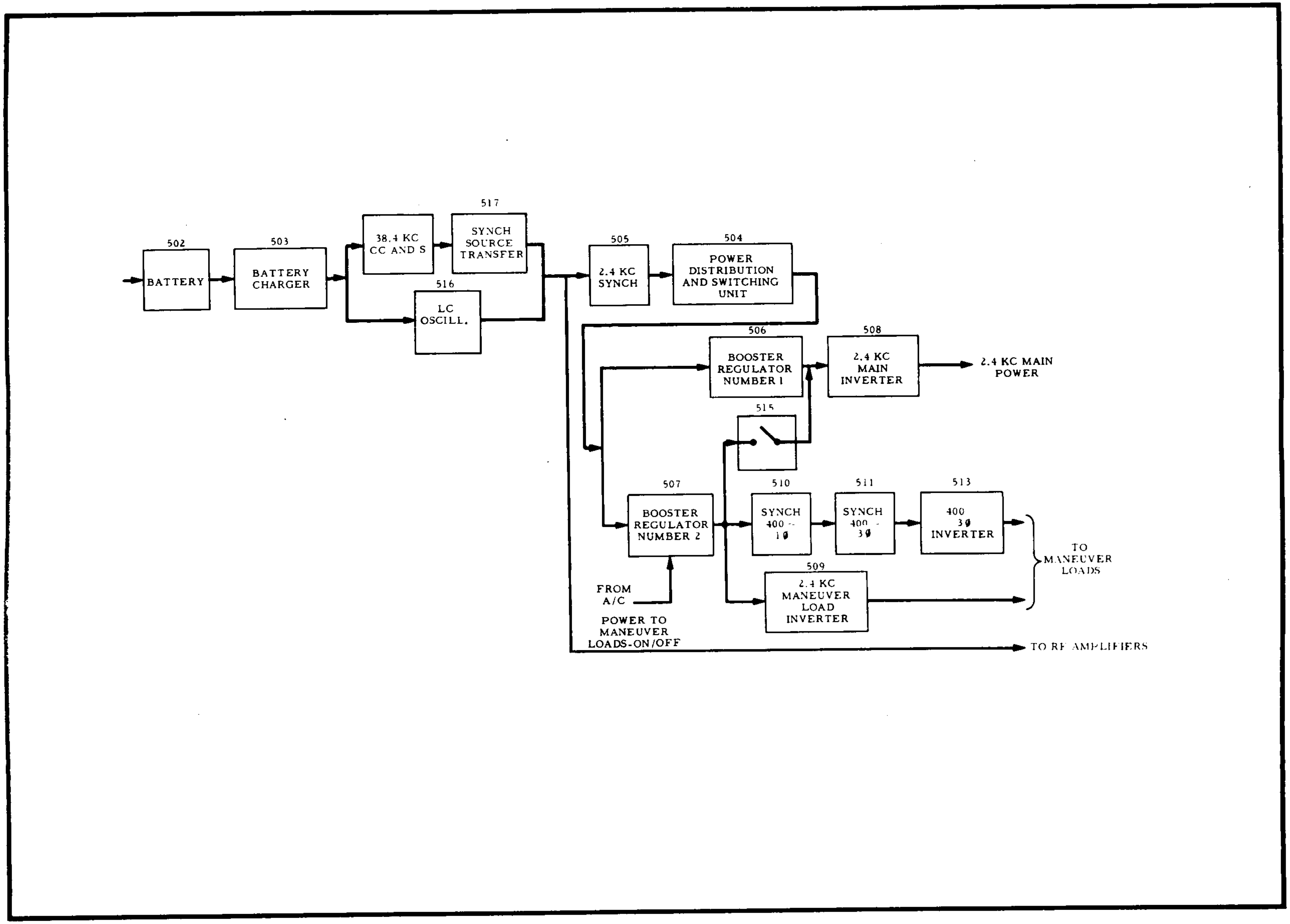


EXHIBIT 28 - POWER SUPPLY, LAUNCH THROUGH ACQUISITION AND MANEUVER

sun. Thus, unit 501 is shown as the primary source of energy in Exhibit 29. The principal function of the power supply during these extended periods is to provide a 2.4-kc/s source of power for all spacecraft loads. Hence, it will be noted from the diagram that operation of the main inverter, unit 508, is the principal requirement for reliability.

Since maneuver loads are not normally anticipated during cruise, the number 2 booster regulator, unit 507, becomes switchably redundant to booster regulator number 1, unit 506. Switching is accomplished as before through unit 515. The standby sychronizing source is shown explicitly as unit 516, and the frequency division function again is incorporated in unit 505. Although the main inverter is capable of free running, dependence on a synchronization signal is indicated inasmuch as the lack of degradation associated with uncontrolled frequency has not been satisfactorily demonstrated.

Unit 950 represents the probability that sun orientation will not be lost due to a noncatastrophic impact on the spacecraft. Should such an impact occur, reacquisition must take place, and this would require the use of the maneuver inverter and other units such as the battery.

The added load on the power supply during the encounter phase introduces the possibility that the solar panels will not be able to supply the required energy. In such a case the battery would be required to sustain spacecraft power. This possibility would evidently arise if the solar cells had suffered degradation due to such effects as proton bombardment in the earlier phases of the mission. The probability that solar panel degradation will not occur is indicated in Exhibit 30 by unit 951, and the battery and its share protector are shown as redundant to this probability. In the previous representations of the power supply, the share protector functioned as a series unit; however, it is now made clear that this unit, 503, would be needed only in the event that the battery was called upon.

The addition of units 516 and 517 to provide redundant synchronization sources was noted above, and they have been added to this diagram. One further change in the analysis of the power supply during the encounter phase is indicated by the solid line around unit 510. This represents a decision that the 400-cycle synchronization source is not absolutely

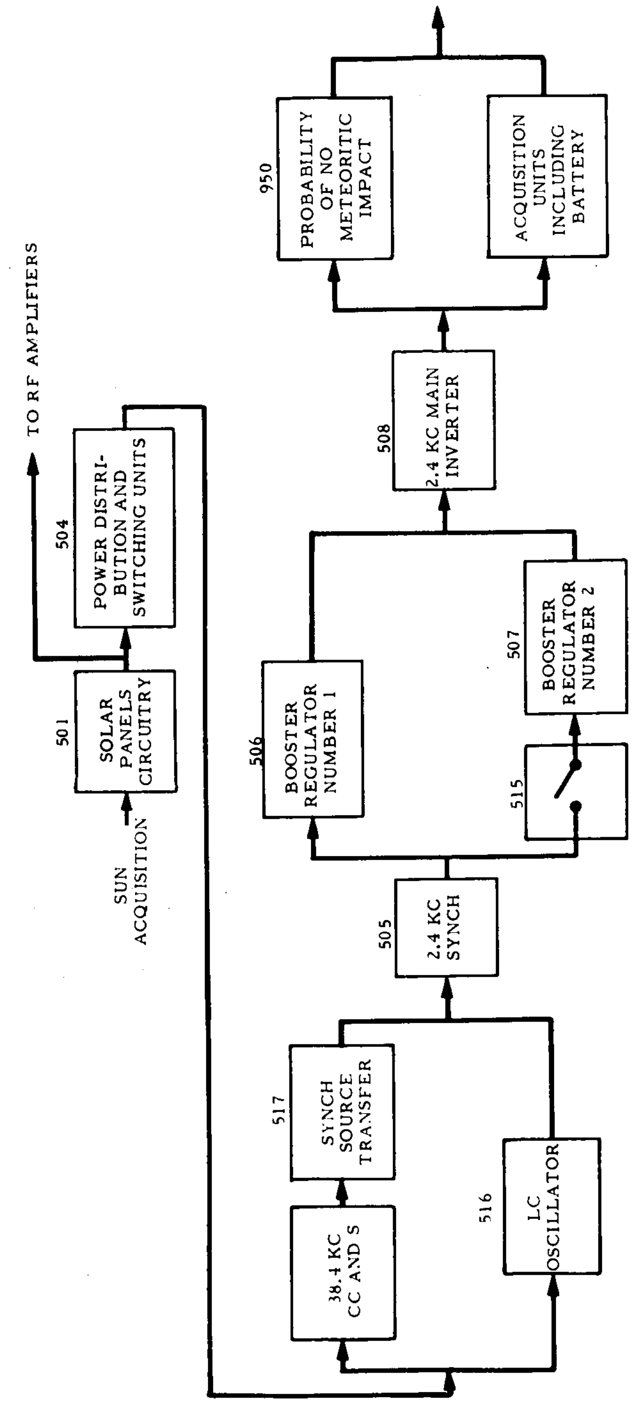


EXHIBIT 29 - POWER SUPPLY, CRUISE AND POST-ENCOUNTER

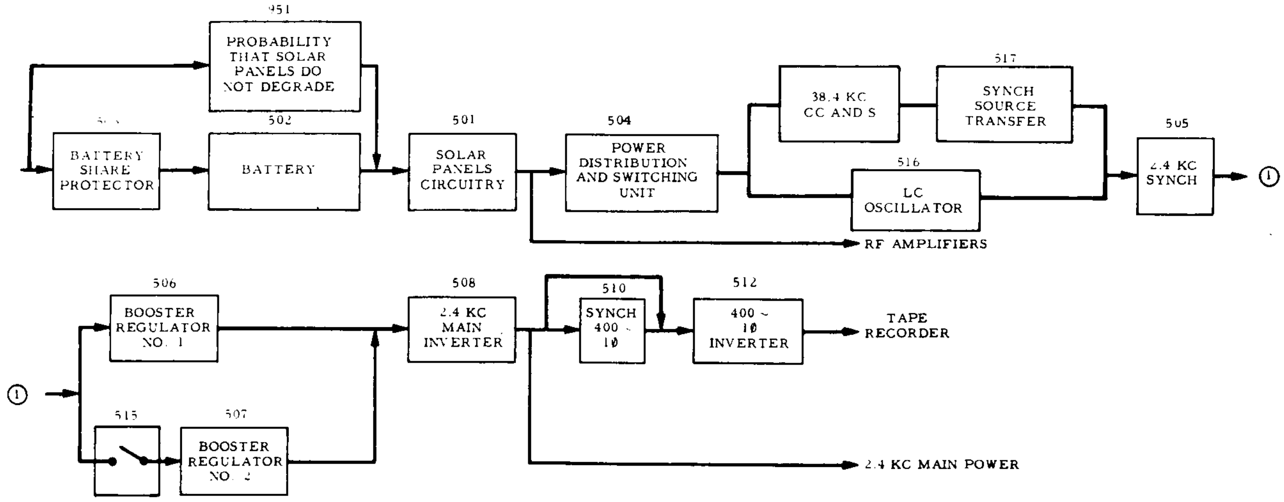


EXHIBIT 30 - POWER SUPPLY, ENCOUNTER

necessary for the operation of the single-phase inverter, and that no degradation would ensue in the event of a failure of this source.

F. Attitude Control

The initial operation of the attitude control system is the acquisition of the sun, and the connection of reliability units for this function is shown in Exhibit 31. Unit 602 now consists of the cadmium sulphide sun sensors only, and does not contain any electronics as previously indicated. Unit 604 has been eliminated and unit 605 has been assigned to the transformer rectifier within the attitude control logic. Unit 605 had previously been denoted as the Canopus acquisition gate and placed in series with the gyros; however, it is now clear that gyro control during the sun acquisition phase will not be dependent upon the Canopus acquisition gate.

It was previously decided that gyro rate feedback would be essential to the normal mode of stabilization during the acquisition phase. Other possible forms of stabilization included the use of special sun sensors which would reset the derived rate stabilization integrator; this had been shown as a degraded mode of sun acquisition in view of the longer time required. It has now been determined that derived rate or switching amplifier compensation, even without the action of the reset sun sensors, will be considered satisfactory for normal operation of the spacecraft. Accordingly, unit 610 is shown as completely redundant to the gyro stabilization system. Units 611, 612, and 613 represent the cold gas valves in the pitch and yaw axes. These units, with their associated switching amplifiers, are, of course, required for the application of control torques about these axes.

The sun tracking system is illustrated in Exhibit 32. The principal changes which have been made in this representation are concerned with the cruise sun sensors. These sun sensors, shown as unit 614, had previously been associated with a certain amount of unspecified electronic circuitry. This circuitry has now been explicitly defined as consisting of a zener diode regulator. Unit 605 replaces unit 604 and represents the transformer rectifier contained within the attitude control logic. The only further change in this reliability block diagram is the elimination of

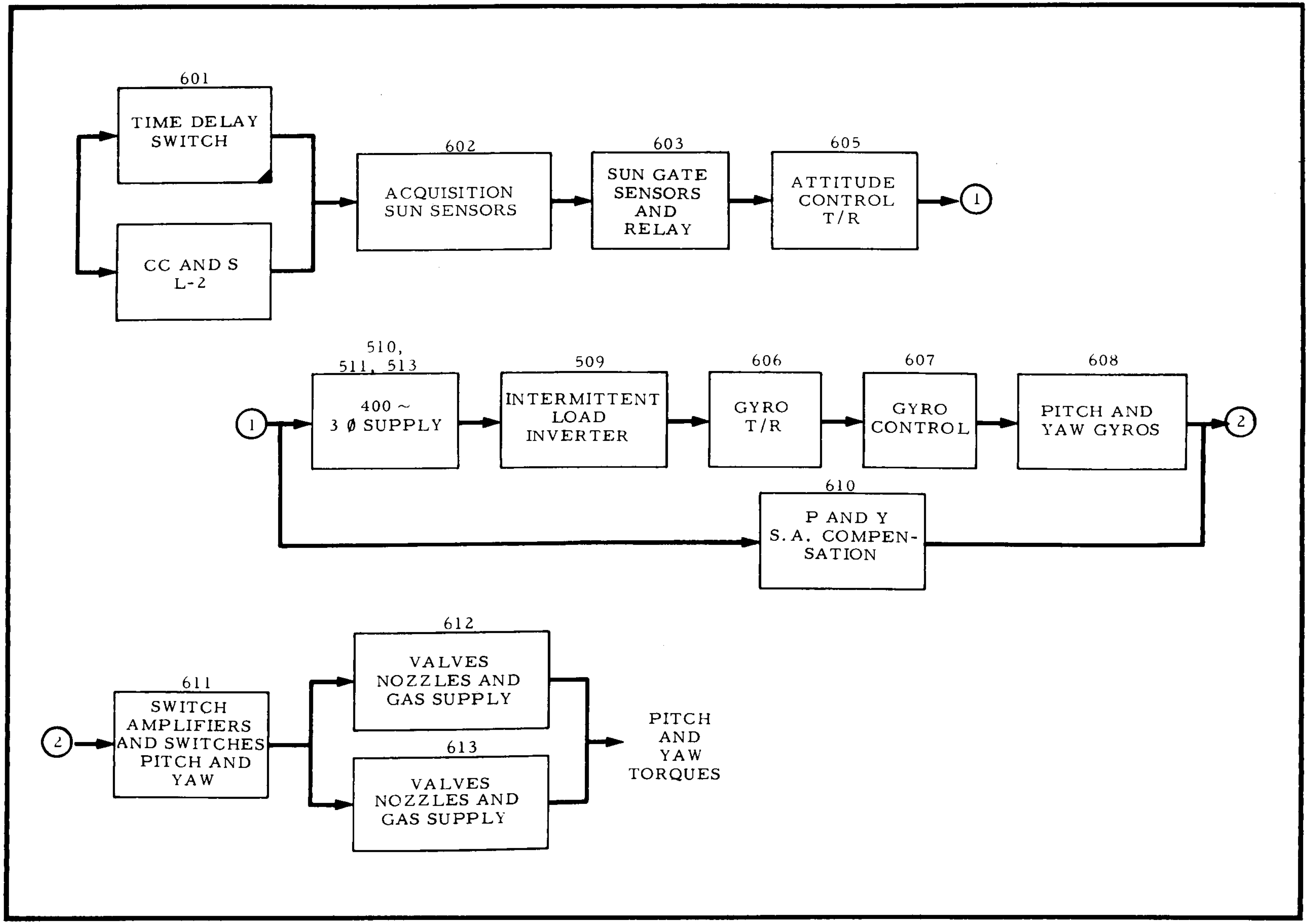
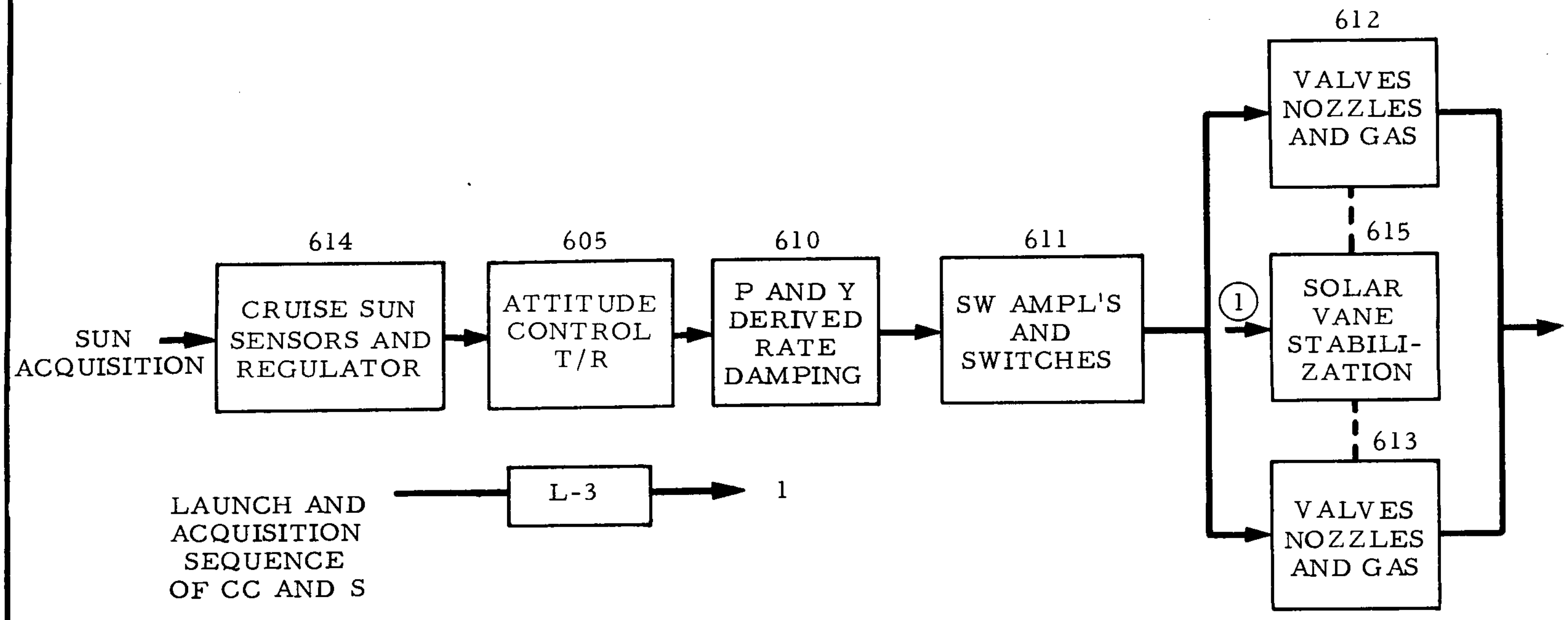


EXHIBIT 31 - SUN ACQUISITION



NOTE: UNIT 615 DOES NOT APPEAR IN SUN TRACKING MODEL PRIOR TO $t = t_4$

EXHIBIT 32 - SUN TRACKING

discrete command 13, which had been shown as redundant to CC and S signal L-3. Although this command is indeed redundant to signal L-3, the likelihood of its usage is considered negligible, since its primary function is to inhibit the maneuver.

Unit 615, the solar vane stabilization, has not previously been defined in detail. This is accomplished to some extent in Exhibit 33, which illustrates unit 615e, consisting of the activation relay necessary to energize this stabilization system. The system is divided between the pitch and yaw axes by separating it into four units, namely 616a, b, c, and d. These units are identical and each consists of a stepping motor, associated gear train, and the necessary control electronics. It will be observed that they have been arranged in redundant pairs, which illustrates that only one solar vane in each axis is required for stabilization.

The duty cycle on these main control units has been investigated, and it has been estimated that complete stabilization will have been achieved after approximately 1,000 operations of each stepping motor. In turn, it is estimated that this will have occurred after approximately 333 hours following the final midcourse maneuver. During this time, the gear motors are considered to be operating at a 5 percent duty cycle, and following this period it is assumed that no significant operations take place. On the other hand, it is assumed that the associated electronics must remain operable throughout the entire mission if a unit failure is to be avoided.

The ultimate effect of this stabilization system is to reduce the duty cycle on the pitch and yaw cold gas valves. Without the solar vane stabilization system, a duty cycle of four operations per hour per valve is assumed throughout the cruise phase of the mission. With solar vane stabilization operable, the valve duty cycle is reduced to three operations per hour as an average for the first 333 hours following maneuver. After this time, no further operations of the cold gas valves are anticipated. It should be noted that this solar vane stabilization applies only to the pitch and yaw axes.

Exhibit 34 shows the reliability diagram for the star acquisition function. This does not appear to be essentially different from that which

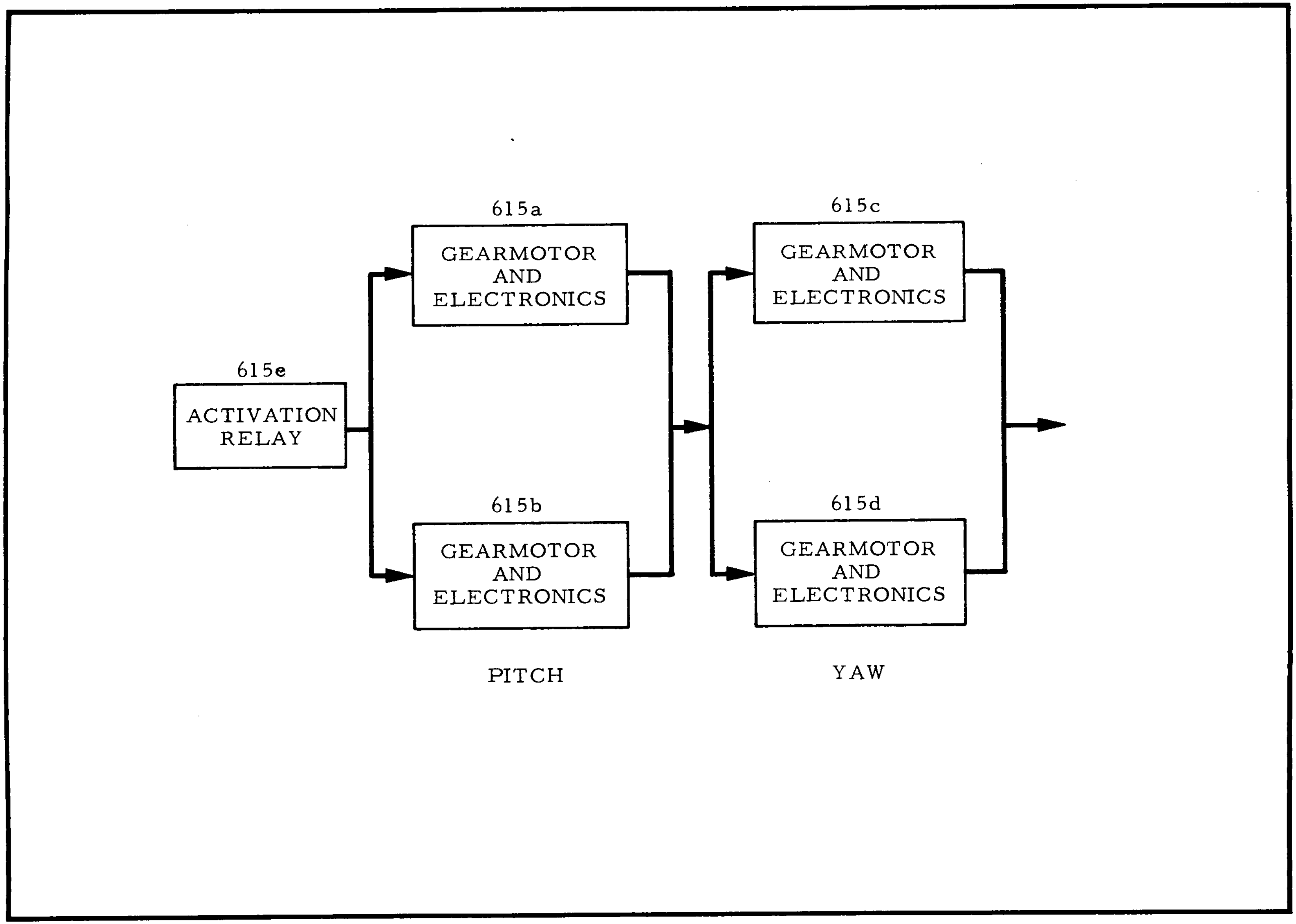


EXHIBIT 33 - SOLAR VANE STABILIZATION

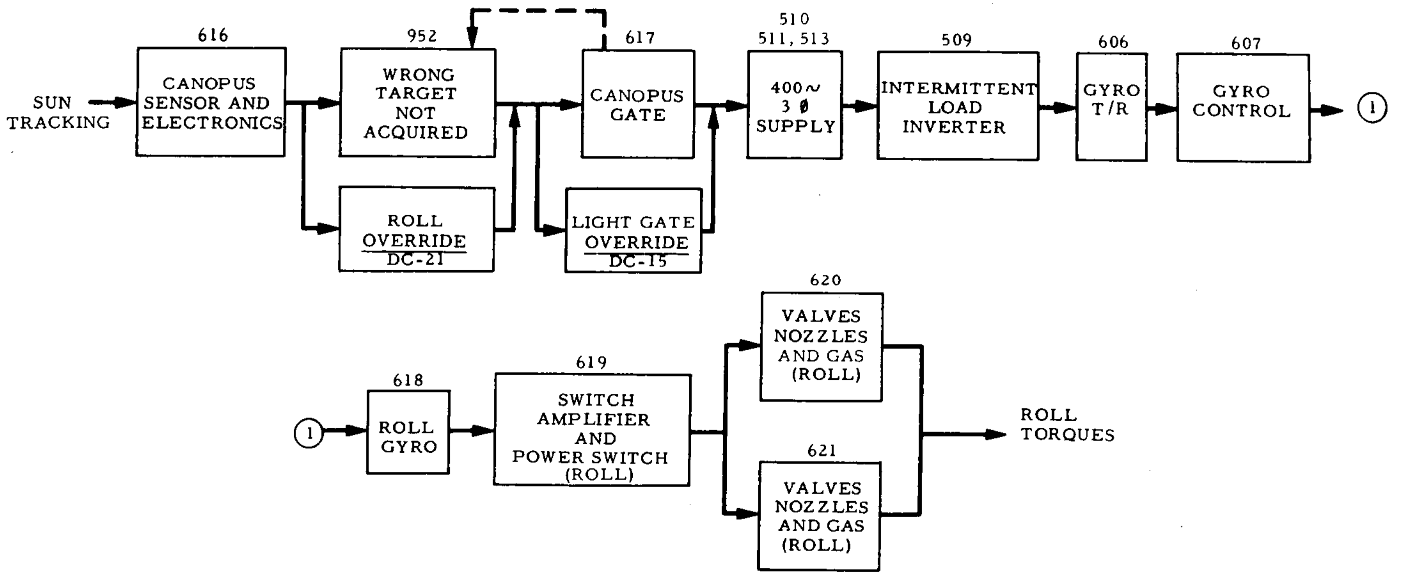


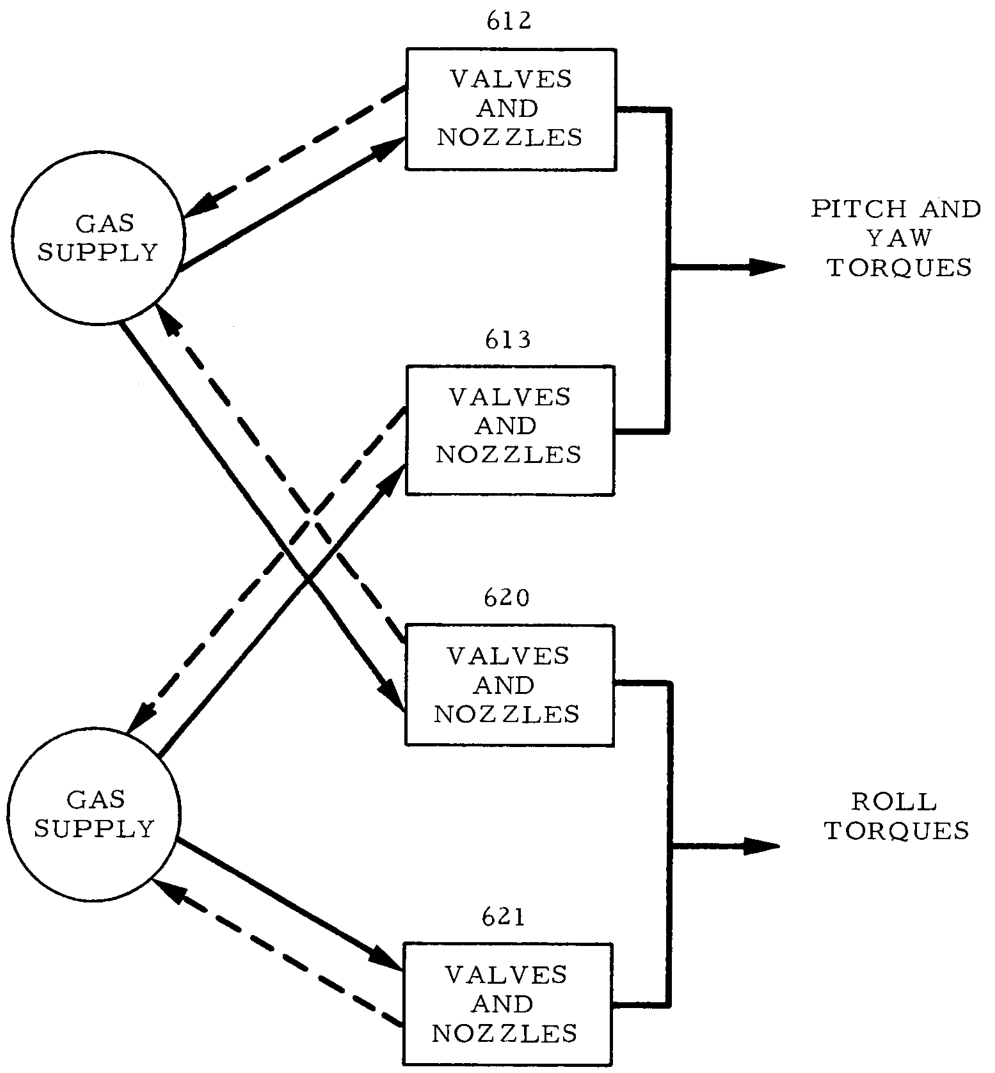
EXHIBIT 34 - STAR ACQUISITION

was presented in the interim report except that unit 605, the Canopus acquisition gate, has been eliminated. Unit 617, previously designated as the light gate, has now been retitled Canopus gate. Unit 617 now contains all circuitry which is concerned with preventing acquisition of targets outside the specified brightness range, as well as the logic which switches the roll control from a search mode to an acquired mode. Although command DC-15 has been designated as the light gate override, a study of its function indicates that it causes the logic to become fixed in the acquired mode. Thus, the brightness gate has no function when DC-15 has been exercised and the only way a search mode can be instituted is by the exercising of command DC-21, the roll override.

It is important to note that the probability of acquiring the correct target, as indicated by unit 952, becomes effectively zero if unit 617 is not operating. In other words, without an operable brightness gate and with the logic fixed in the acquisition mode, it is almost certain that some target other than Canopus will be acquired. Thus, it can be seen that the exercising of command DC-15 will require that command DC-21 be available until Canopus is acquired.

A further change in the star acquisition diagram is the addition of unit 510 in the makeup of the 400-cycle three-phase supply. This is a synchronization source which must be operable for successful operation of this supply. It should also be noted that rate stabilization derived from the roll gyro is essential to the proper acquisition of Canopus. Roll torques are developed by the redundant valves and nozzles, units 620 and 621, which are activated by the roll switching amplifier, unit 619.

An additional failure mode has been introduced into the model by recognizing the cross coupling which exists between the roll valves and the pitch and yaw valves. This coupling is illustrated in Exhibit 35, where it is shown that common gas supplies are used for all three axes. Should any valve fail in the open condition, it will exhaust its associated gas supply and destroy the redundancy which exists in all three axes. The previous representation had treated the roll control system as independent of the pitch and yaw control system.



Broken lines indicate that gas supply fails if any associated valve fails open

EXHIBIT 35 - FAILURE MODE COUPLING IN COLD GAS SUPPLIES

Exhibit 36 depicts the unit configuration required to maintain roll orientation, and it will be noted that alternative operating paths are allowed for.

In the primary path, unit 617 (previously the light gate) now is described as the Canopus gate as explained above. Unit 627 has been added to account for those portions of the Canopus sensor electronics which are concerned solely with the updating of the cone angle. This unit includes the relay ring counter and associated driving circuits.

In the analysis which is part of this study, the inertial roll control operating path is considered as degraded only in the sense that it will not be called upon until 50 hours before encounter. Given that all equipment operates as designed, inertial control is not considered to be inferior to automatic star tracking as a means of maintaining roll orientation. It is clear, however, that this alternative scheme is less reliable and involves more equipment. For this reason, it has been arbitrarily excluded as an operating means until 50 hours before encounter. It is assumed that the operating path designated as free roll would be followed in the event of a failure of the automatic star tracking system until 50 hours prior to encounter. In the free roll mode, it is assumed that science measurements are of no value, but that engineering measurements continue to carry full value. The possible side effects which might arise because of a free rolling spacecraft, such as upset in the thermal balance or interactions with the pitch and yaw control, have not been considered.

G. Trajectory Corrections

Nearly all of the spacecraft subsystems are required for the execution of a successful midcourse maneuver; however, the attitude control subsystem appears to be most closely tied in with this operation. The midcourse maneuver reliability diagram shown in Exhibit 37 has not been altered significantly from that which was presented in the interim report. It had been assumed that command DC-14 might have to be executed in order to remove the maneuver inhibit; however, it was learned that this is not likely to be true for a normal maneuver.

The more important attitude control units required for the maneuver are shown in the large box in the exhibit. Other units, such as those

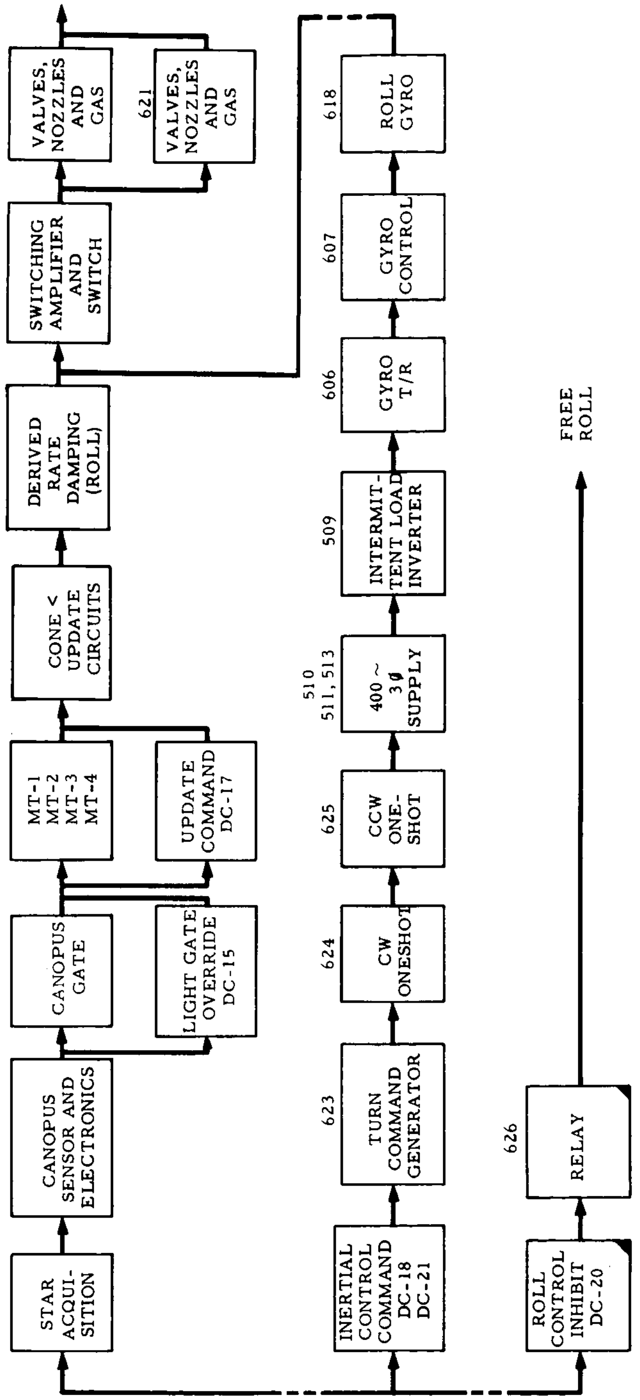


EXHIBIT 36 - STAR TRACKING

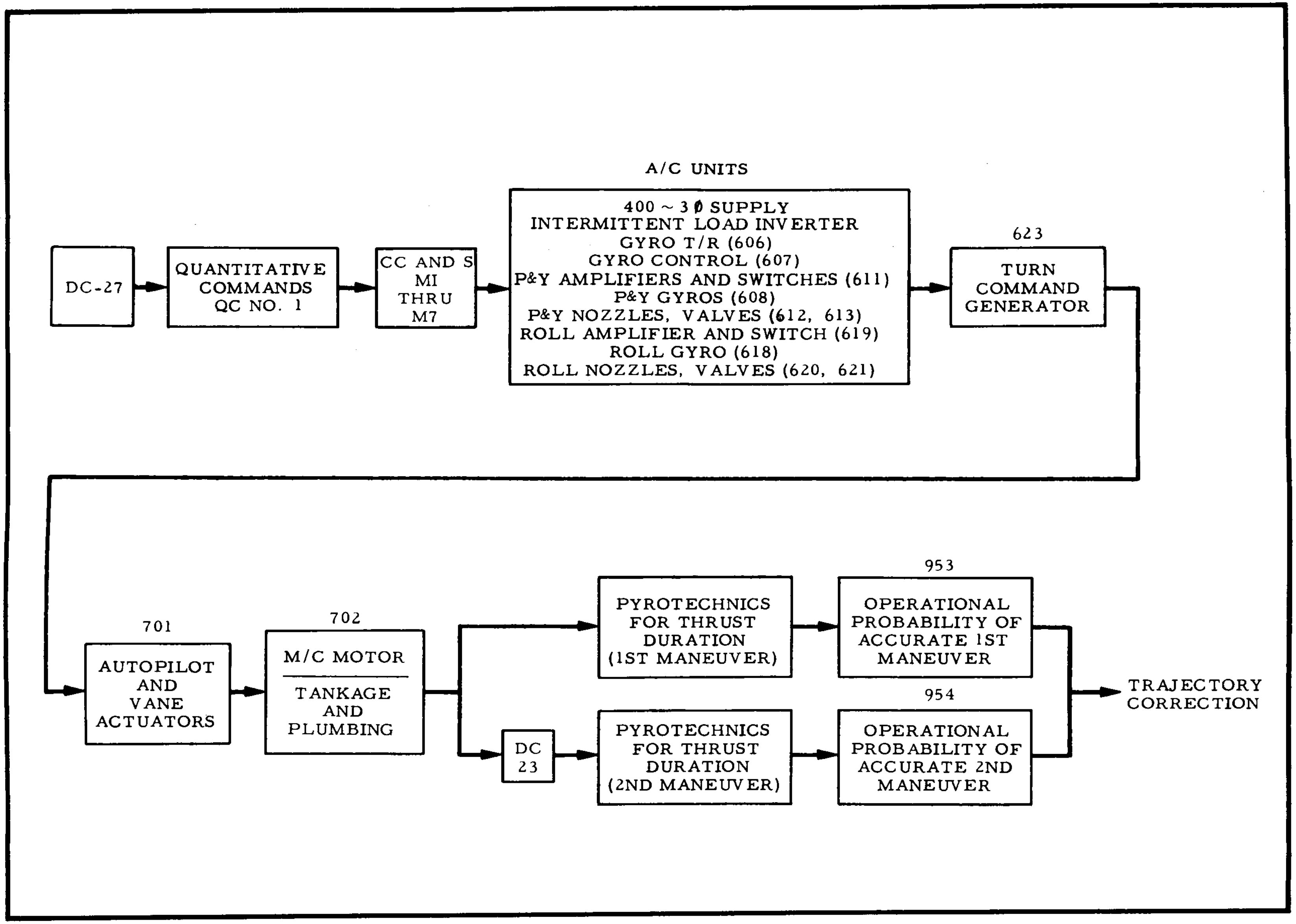


EXHIBIT 37 - MIDCOURSE MANEUVER

from the command subsystem and the central computer and sequencer, together with the turn command generator, are shown in series with this large box. The only two units which function specifically for the midcourse maneuver are 701 and 702, the autopilot and midcourse motor respectively.

The capability for execution of two midcourse maneuvers has been designed into the equipment by the replication of the pyrotechnically operated valves which initiate and stop the propulsion. This redundancy is indicated by the parallel paths in the exhibit. Units 953 and 954 allow for an estimation of the operational probability that an accurate maneuver will be executed.

H. Radio Subsystem

Discussions regarding the radio subsystem and an examination of the performance margin curves have resulted in certain changes to the representation of this subsystem.

Exhibit 38 depicts the receiver antenna control. Allowance had been made for failure of the excitation circuits associated with the ferrite circulators which accomplish this control. Such a failure is equivalent to the loss of the isolation properties of these circulators and is likely to result in a 3-db loss of received power. However, the predicted performance margin for the DSIF-Spacecraft link is sufficiently high to allow this loss to be ignored. Accordingly, unit 805, the magnetization circuits for the circulator switches, no longer appears in this diagram.

The parallel low-gain and high-gain paths appear to indicate a redundancy, and it had been assumed that such a redundancy did exist at least for a portion of the mission. This has been verified, and it is now estimated that the receiver can be operated from either the low-gain or high-gain antenna during the period t_{17} to t_{20} on the mission profile.

The receiver itself is shown in Exhibit 39. A study of the circuit diagrams has disclosed that the ranging channel, units 811 and 812, is fed from the first IF unit (808). This had previously been represented as being dependent only upon unit 807, the transformer rectifier. The other units for the receiver have been regrouped for reliability purposes and retitled.

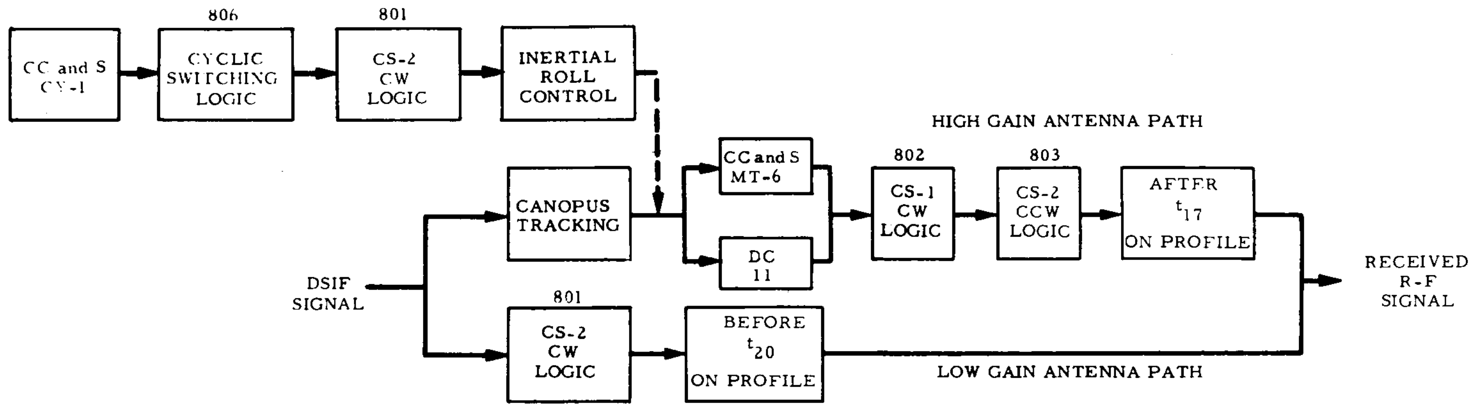


EXHIBIT 38 - RECEIVER ANTENNA CONTROL

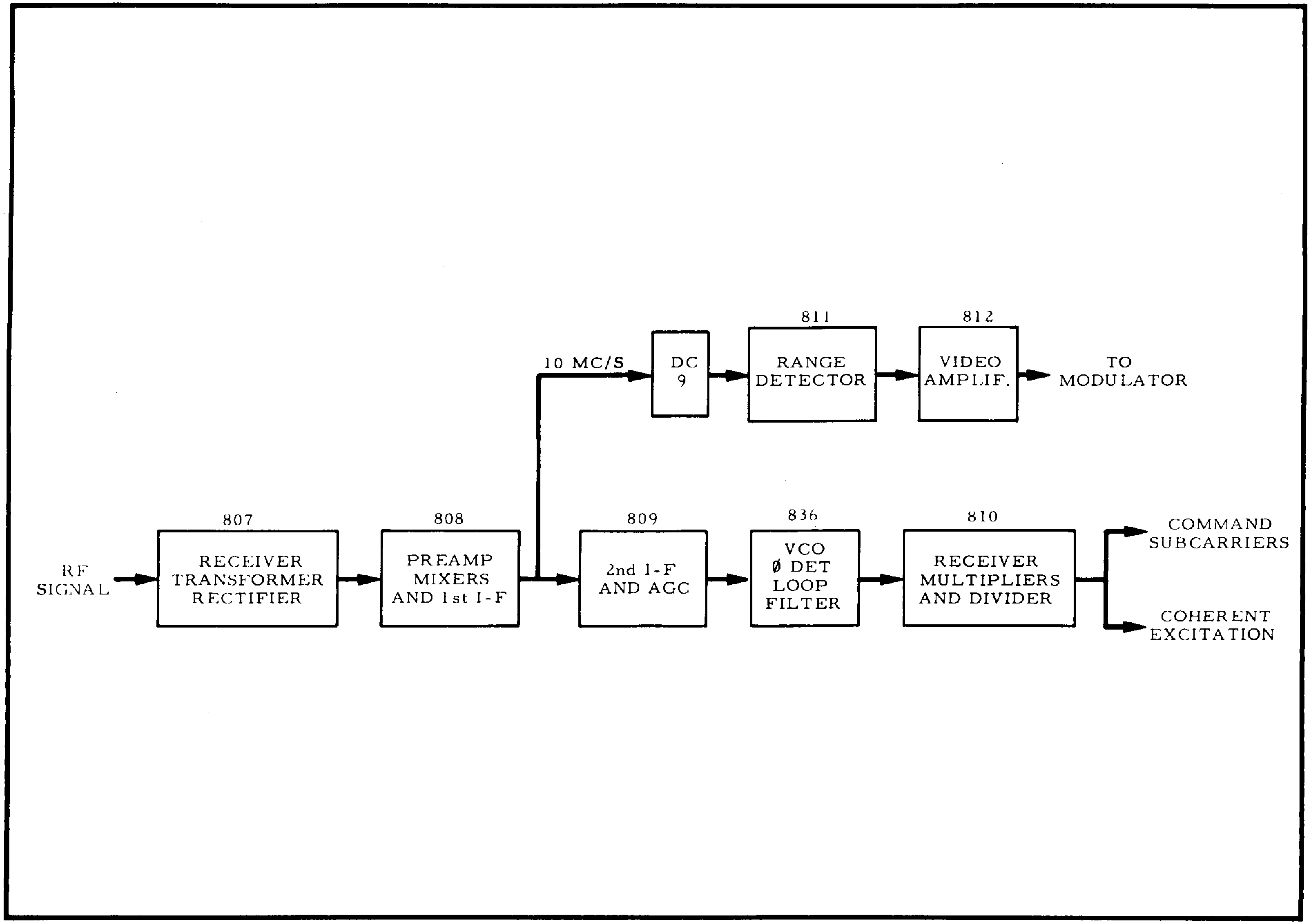


EXHIBIT 39 - RECEIVER

The two primary functions of the receiver are to supply coherent excitation of the transmitter and to strip off the command subcarriers. Both of these functions appear to be dependent upon all of the receiver units and are now depicted in that fashion.

The starting point for the radio transmitter is the representation of the redundant oscillators or exciters as shown in Exhibit 40. It will be noted that the voltage-controlled oscillator (VCO) is the primary source of excitation, but that redundant auxiliary oscillators are automatically switched in, should the VCO output fail. Parallel exciters are employed for reliability purposes, and switching between them is accomplished by ferrite circulator switch 5. The control logic for this switch has been divided between units 816 and 820. No actual circuit diagrams of the control logic were available for this study; however, a parts count was available and, for want of necessary details, this was apportioned equally to the various units which accomplish the switching functions.

A significant change was made in the composition of units 815 and 819. These units had previously been assigned as the exciter level detectors, but no information on their composition could be made available. Accordingly, the exciter level detectors and the redundant command DC-8 have been eliminated, a step resulting in an optimistic prediction of reliability. These unit numbers have been reassigned to the exciter transformer rectifiers. Unit 822, which had previously been designated as the exciter transformer rectifier, has been eliminated.

The loss of excitation for the circulator switch, which could come about through failure of units 804 or 821, would result in a 3-db drop in the exciter output. This reduction in drive power would become significant shortly before encounter, as is indicated by the presence of the box marked "Before t_{23}."

The exciters provide drive power for the transmitter power amplifiers illustrated in Exhibit 41. This block diagram is similar to that which was constructed for the interim report, except that the power level detectors, units 828 and 832, have been removed. The makeup of these detectors could not be ascertained, and it was not possible to include them; this represents another step leading to optimism in the prediction of reliability.

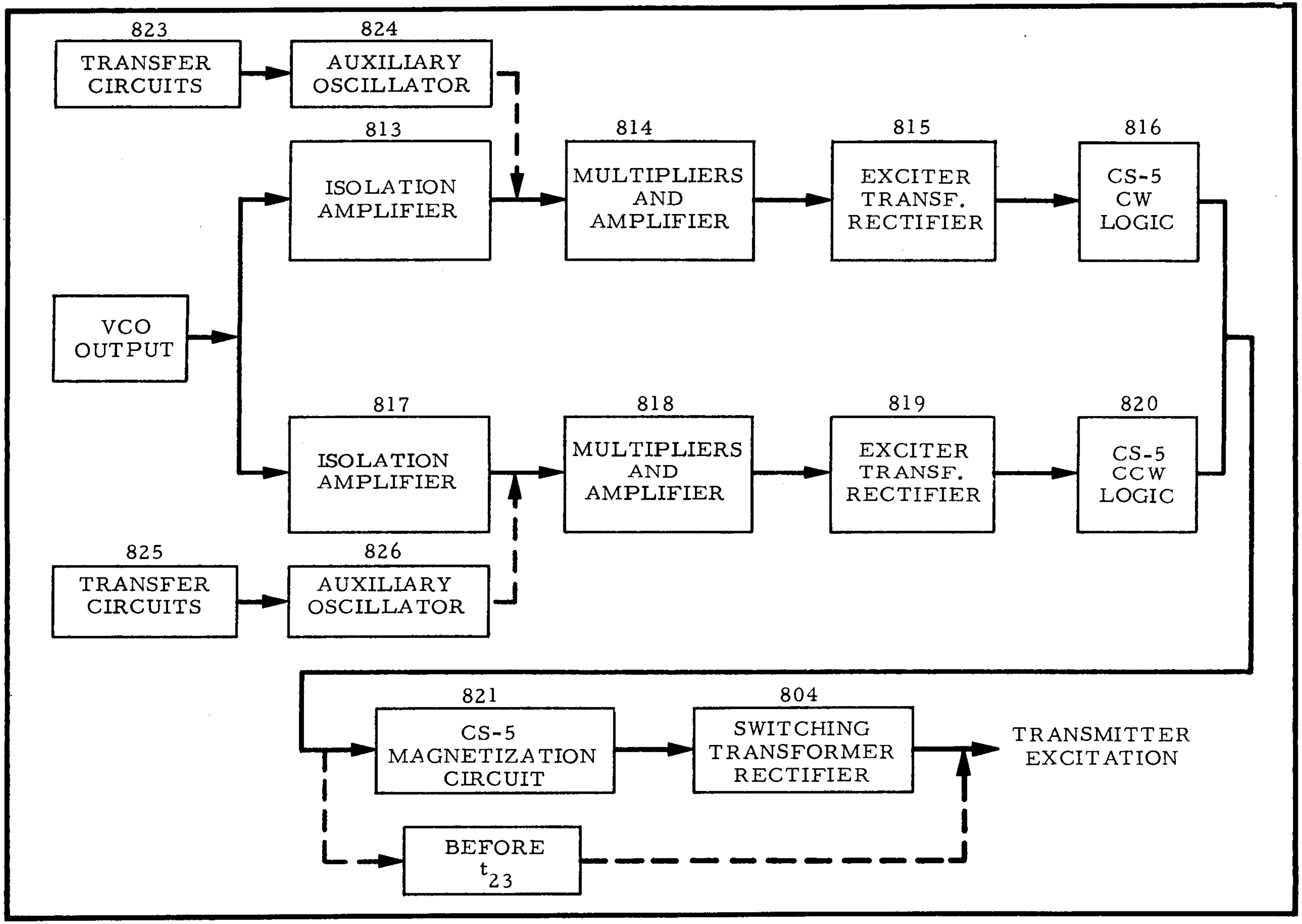


EXHIBIT 40 - RADIO TRANSMITTER OSCILLATORS

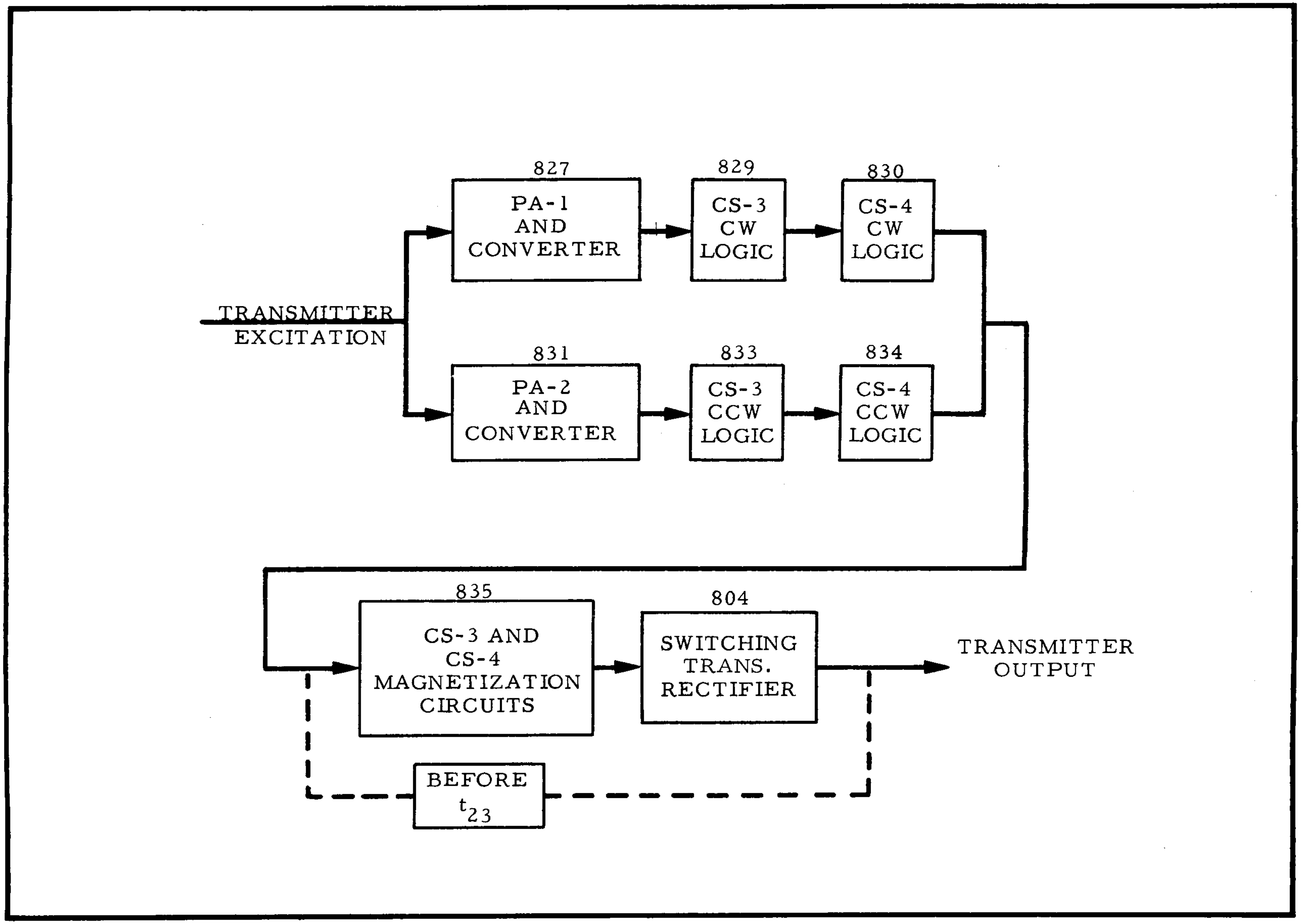


EXHIBIT 41 - TRANSMITTER POWER AMPLIFIERS

The redundancy of the power amplifiers is made clear by the diagram, which also shows that switching between them is accomplished by establishing the proper combinations of circulator switches 3 and 4. The control logic for these switches, units 829, 830, 833, and 834, was derived from an apportionment of the parts complement as previously described. Failure of the excitation to these switches, which could arise from a failure of units 804 or 835, is not considered significant until time t_{23} on the mission profile, at which point the 3-db loss would become catastrophic.

Transmitter antenna control is depicted in Exhibit 42. The principal change in this diagram is the addition of unit 804 in series with the magnetization circuits for circulator switches CS-1 and CS-2. This addition is not a change, but merely makes the dependence upon the switching transformer rectifier more explicit.

The parallel connection of a low-gain antenna path and high-gain antenna path would indicate redundancy in a manner similar to that of the receiver antenna control. A study of the performance margin on the Spacecraft-DSIF link reveals that no such redundancy exists and that the operating coverage of the antennas does not overlap. As shown by the time blocks in the diagram, a communications blackout can be anticipated between t_{19} and t_{20} on the mission profile.

I. Pyrotechnic Control

The basic functions of current storage and control for the pyrotechnics are illustrated in Exhibit 43. This representation does not differ from that which was previously submitted; however, a design change has affected the makeup of units 904, 905, 909, and 910. These units, which represent the rectifiers and capacitors, no longer have redundant charge-limiting resistors, although the feature of redundant rectifiers has been retained.

The pyrotechnics which are involved in the deployment of the solar panels are shown in Exhibit 44. Design changes have caused the introduction of units 928 and 929 which serve as isolation filters for the CC and S L-1 signal. The fact that the latches and pin pullers are actually combined has been recognized by the elimination of the pin puller boxes.

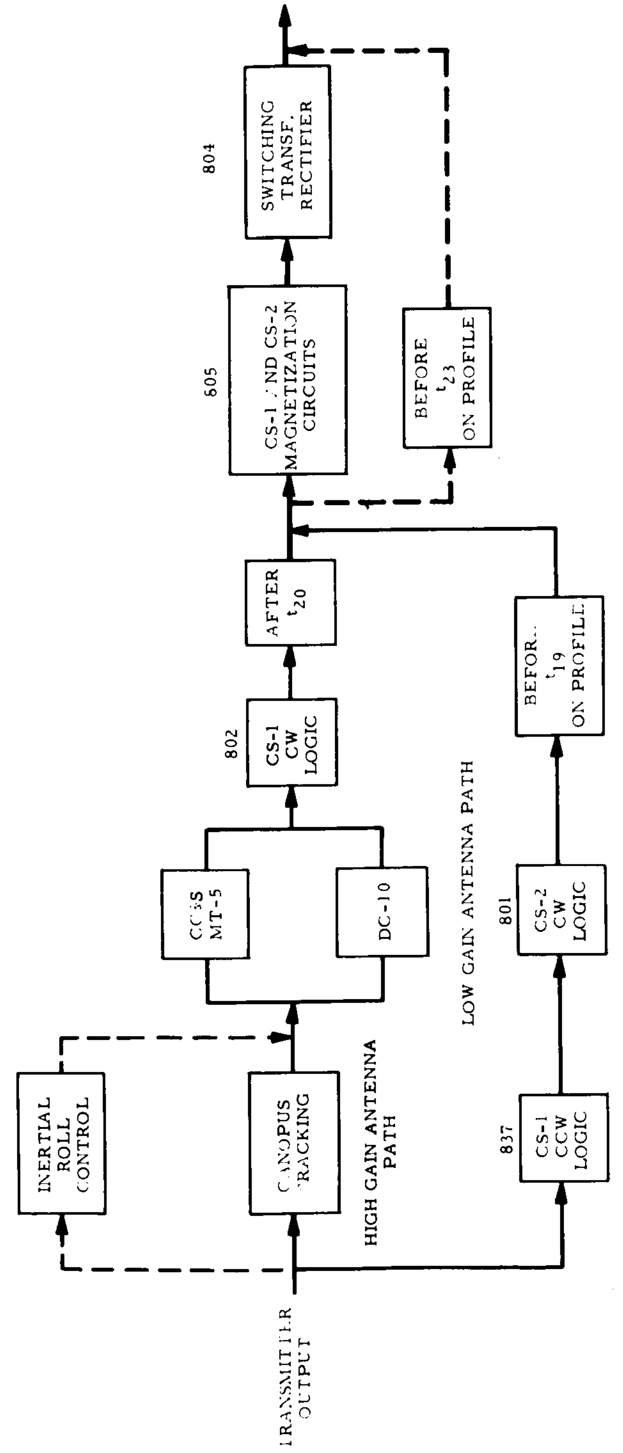
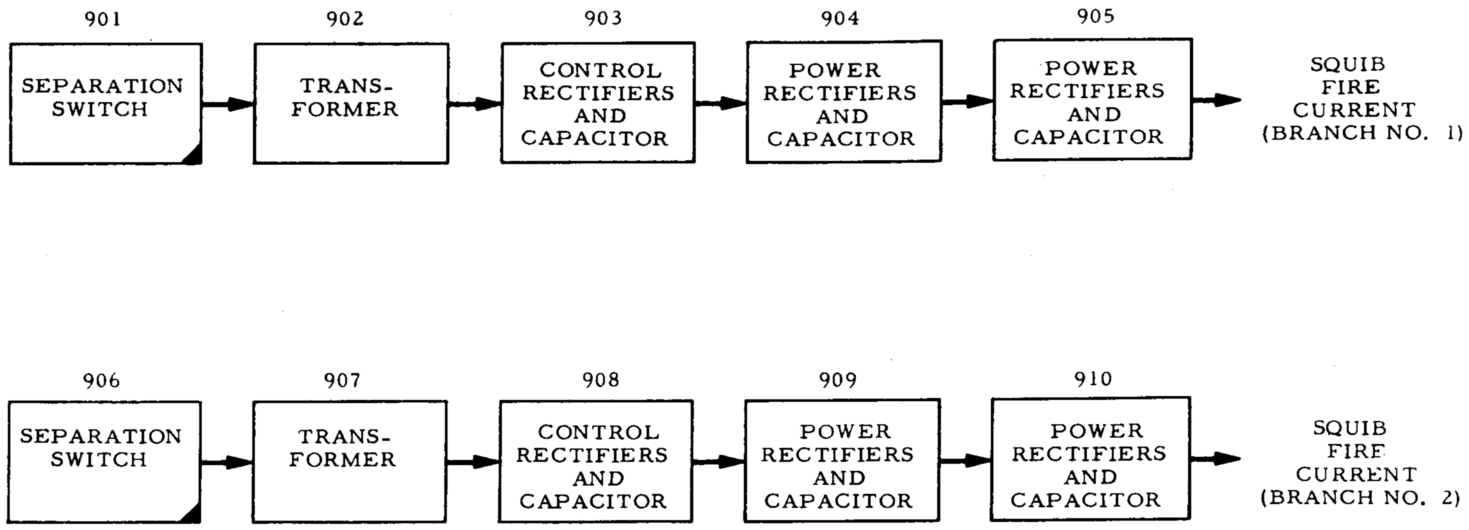


EXHIBIT 42 - TRANSMITTER ANTENNA CONTROL



NOTES: (1) UNITS 904, 905, 909, 910 HAVE REDUNDANT RECTIFIERS

(2) AFTER M/C MANEUVER, UNITS 905 AND 910 MAY FAIL IF POWER DRAIN IS NOT CATASTROPHIC.

(3) THESE TWO STRINGS SEPARATELY FIRE REDUNDANT SQUIBS OR BRIDGEWIRES.

EXHIBIT 43 - PYROTECHNICS, CURRENT STORAGE AND CONTROL

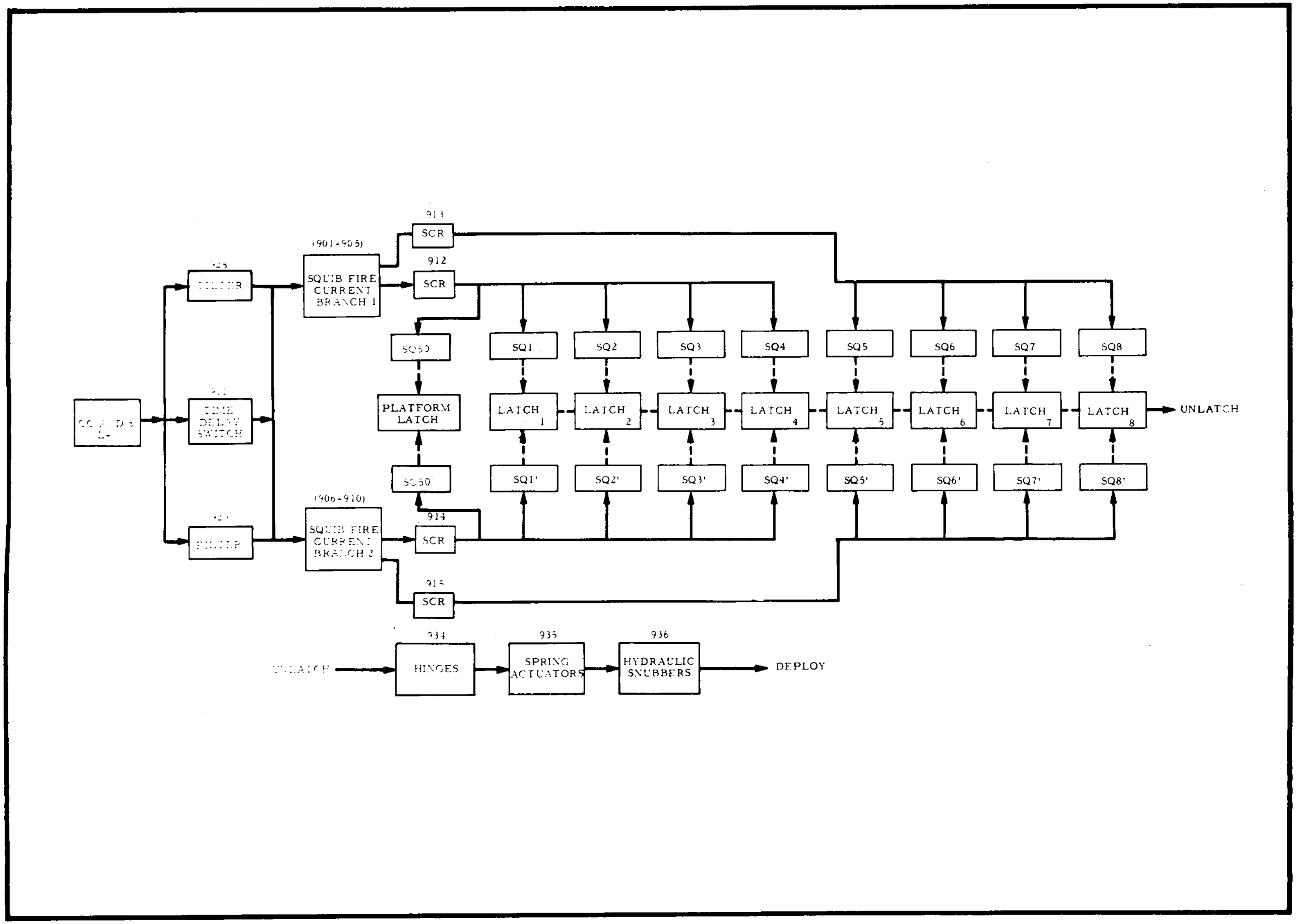


EXHIBIT 44 - PYROTECHNICS, SOLAR PANEL DEPLOYMENT

In the previous representation, the firing current for silicon-controlled rectifiers, units 913 and 915, was supplied by units 912 and 914 respectively. This dependency has been eliminated by a design change, and the diagram reflects the new configuration. The additional function of unlatching the science scan platform has been added to the diagram. The hardware associated with the mechanical deployment of the panels is explicitly shown in units 934, 935, and 936.

Pyrotechnic events associated with the midcourse maneuver are illustrated in Exhibit 45. This is essentially the same diagram as that submitted with the interim report; however, it is now made clear that redundant bridge wires rather than squibs are used for the explosive valves. Separate silicon-controlled rectifiers are used for each of the maneuvers, and the additional rectifiers are identified as units 924, 925, 926, and 927. The fact that the arming relays, K-2, K-2', K-4, and K-4' are needed only for the second maneuver is indicated on the diagram.

J. Normal Mission Profile

The various configurations of reliability units constituting the spacecraft subsystems have been described in the foregoing subsections. These representations indicate, in a general way, that different configurations may apply to each subsystem at specific points in time throughout the mission. It is essential, however, that the concept of time-changing requirements for unit functions be introduced into the reliability analysis in an exact manner. For example, the function of the battery charger in the power supply is fulfilled within two weeks following the second maneuver. It is then deenergized, but it may be required in a redundant capacity at encounter. This scheduling of unit requirements must be dealt with in an explicit fashion if meaningful calculations are to be made.

The most convenient display of such a schedule is a mission time profile which lists all of the reliability units and states the manner in which each unit enters the operating picture during each part of the mission. The mission itself is, accordingly, divided into discrete intervals marking the occurrence of important events such as maneuvers, acquisitions, switching times, and so on through the actual encounter and post-encounter events.

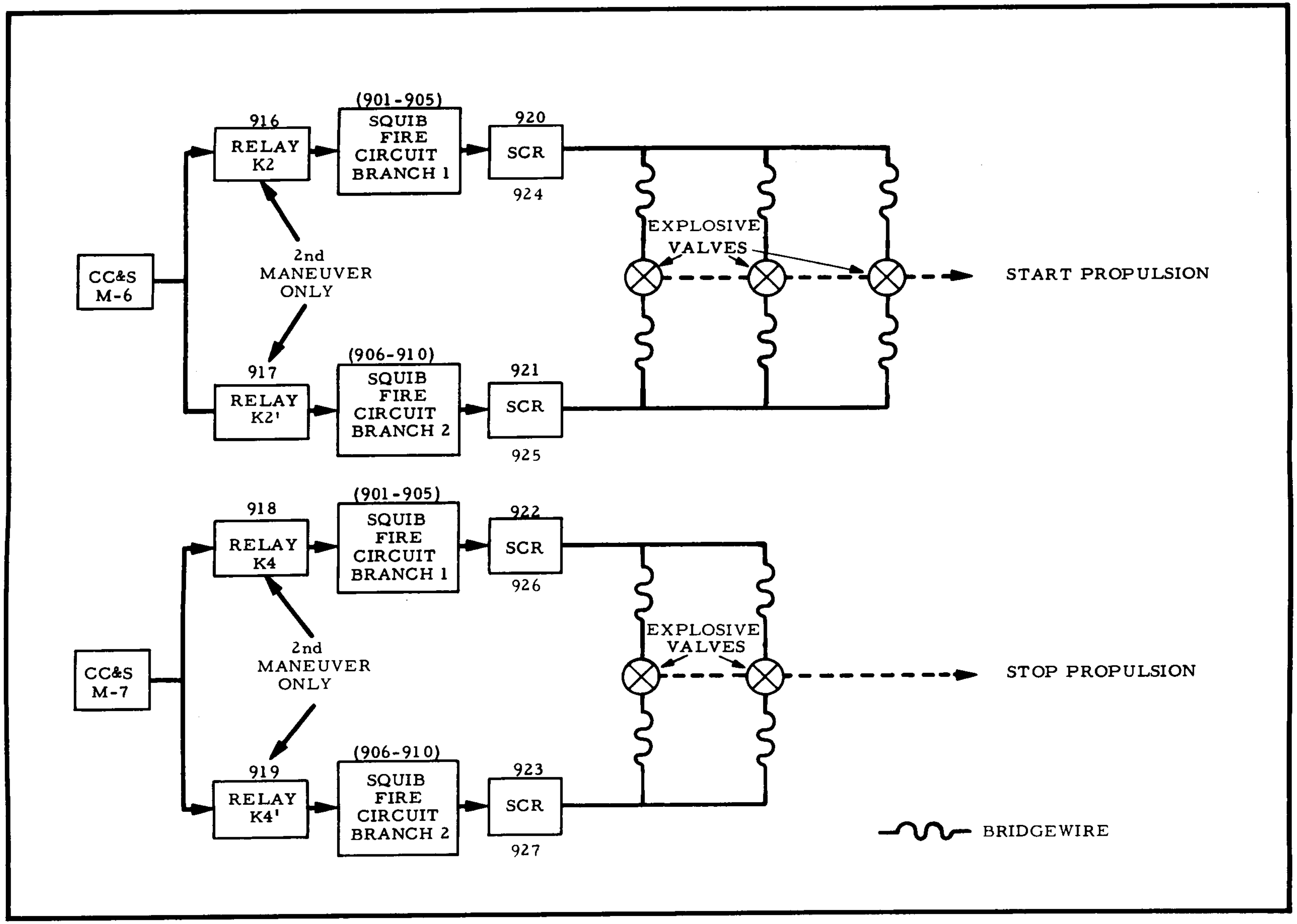


EXHIBIT 45 - PYROTECHNICS, MIDCOURSE MANEUVER

Exhibit 46, comprising the next several pages, shows the exact mission profile used in this reliability assessment. Information regarding the required or scheduled status of any unit at any time can be obtained from this tabulation. This extends to sufficient detail to differentiate between an in-line or series requirement and a requirement where the unit is serving in a redundant capacity. The state of energization of the unit also is shown.

EXHIBIT 46 - STATE OF UNITS IN A NORMAL MISSION

	Injection-- Deploy Solar Panels	Begin Sun Acquisition	End Sun Acq., Start Canopus Acq.	End Canopus Acquisition	Turn Solar Stabilization System On	Begin Data Insertion	End Data Insertion	Begin M/C$_1$ Maneuver	End M/C$_1$ Maneuver	End Sun Acquisition	End Canopus Acquisition	Begin Data Insertion	End Data Insertion	Begin M/C$_2$	End M/C$_2$	End Sun Acquisition	End Canopus Acquisition	Receiver High-Gain Antenna Limit	Set Canopus Sensor Cone Angle 1	Transmitter Low-Gain Antenna Limit	Transfer to Transmit Via High-Gain Antenna	Set Canopus Sensor Cone Angle 2	Set Canopus Sensor Cone Angle 3	Half-Power Transmitter Limit	Set Canopus Sensor Cone Angle 4	End Cruise	Begin Encounter	Closest Approach	End Encounter	Begin Playback	End Playback
	t_0	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	t_{14}	t_{15}	t_{16}	t_{17}	t_{18}	t_{19}	t_{20}	t_{21}	t_{22}	t_{23}	t_{24}	t_{25}	t_{26}	t_E	t_{27}	t_{28}	t_{29}
Unit \ Cumulative Time (hrs):			0.5	1.5	16	24	25	41	43	43.5	44.5	273.5	274.5	284.5	286.5	287	288	1752	2160	2376	2688	2976	3768	4248	4800	5950	5993	6000	6006	6013	6213
101																											u(1)				
102																											u(1)				
103																											u				
104																											u				
105																											u			u	
106																											u				
107																														u	
2001	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
2002	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
2003-1	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	
2003-2	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	
2003-3	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	
2004-1	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	
2004-2	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	
2005	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	
2006	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	
2007-8	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
2010-13	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u						
2014	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$	$0,\bar{e}$					
2015-2148	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u						
3000	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u		
3001-1	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u		
3002	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u		
3003	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u		

KEY: A blank space indicates that the unit is not needed during this particular interval.
u = required.
e = energized.
0 = required in a redundant capacity.
$0,\bar{e}$ = required in a redundant capacity but not energized until needed.

NOTE: Numbers in parentheses refer to remarks listed at the end of the tabulation.

EXHIBIT 46 (Continued)

t_0	Injection--Deploy Solar Panels	
t_1	Begin Sun Acquisition	
t_2	End Sun Acq., Start Canopus Acq.	0.5
t_3	End Canopus Acquisition	1.5
t_4	Turn Solar Stabilization System On	16
t_5	Begin Data Insertion	24
t_6	End Data Insertion	25
t_7	Begin M/C$_1$ Maneuver	41
t_8	End M/C$_1$ Maneuver	43
t_9	End Sun Acquisition	43.5
t_{10}	End Canopus Acquisition	44.5
t_{11}	Begin Data Insertion	273.5
t_{12}	End Data Insertion	274.5
t_{13}	Begin M/C$_2$	284.5
t_{14}	End M/C$_2$	286.5
t_{15}	End Sun Acquisition	287
t_{16}	End Canopus Acquisition	288
t_{17}	Receiver High-Gain Antenna Limit	1752
t_{18}	Set Canopus Sensor Cone Angle 1	2160
t_{19}	Transmitter Low-Gain Antenna Limit	2376
t_{20}	Transfer to Transmit Via High-Gain Antenna	2688
t_{21}	Set Canopus Sensor Cone Angle 2	2976
t_{22}	Set Canopus Sensor Cone Angle 3	3768
t_{23}	Half-Power Transmitter Limit	4248
t_{24}	Set Canopus Sensor Cone Angle 4	4800
t_{25}	End Cruise	5950
t_{26}	Begin Encounter	5993
t_E	Closest Approach	6000
t_{27}	End Encounter	6006
t_{28}	Begin Playback	6013
t_{29}	End Playback	6213

Unit \ Cumulative Time (hrs):																														
3004-1																														
3004-2																														
3005-1(2)	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3005-2(3)	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3006-1(4)	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3006-2(5)	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3007-1(6)	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3007-2(7)	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3008-1(8)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3008-2(9)	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3009(10)	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3010(11)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3011(12)	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3012(13)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3013(14)	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3014(15)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3015(16)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3016(17)	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3017(18)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3018(19)	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3019(20)	u	u	u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3021*-23*																														
3024*(22)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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0,ē = required in a redundant capacity but not energized until needed.

EXHIBIT 46 (Continued)

		Cumulative Time (hrs):
t_0	Injection--Deploy Solar Panels	
t_1	Begin Sun Acquisition	
t_2	End Sun Acq., Start Canopus Acq.	0.5
t_3	End Canopus Acquisition	1.5
t_4	Turn Solar Stabilization System On	16
t_5	Begin Data Insertion	24
t_6	End Data Insertion	25
t_7	Begin M/C_1 Maneuver	41
t_8	End M/C_1 Maneuver	43
t_9	End Sun Acquisition	43.5
t_{10}	End Canopus Acquisition	44.5
t_{11}	Begin Data Insertion	273.5
t_{12}	End Data Insertion	274.5
t_{13}	Begin M/C_2	284.5
t_{14}	End M/C_2	286.5
t_{15}	End Sun Acquisition	287
t_{16}	End Canopus Acquisition	288
t_{17}	Receiver High-Gain Antenna Limit	1752
t_{18}	Set Canopus Sensor Cone Angle 1	2160
t_{19}	Transmitter Low-Gain Antenna Limit	2376
t_{20}	Transfer to Transmit Via High-Gain Antenna	2688
t_{21}	Set Canopus Sensor Cone Angle 2	2976
t_{22}	Set Canopus Sensor Cone Angle 3	3768
t_{23}	Half-Power Transmitter Limit	4248
t_{24}	Set Canopus Sensor Cone Angle 4	4800
t_{25}	End Cruise	5950
t_{26}	Begin Encounter	5993
t_E	Closest Approach	6000
t_{27}	End Encounter	6006
t_{28}	Begin Playback	6013
t_{29}	End Playback	6213

Unit	t_0	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	t_{14}	t_{15}	t_{16}	t_{17}	t_{18}	t_{19}	t_{20}	t_{21}	t_{22}	t_{23}	t_{24}	t_{25}	t_{26}	t_E	t_{27}	t_{28}
3025*																														
3026*(23)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3027*-29*																														
3030*(24)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0											
3031*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
3032*-3034-A3*																														
3035*(25)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3036*																														
3037*(26)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
3038*(27)	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0	0	0	
3039*																														
3040*																														
3041*(28)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3042*	u	u	u	u	u	u	u	u	u	u	u																			
3043*																														
3044*(29)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
3045*(30)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
3046*	u	u	u	u	u	u	u	u	u	u	u	u	u																	
3081*	u	u	u	u	u	u	u	u	u	u	u	u																		
3047-48																														
3049-1	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
3049-2	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
3050																														
3051-1	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	

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0,ē = required in a redundant capacity but not energized until needed.

EXHIBIT 46 (Continued)

t_0	Injection--Deploy Solar Panels	
t_1	Begin Sun Acquisition	
t_2	End Sun Acq., Start Canopus Acq.	0.5
t_3	End Canopus Acquisition	1.5
t_4	Turn Solar Stabilization System On	16
t_5	Begin Data Insertion	24
t_6	End Data Insertion	25
t_7	Begin M/C_1 Maneuver	41
t_8	End M/C_1 Maneuver	43
t_9	End Sun Acquisition	43.5
t_{10}	End Canopus Acquisition	44.5
t_{11}	Begin Data Insertion	273.5
t_{12}	End Data Insertion	274.5
t_{13}	Begin M/C_2	284.5
t_{14}	End M/C_2	286.5
t_{15}	End Sun Acquisition	287
t_{16}	End Canopus Acquisition	288
t_{17}	Receiver High-Gain Antenna Limit	1752
t_{18}	Set Canopus Sensor Cone Angle 1	2160
t_{19}	Transmitter Low-Gain Antenna Limit	2376
t_{20}	Transfer to Transmit Via High-Gain Antenna	2688
t_{21}	Set Canopus Sensor Cone Angle 2	2976
t_{22}	Set Canopus Sensor Cone Angle 3	3768
t_{23}	Half-Power Transmitter Limit	4248
t_{24}	Set Canopus Sensor Cone Angle 4	4800
t_{25}	End Cruise	5950
t_{26}	Begin Encounter	5993
t_E	Closest Approach	6000
t_{27}	End Encounter	6006
t_{28}	Begin Playback	6013
t_{29}	End Playback	6213

Unit \ Cumulative Time (hrs):	t_0	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	t_{14}	t_{15}	t_{16}	t_{17}	t_{18}	t_{19}	t_{20}	t_{21}	t_{22}	t_{23}	t_{24}	t_{25}	t_{26}	t_E	t_{27}	t_{28}
3051-2(31)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3052-55																														
3057-1																														
3057-2																														
3058-1	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
3058-2	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u											
3059-1(32)	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0	0	0	
3059-2	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u										
3060-65																														
3066-1(33)	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
3066-2(34)	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
3067																														
3068-1	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
3068-2	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u						
3069-1	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
3069-2	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
3070																														
3071-1																														
3071-2																														
3072-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3072-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3073-1	u	u	u	u	u	u	u	u	u	u	u																			
3073-2	u	u	u	u	u	u	u	u	u	u	u																			
3074																														
3075-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				

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EXHIBIT 46 (Continued)

		Cumulative Time (hrs):
t_0	Injection -- Deploy Solar Panels	
t_1	Begin Sun Acquisition	
t_2	End Sun Acq., Start Canopus Acq.	0.5
t_3	End Canopus Acquisition	1.5
t_4	Turn Solar Stabilization System On	16
t_5	Begin Data Insertion	24
t_6	End Data Insertion	25
t_7	Begin M/C 1 Maneuver	41
t_8	End M/C 1 Maneuver	43
t_9	End Sun Acquisition	43.5
t_{10}	End Canopus Acquisition	44.5
t_{11}	Begin Data Insertion	273.5
t_{12}	End Data Insertion	274.5
t_{13}	Begin M/C 2	284.5
t_{14}	End M/C 2	286.5
t_{15}	End Sun Acquisition	287
t_{16}	End Canopus Acquisition	288
t_{17}	Receiver High-Gain Antenna Limit	1752
t_{18}	Set Canopus Sensor Cone Angle 1	2160
t_{19}	Transmitter Low-Gain Antenna Limit	2376
t_{20}	Transfer to Transmit Via High-Gain Antenna	2688
t_{21}	Set Canopus Sensor Cone Angle 2	2976
t_{22}	Set Canopus Sensor Cone Angle 3	3768
t_{23}	Half-Power Transmitter Limit	4248
t_{24}	Set Canopus Sensor Cone Angle 4	4800
t_{25}	End Cruise	5950
t_{26}	Begin Encounter	5993
t_E	Closest Approach	6000
t_{27}	End Encounter	6006
t_{28}	Begin Playback	6013
t_{29}	End Playback	6213

Unit	t_0	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	t_{14}	t_{15}	t_{16}	t_{17}	t_{18}	t_{19}	t_{20}	t_{21}	t_{22}	t_{23}	t_{24}	t_{25}	t_{26}	t_E	t_{27}	t_{28}
3075-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
3076-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
3076-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
3077-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
3077-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
3078-1	u	u	u	u	u	u	u	u	u	u	u	u	u																	
3078-2	u	u	u	u	u	u	u	u	u	u	u	u	u																	
3079	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
3080	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
3082	u	u	u	u	u	u	u	u	u	u	u	u																		
3083	u	u	u	u	u	u	u	u	u	u	u	u																		
3084	u	u	u	u	u	u	u	u	u	u	u	u																		
3085	u	u	u	u	u	u	u	u	u	u	u	u																		
401(35)	u	u	u	u	0	u	0	u	0	0	0	u	0	u	0	0	0	0	0	0	0	0	0	e	0	0	0	0	0	0
402	u	u	u	u	0	0	0	u	0	0	0	0	0	u	0	0	0	0	0	0	0	0	0	e	o	0	0	0	0	0
403(36)	u	u	u	u	e	e	e	u	e	e	e	e	e	u	e	e	e	e	0	0	0	0	0	e	0	0	0	0	0	0
404	u	u	u	u	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0	0	0	0	0	e	0	0	0	0	0	0
405	u	u	u	u																										
406	u																													
406a	u(1)																													
407	u																													
407a	u(1)																													
408	e	e	e	e	u(37)																									
408a					u(1)																									

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0,$\overline{e}$ = required in a redundant capacity but not energized until needed.

EXHIBIT 46 (Continued)

Unit	t_0 Injection-- Deploy Solar Panels	t_1 Begin Sun Acquisition	t_2 End Sun Acq., Start Canopus Acq.	t_3 End Canopus Acquisition	t_4 Turn Solar Stabilization System On	t_5 Begin Data Insertion	t_6 End Data Insertion	t_7 Begin M/C$_1$ Maneuver	t_8 End M/C$_1$ Maneuver	t_9 End Sun Acquisition	t_{10} End Canopus Acquisition	t_{11} Begin Data Insertion	t_{12} End Data Insertion	t_{13} Begin M/C$_2$	t_{14} End M/C$_2$	t_{15} End Sun Acquisition	t_{16} End Canopus Acquisition	t_{17} Receiver High-Gain Antenna Limit	t_{18} Set Canopus Sensor Cone Angle 1	t_{19} Transmitter Low-Gain Antenna Limit	t_{20} Transfer to Transmit Via High-Gain Antenna	t_{21} Set Canopus Sensor Cone Angle 2	t_{22} Set Canopus Sensor Cone Angle 3	t_{23} Half-Power Transmitter Limit	t_{24} Set Canopus Sensor Cone Angle 4	t_{25} End Cruise	t_{26} Begin Encounter	t_E Closest Approach	t_{27} End Encounter	t_{28} Begin Playback	t_{29} End Playback
Cumulative Time (hrs):			0.5	1.5	16	24	25	41	43	43.5	44.5	273.5	274.5	284.5	286.5	287	288	1752	2160	2376	2688	2976	3768	4248	4800	5950	5993	6000	6006	6013	6213
409-410	e	e	e	e	e	u	e	e	e	e	e	u																			
411-416	e	e	e	e	e	u	e	u	e	e	e	u	e	u																	
417-418	e	e	e	e	e	e	e	u	e	e	e	e	e	u																	
419								u(1)	e	e	e	e	e	u(1)																	
420	e	e	e	e	e	e	e	u	e	e	e	e	e	u																	
421-422								u(1)	e	e	e	e	e	u(1)																	
424	e	e	e	e	e	e	e	u	e	e	e	e	e	u																	
425(38)	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0	0	0	0	0	0	0	0	0	0	0	0	
426(39)	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0	0	0	0	0	0	0	0	0	0	0	0	
427(40)	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0(37)												
427a(41)																			0(1)												
428(42)	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0(37)									
428a(43)																						0(1)									
429(44)	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0(37)								
429a(45)																							0(1)								
430(46)	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0(37)	0(37)					
430a(47)																									0(1)	0(1)					
431(48)	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0(37)											
431a(49)																				0(1)											
432(50)	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0(37)										
432a(51)																					0(1)										
433(52)																															
433a(53)																															
434(54)	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0(37)				

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EXHIBIT 46 (Continued)

t_0	Injection-- Deploy Solar Panels	
t_1	Begin Sun Acquisition	
t_2	End Sun Acq., Start Canopus Acq.	0.5
t_3	End Canopus Acquisition	1.5
t_4	Turn Solar Stabilization System On	16
t_5	Begin Data Insertion	24
t_6	End Data Insertion	25
t_7	Begin M/C$_1$ Maneuver	41
t_8	End M/C$_1$ Maneuver	43
t_9	End Sun Acquisition	43.5
t_{10}	End Canopus Acquisition	44.5
t_{11}	Begin Data Insertion	273.5
t_{12}	End Data Insertion	274.5
t_{13}	Begin M/C$_2$	284.5
t_{14}	End M/C$_2$	286.5
t_{15}	End Sun Acquisition	287
t_{16}	End Canopus Acquisition	288
t_{17}	Receiver High-Gain Antenna Limit	1752
t_{18}	Set Canopus Sensor Cone Angle 1	2160
t_{19}	Transmitter Low-Gain Antenna Limit	2376
t_{20}	Transfer to Transmit Via High-Gain Antenna	2688
t_{21}	Set Canopus Sensor Cone Angle 2	2976
t_{22}	Set Canopus Sensor Cone Angle 3	3768
t_{23}	Half-Power Transmitter Limit	4248
t_{24}	Set Canopus Sensor Cone Angle 4	4800
t_{25}	End Cruise	5950
t_{26}	Begin Encounter	5993
t_E	Closest Approach	6000
t_{27}	End Encounter	6006
t_{28}	Begin Playback	6013
t_{29}	End Playback	6213

Unit	t_0–t_1	t_1–t_2	t_2–t_3	t_3–t_4	t_4–t_5	t_5–t_6	t_6–t_7	t_7–t_8	t_8–t_9	t_9–t_{10}	t_{10}–t_{11}	t_{11}–t_{12}	t_{12}–t_{13}	t_{13}–t_{14}	t_{14}–t_{15}	t_{15}–t_{16}	t_{16}–t_{17}	t_{17}–t_{18}	t_{18}–t_{19}	t_{19}–t_{20}	t_{20}–t_{21}	t_{21}–t_{22}	t_{22}–t_{23}	t_{23}–t_{24}	t_{24}–t_{25}	t_{25}–t_{26}	t_{26}–t_E	t_E–t_{27}	t_{27}–t_{28}	t_{28}–t_{29}
434a(55)																											0(1)			
435(56)	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0(37) 0(1)	
435a(57)																														
436(58)	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0(37) 0(1)
436a(59)																														
437								u						u																
438								u(1)						u(1)																
439								u						u																
440-41								u(1)						u(1)																
442								u						u																
443								u(1)						u(1)																
444								u						u																
445								u(1)						u(1)																
446								u						u																
447								u(1)						u(1)																
448-49								u						u																
450								u(1)						u(1)																
451								u																						
452-53								u(1)																						
454								u																						
455								u(1)						u(1)																
501	e	e	u	u	u	u	u	e	e	u	u	u	u	e	e	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u
502(60)	u	u	e	e	e	e	e	u	u	e	e	e	e	u	u	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
503	e	e	u	u	u	u	u	e	e	u	u	u	u	e	e	u(61)											0	0		

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u = required.
e = energized.
0 = required in a redundant capacity.
0, $\overline{e}$ = required in a redundant capacity but not energized until needed.

EXHIBIT 46 (Continued)

Unit	t_0 Injection-- Deploy Solar Panels	t_1 Begin Sun Acquisition	t_2 End Sun Acq., Start Canopus Acq.	t_3 End Canopus Acquisition	t_4 Turn Solar Stabilization System On	t_5 Begin Data Insertion	t_6 End Data Insertion	t_7 Begin M/C$_1$ Maneuver	t_8 End M/C$_1$ Maneuver	t_9 End Sun Acquisition	t_{10} End Canopus Acquisition	t_{11} Begin Data Insertion	t_{12} End Data Insertion	t_{13} Begin M/C$_2$	t_{14} End M/C$_2$	t_{15} End Sun Acquisition	t_{16} End Canopus Acquisition	t_{17} Receiver High-Gain Antenna Limit	t_{18} Set Canopus Sensor Cone Angle 1	t_{19} Transmitter Low-Gain Antenna Limit	t_{20} Transfer to Transmit Via High-Gain Antenna	t_{21} Set Canopus Sensor Cone Angle 2	t_{22} Set Canopus Sensor Cone Angle 3	t_{23} Half-Power Transmitter Limit	t_{24} Set Canopus Sensor Cone Angle 4	t_{25} End Cruise	t_{26} Begin Encounter	t_E Closest Approach	t_{27} End Encounter	t_{28} Begin Playback	t_{29} End Playback
Cumulative Time (hrs):			0.5	1.5	16	24	25	41	43	43.5	44.5	273.5	274.5	284.5	286.5	287	288	1752	2160	2376	2688	2976	3768	4248	4800	5950	5993	6000	6006	6013	6213
504-505	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
506(62)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
507(63)	u	u	u	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	u	u	u	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	u	u	u	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	
508	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
509(64)	e	u	u					u	u	u				u	u	u	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	
510(65)	e	u	u					u	u	u				u	u	u	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	
511(66)	e	u	u					u	u	u				u	u	u	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	
512																											u	u	u	u	
513(67)	e	u	u					u	u	u				u	u	u	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	
515(68)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
516(69)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
517(70)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
601		u(4)																													
602(71)		u	u	u	u	u	u	u	u	u	u	u	u	u	u	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	
603(72)		u	u	u	u	u	u	u	u	u	u	u	u	u	u	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	
605		u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
606(73)	u	u	u					u	u	u				u	u	u	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	
607(74)	u	u	u					u	u	u				u	u	u	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	
608(75)	e	0	e					u	0	e				u	0	e	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	
610(76)	e	0	u	u	u	u	u	e	0	u	u	u	u	e	0	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
611	e	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
612(77)	e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
613(78)	e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
614			u	u	u	u	u			u	u	u	u			u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	

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0, $\overline{e}$ = required in a redundant capacity but not energized until needed.

EXHIBIT 46 (Continued)

	t_0	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	t_{14}	t_{15}	t_{16}	t_{17}	t_{18}	t_{19}	t_{20}	t_{21}	t_{22}	t_{23}	t_{24}	t_{25}	t_{26}	t_E	t_{27}	t_{28}	t_{29}
	Injection--Deploy Solar Panels	Begin Sun Acquisition	End Sun Acq., Start Canopus Acq.	End Canopus Acquisition	Turn Solar Stabilization System On	Begin Data Insertion	End Data Insertion	Begin M/C$_1$ Maneuver	End M/C$_1$ Maneuver	End Sun Acquisition	End Canopus Acquisition	Begin Data Insertion	End Data Insertion	Begin M/C$_2$	End M/C$_2$	End Sun Acquisition	End Canopus Acquisition	Receiver High-Gain Antenna Limit	Set Canopus Sensor Cone Angle 1	Transmitter Low-Gain Antenna Limit	Transfer to Transmit Via High-Gain Antenna	Set Canopus Sensor Cone Angle 2	Set Canopus Sensor Cone Angle 3	Half-Power Transmitter Limit	Set Canopus Sensor Cone Angle 4	End Cruise	Begin Encounter	Closest Approach	End Encounter	Begin Playback	End Playback
Unit \ Cumulative Time (hrs):			0.5	1.5	16	24	25	41	43	43.5	44.5	273.5	274.5	284.5	286.5	287	288	1752	2160	2376	2688	2976	3768	4248	4800	5950	5993	6000	6006	6013	6213
615(79)					u	u	u			u	u	u	u			u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
616(80)			u	u	u	u	u			u	u	u	u			u	u	u	u	u	u	u	u	u	u	u	0	0	0	0	
617(81)			0	0	0	0	0			0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
618(82)	e	e	u					u	u	u				u	u	u	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	
619		u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
620(83)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
621(84)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
622(85)	e	e	e	u	u	u	u	e	e	e	u	u	u	e	e	e	u	u	u	u	u	u	u	u	u	0	0	0	0	0	
623(86)		e	e					u	e	e				u	e	e										0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	
624-625		e	e					u	e	e				u	e	e										0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	0, $\overline{e}$	
626																															
627(87)			e	e	e	e	e			e	e	e	e			e	e	e	u	u	u	u	u	u	u	0	0	0	0	0	
701								u						u																	
702								u(4)						u(4)																	
801(88)	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	e	e	e	e	e	e	e	0	0	0	0	
802	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	u	u	u	u	u	u	u	u	u	u	
803	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	u	u	u	u	u	u	u	u	u	
804-805	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	u	u	u	u	u	u	u	
806(89)	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0	0	0	0	
807-810	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
811-812	u	u	u	u	u	u	u	u	u	u	u	u	u	u																	
813(90)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
814(91)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
815(92)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

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u = required.
e = energized.
0 = required in a redundant capacity.
0, $\overline{e}$ = required in a redundant capacity but not energized until needed.

EXHIBIT 46 (Continued)

Unit	t_0	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	t_{14}	t_{15}	t_{16}	t_{17}	t_{18}	t_{19}	t_{20}	t_{21}	t_{22}	t_{23}	t_{24}	t_{25}	t_{26}	t_E	t_{27}	t_{28}	t_{29}
	Injection--Deploy Solar Panels	Begin Sun Acquisition	End Sun Acq., Start Canopus Acq.	End Canopus Acquisition	Turn Solar Stabilization System On	Begin Data Insertion	End Data Insertion	Begin M/C$_1$ Maneuver	End M/C$_1$ Maneuver	End Sun Acquisition	End Canopus Acquisition	Begin Data Insertion	End Data Insertion	Begin M/C$_2$	End M/C$_2$	End Sun Acquisition	End Canopus Acquisition	Receiver High-Gain Antenna Limit	Set Canopus Sensor Cone Angle 1	Transmitter Low-Gain Antenna Limit	Transfer to Transmit Via High-Gain Antenna	Set Canopus Sensor Cone Angle 2	Set Canopus Sensor Cone Angle 3	Half-Power Transmitter Limit	Set Canopus Sensor Cone Angle 4	End Cruise	Begin Encounter	Closest Approach	End Encounter	Begin Playback	End Playback
Cumulative Time (hrs):			0.5	1.5	16	24	25	41	43	43.5	44.5	273.5	274.5	284.5	286.5	287	288	1752	2160	2376	2688	2976	3768	4248	4800	5950	5993	6000	6006	6013	6213
816(93)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
817(94)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
818(95)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
819(96)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
820(97)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
821	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	u	u	u	u	u	u	u	
823-826																															
827(98)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
829-830	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
831(99)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
833-834	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
835	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	u	u	u	u	u	u	u	
836	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	
837	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u												
901(100)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
902(101)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
903(102)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
904(103)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
905(104)	0	0	0	0	0	0	0	0	0	0	0	0	0	0																	
906(105)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
907(106)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
908(107)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
909(108)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
910(109)	0	0	0	0	0	0	0	0	0	0	0	0	0	0																	

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0, $\bar{e}$ = required in a redundant capacity but not energized until needed.

EXHIBIT 46 (Continued)

Unit	t_0 Injection-- Deploy Solar Panels	t_1 Begin Sun Acquisition	t_2 End Sun Acq., Start Canopus Acq.	t_3 End Canopus Acquisition	t_4 Turn Solar Stabilization System On	t_5 Begin Data Insertion	t_6 End Data Insertion	t_7 Begin M/C_1 Maneuver	t_8 End M/C_1 Maneuver	t_9 End Sun Acquisition	t_{10} End Canopus Acquisition	t_{11} Begin Data Insertion	t_{12} End Data Insertion	t_{13} Begin M/C_2	t_{14} End M/C_2	t_{15} End Sun Acquisition	t_{16} End Canopus Acquisition	t_{17} Receiver High-Gain Antenna Limit	t_{18} Set Canopus Sensor Cone Angle 1	t_{19} Transmitter Low-Gain Antenna Limit	t_{20} Transfer to Transmit Via High-Gain Antenna	t_{21} Set Canopus Sensor Cone Angle 2	t_{22} Set Canopus Sensor Cone Angle 3	t_{23} Half-Power Transmitter Limit	t_{24} Set Canopus Sensor Cone Angle 4	t_{25} End Cruise	t_{26} Begin Encounter	t_E Closest Approach	t_{27} End Encounter	t_{28} Begin Playback	t_{29} End Playback
Cumulative Time (hrs):			0.5	1.5	16	24	25	41	43	43.5	44.5	273.5	274.5	284.5	286.5	287	288	1752	2160	2376	2688	2976	3768	4248	4800	5950	5993	6000	6006	6013	6213
911$^{(110)}$	0																														
912$^{(111)}$	0																														
913$^{(112)}$	0																														
914$^{(113)}$	0																														
915$^{(114)}$	0																														
916$^{(115)}$												$0^{(4)}$																			
917$^{(116)}$												$0^{(4)}$																			
918$^{(117)}$												$0^{(4)}$																			
919$^{(118)}$												$0^{(4)}$																			
920$^{(119)}$	e	e	e	e	e	e	e	e	0																						
921$^{(120)}$	e	e	e	e	e	e	e	e	0																						
922$^{(121)}$	e	e	e	e	e	e	e	e	0																						
923$^{(122)}$	e	e	e	e	e	e	e	e	0																						
924$^{(123)}$	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0																
925$^{(124)}$	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0																
926$^{(125)}$	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0																
927$^{(126)}$	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0																
928$^{(127)}$	0																														
929$^{(128)}$	0																														
930$^{(129)}$	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0				
931$^{(130)}$	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	0				
932$^{(131)}$																											0				
933$^{(132)}$																											0				
934-936	u																														

KEY: A blank space indicates that the unit is not needed during this particular interval.
u = required.
e = energized.
0 = required in a redundant capacity.
0, $\overline{e}$ = required in a redundant capacity but not energized until needed.

EXHIBIT 46 (Continued)

	Injection--Deploy Solar Panels	Begin Sun Acquisition	End Sun Acq., Start Canopus Acq.	End Canopus Acquisition	Turn Solar Stabilization System On	Begin Data Insertion	End Data Insertion	Begin M/C$_1$ Maneuver	End M/C$_1$ Maneuver	End Sun Acquisition	End Canopus Acquisition	Begin Data Insertion	End Data Insertion	Begin M/C$_2$	End M/C$_2$	End Sun Acquisition	End Canopus Acquisition	Receiver High-Gain Antenna Limit	Set Canopus Sensor Cone Angle 1	Transmitter Low-Gain Antenna Limit	Transfer to Transmit Via High-Gain Antenna	Set Canopus Sensor Cone Angle 2	Set Canopus Sensor Cone Angle 3	Half-Power Transmitter Limit	Set Canopus Sensor Cone Angle 4	End Cruise	Begin Encounter	Closest Approach	End Encounter	Begin Playback	End Playback
	t_0	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	t_{14}	t_{15}	t_{16}	t_{17}	t_{18}	t_{19}	t_{20}	t_{21}	t_{22}	t_{23}	t_{24}	t_{25}	t_{26}	t_E	t_{27}	t_{28}	t_{29}
Unit \ Cumulative Time (hrs):			0.5	1.5	16	24	25	41	43	43.5	44.5	273.5	274.5	284.5	286.5	287	288	1752	2160	2376	2688	2976	3768	4248	4800	5950	5993	6000	6006	6013	6213
950	Probability of noncatastrophic impact																														
951	Probability solar panel not degrading to the extent the battery is required																														
952	Probability wrong target not acquired																														
953	Operational probability of adequate first maneuver																														
954	Operational probability of adequate second maneuver																														

KEY: A blank space indicates that the unit is not needed during this particular interval.
u = required.
e = energized.
0 = required in a redundant capacity.
0,ē = required in a redundant capacity but not energized until needed.

EXHIBIT 46 (Continued): REMARKS

1. A non-time-dependent unit. Its probability of surviving the interval(s) shown is based on a failure rate per number of expected cycles for that interval.
2. 3005-1 Required for DC-6 and DC-15; redundant to selected units of the data encoder and Canopus gate.
3. 3005-2 (same as 2)
4. 3006-1 (same as 2)
5. 3006-2 Required for DC-15, redundant to Canopus gate only.
6. 3007-1 (same as 2)
7. 3007-2 Redundant to selected units of CC and S
8. 3008-1 (same as 2)
9. 3008-2 (same as 7)
10. 3009 Required for DC-27; after t_{13}, redundant to selected units of CC and S.
11. 3010 (same as 2)
12. 3011 (same as 2)
13. 3012 (same as 5)
14. 3013 (same as 2 and 7)
15. 3014 (same as 7)
16. 3015 (same as 5)
17. 3016 Required for DC-6, redundant to selected data encoder units and CC and S.
18. 3017 (same as 7)
19. 3018 (same as 2 and 7)
20. 3019 (same as 10)
21. 3020 (same as 2 and 7)
22. 3024* (same as 7)
23. 3026* Required for DC-6, redundant to selected units of data encoder.
24. 3030* Redundant to selected units of CC and S.
25. 3035* (same as 5)
26. 3037* (same as 7)
27. 3038* Redundant to Canopus tracking.

EXHIBIT 46 (Continued): REMARKS

28.	3041*	Redundant to the probability unit 951, the probability the solar panels do not degrade to the extent the battery is required.
29.	3044*	(same as 7)
30.	3045*	(same as 7)
31.	3051-2	(same as 17)
32.	3059-1	(same as 27)
33.	3066-1	(same as 5)
34.	3066-2	(same as 5)
35.	401	Redundant to 516 throughout mission; redundant to miscellaneous commands beginning at t_{18}.
36.	403	Redundant to miscellaneous commands beginning at t_{18}.
37.	408	Subject to failure only at the beginning of the time interval shown.
38.	425	(same as 36)
39.	426	(same as 36)
40.	427	Redundant to DC-17.
41.	427a	(same as 40)
42.	428	(same as 40)
43.	428a	(same as 40)
44.	429	(same as 40)
45.	429a	(same as 40)
46.	430	(same as 40)
47.	430a	(same as 40)
48.	431	Redundant to DC-10.
49.	431a	(same as 48)
50.	432	Redundant to DC-11.
51.	432a	(same as 50)
52.	433	Redundant to Canopus tracking; not needed in normal path.
53.	433a	(same as 52)
54.	434	Redundant to DC-25.
55.	434a	(same as 54)

EXHIBIT 46 (Continued): REMARKS

56.	435	Redundant to DC-26.
57.	435a	(same as 56)
58.	436	Redundant to DC-4.
59.	436a	(same as 58)
60.	502	Redundant to 950, the probability of noncatastrophic impact and to 951, the probability the solar panels do not degrade.
61.	503	Used to t_{15} +168 hours.
62.	506	Redundant to 507.
63.	507	Redundant to 506 and 950.
64.	509	Redundant to 950.
65.	510	(same as 64)
66.	511	(same as 64)
67.	513	(same as 64)
68.	515	Redundant to 506 and 507.
69.	516	Redundant to 517 and selected units of CC and S.
70.	517	Redundant to 516 and selected units of CC and S.
71.	602	Redundant to 950.
72.	603	Redundant to 950.
73.	606	Redundant to 950 and to inertial roll control.
74.	607	Redundant to 950 and to inertial roll control.
75.	608	Redundant and energized, related unit 610; $0, \bar{e}$ related to 950.
76.	610	Redundant to 608, 607, 606, 510, 511, 513, and 509 .
77.	612	Redundant to 613 and cross-coupled with 620.
78.	613	Redundant to 612 and cross-coupled with 621.
79.	615	Not needed in usual sense; affects failure rates of 612 and 613.
80.	616	Redundant to inertial roll control.
81.	617	Redundant to DC-15.
82.	618	Redundant to 950.
83.	620	Redundant to 621 and cross-coupled with 612.

EXHIBIT 46 (Continued): REMARKS

84.	621	Redundant to 620 and cross-coupled with 613.
85.	622	Redundant to inertial roll control.
86.	623	Redundant to Canopus acquisition.
87.	627	Redundant to inertial roll control.
88.	801	Redundant to Canopus tracking.
89.	806	Redundant to Canopus tracking.
90.	813	Redundant to 817, 818, 820.
91.	814	(same as 90)
92.	815	(same as 90)
93.	816	(same as 90)
94.	817	Redundant to 813, 814, 816.
95.	818	(same as 94)
96.	819	(same as 94)
97.	820	(same as 94)
98.	827	Redundant to 831, 833, 834.
99.	831	Redundant to 827, 829, 830.
100.	901	Redundant to 906, 907, 908, 909, 910.
101.	902	(same as 100)
102.	903	(same as 100)
103.	904	(same as 100)
104.	905	(same as 100)
105.	906	Redundant to 901, 902, 903, 904, 905.
106.	907	(same as 105)
107.	908	(same as 105)
108.	909	(same as 105)
109.	910	(same as 105)
110.	911	Redundant to 928 and 929.
111.	912	Related to 914, see diagram.
112.	913	Related to 915, see diagram.
113.	914	Related to 912, see diagram.

EXHIBIT 46 (Continued): REMARKS

114.	915	Related to 913, see diagram.
115.	916	Related to 917, 925, branch 2, see diagrams.
116.	917	Related to 916, 924, branch 1, see diagrams.
117.	918	Related to 919, 927, branch 2, see diagrams.
118.	919	Related to 918, 926, branch 1, see diagrams.
119.	920	Related to 921 and branch 2, see diagrams.
120.	921	Related to 920 and branch 1, see diagrams.
121.	922	Related to 923 and branch 2, see diagrams.
122.	923	Related to 922 and branch 1, see diagrams.
123.	924	Related to 917, 925, branch 2, see diagrams.
124.	925	Related to 916, 924, branch 1, see diagrams.
125.	926	Related to 919, 927, branch 2, see diagrams.
126.	927	Related to 918, 926, branch 1, see diagrams.
127.	928	Redundant to 911.
128.	929	Redundant to 911.
129.	930	Redundant to 931 and branch 2, see diagrams.
130.	931	Redundant to 930 and branch 1, see diagrams.
131.	932	Redundant to DC-25.
132.	933	Redundant to DC-25.

IV. NUMERICAL ASSESSMENT

A. Unit Failure Rates

The extensive unit breakdown which has resulted from the analysis of each subsystem provides the flexibility required to recognize and account for the many configurations of the system, allowing it to reach at least some (if not all) of the mission objectives. To conduct a numerical assessment, it is essential that a failure rate be assigned to each unit. This is accomplished by enumerating the piece parts which compose each unit and summing the part failure rates. The details of this parts counting activity are contained in Appendix A, and the component failure rates which have been employed are listed in Appendix B.

As an aid to interpreting the numerical results presented, a summary of the estimated unit failure rates is shown in Exhibit 47. From this tabulation, it is possible to identify those units that significantly degrade reliability, and, conversely, those which have little effect on it. Since this property is sometimes merely a function of the number of parts embraced by a unit, the total number of parts within each unit also is given.

B. Classical Reliability

The introduction of worth assignments to account for degraded operating paths is a concept which finds greatest applicability in consideration of a total system charged with the accomplishment of a number of specified objectives. It generally happens that meeting an objective demands the operability of a group of equipments which cannot be described by a simple functional name. This is often a set of functional subsystems, or parts thereof, which, operating in combination, produce the desired result. Thus, a system viewpoint of reliability, developed by means of the figure-of-merit technique, will be concerned with the computation of reliability of such combinations of equipment.

This tends to leave unanswered those questions (of special interest to the subsystem designer) regarding the reliability of discrete subsystems or the probability of successful occurrence of interesting events

EXHIBIT 47 - UNIT FAILURE RATES

Unit Number	Name	Number of Components	Failure Rate, $\lambda \times 10^{-6}$/hour
Science Equipment			
101	Cover Latch	1	.02
102	Hinge and Actuating Spring	2	1.07a(1)
103	Motor and Gearing	3	10.38
104	Scan Electronics	223	35.98
105	Recorder Mechanism:		
	During Mission	31	9.80
	At Encounter Only	30	93.04
106	Record Electronics	121	15.10
107	Playback Electronics	1,100	70.16
Data Encoder			
2001	Rate Generator	185	16.03(2)
2002	Mode Selector	99	17.55(2)
2003-1	Switching Circuits (Partial)	6	3.60
2003-2	Switching Circuits (Partial)	116	11.51(2)
2003-3	Switching Circuits (Partial)	0	0
2003-4	Switching Circuits (Partial)	0	0
2004-1	PNG "OR" (Partial)	91	5.33(2)
2004-2	PNG "OR" (Partial)	91	5.33(2)
2005	PNG "A"	188	8.70(2)
2006	PNG "B"	188	8.70(2)
2007	Power Supply	127	19.25
2008	Modulator	192	13.12
2010	Mixer Amplifier	17	1.62
2011	Data Selector	194	10.00(2)
2012-1	ADC "OR" (Partial)	15	1.29

Notes: (1) a = actuations.

(2) Failure rate for series components only. See Appendix A for computation of rate for remaining components.

EXHIBIT 47 (Continued)

Unit Number	Name	Number of Components	Failure Rate, $\lambda \times 10^{-6}$/hour
Data Encoder (continued)			
2012-2	ADC "OR" (Partial)	15	1.29
2013	ADC "A"	18	2.20
2014	ADC "B"	18	2.20
2015	Isolation Amplifier "A"	23	5.50
2016	Isolation Amplifier "B"	23	5.50
2017	10, 11, and Medium-Speed Drive	86	6.30
2018	Science Selection Circuits	49	3.77
2019	Master Counter	89	5.91
2020	100 Synchronizer	29	2.56
2021	200 Synchronizer	29	2.56
2022	300 Synchronizer	29	2.56
2023	Word Sync Amplifier	14	1.00
2025	100 Sequencer	77	9.08
2025-1	100 Sequencer (Partial)	23	1.92
2025-2	100 Sequencer (Partial)	6	.78
2025-3	100 Sequencer (Partial)	6	.78
2025-4	100 Sequencer (Partial)	6	.78
2025-5	100 Sequencer (Partial)	6	.78
2025-6	100 Sequencer (Partial)	6	.78
2025-7	100 Sequencer (Partial)	6	.78
2025-8	100 Sequencer (Partial)	6	.78
2025-9	100 Sequencer (Partial)	6	.78
2025-10	100 Sequencer (Partial)	6	.78
2026	110 Sequencer (Same as 100 Sequencer)	77	9.08
2027	200 Sequencer (Same as 100 Sequencer)	77	9.08
2028	212 Sequencer (Same as 100 Sequencer)	77	9.08

EXHIBIT 47 (Continued)

Unit Number	Name	Number of Components	Failure Rate, $\lambda \times 10^{-6}$/hour
Data Encoder (continued)			
2029	1.5-Volt Bucking Supply	9	1.31
2030	300 Sequencer (Same as 100 Sequencer)	77	9.08
2031	401 Sequencer (Same as 100 Sequencer)	77	9.08
2032	1.5-Volt Bucking Supply	9	1.31
2033	423 Sequencer (Same as 100 Sequencer)	77	9.08
2034	0.5-Volt Bucking Supply	12	1.34
2035	Driver	13	.85
2037	40, 41, 42, 43 Drive	24	1.68
2038	Low-Speed Deck Position Indicator	149	10.09
2039	Transfer Register	118	8.88
2040	Digital Word Programmer	342	26.08
2041	Sync Circuits	64	5.20
2042	Event Register, No. 1	22	1.59
2043	Event Register, No. 2	22	1.59
2044	Event Register, No. 3	22	1.59
2045	Event Register, No. 4	22	1.59
2046	Command Detector Monitor (VCO)	232	17.32
2047	Command Detector Monitor (In/Out Lock)	42	2.42
2048	Event Timer	283	16.97
2049	0.5-Volt Bucking Supply	12	1.34
2050	Low-Level Amplifier	57	9.15
2051	101 Switch, Single Pole	22	4.75
2052-2053	102-103 Switches, Single Pole	22	4.75
2054-2063	105-114 Switches, Single Pole	22	4.75

EXHIBIT 47 (Continued)

Unit Number	Name	Number of Components	Failure Rate, $\lambda \times 10^{-6}$/hour
Data Encoder (continued)			
2064-2066	117-119 Switches, Single Pole	22	4.75
2068-2076	202-210 Switches, Single Pole	22	4.75
2077-2080	213-216 Switches, Single Pole	22	4.75
2081-2089	221-229 Switches, Single Pole	22	4.75
2090-2099	300-309 Switches, Single Pole	22	4.75
2100	403 Switch (T), Double Pole	27	3.25
2101	406 Switch (T), Double Pole	27	3.25
2102-2104	415-417 Switches, Single Pole	22	4.75
2105	422 Switch, Single Pole	22	4.75
2106	425 Switch, Single Pole	22	4.75
2107	427 Switch, Single Pole	22	4.75
2108-2109	211-212 Switches (T), Double Pole	27	3.25
2110-2112	217-219 Switches (T), Double Pole	27	3.25
2113-2114	401-402 Switches (T), Double Pole	27	3.25
2115-2116	404-405 Switches (T), Double Pole	27	3.25
2117-2124	407-414 Switches (T), Double Pole	27	3.25
2125-2128	418-421 Switches (T), Double Pole	27	3.25
2129-2130	423-424 Switches (T), Double Pole	27	3.25
2131	426 Switch (T), Double Pole	27	3.25
2132-2143	428-439 Switches (T), Double Pole	27	3.25
2144-2145	10-11 Switches, Single Pole	22	4.75
2146-2149	40-43 Switches, Single Pole	22	4.75
2151	Current Generator	12	1.67

EXHIBIT 47 (Continued)

Unit Number	Name	Number of Components	Failure Rate, $\lambda \times 10^{-6}$/hour
Command Detection and Decoding			
3000	Command Detector (Partial)	792	62.35
3001-1	Command Detector (Partial)	30	2.23
3002	Programming Logic and Counter	321	23.84
3003	Shift Register, Stages 1 and 2	42	2.12
3004-1	In Lock Switch (Partial)	11	.346
3004-2	In Lock Switch (Partial)	12	1.76
3005-1	Shift Register (Partial)	11	.68
3005-2	(Same as 3005-1)	11	.68
3006-1	(Same as 3005-1)	11	.68
3006-2	(Same as 3005-1)	11	.68
3007-1	(Same as 3005-1)	11	.68
3007-2	(Same as 3005-1)	11	.68
3008-1	(Same as 3005-1)	11	.68
3008-2	(Same as 3005-1)	11	.68
3009-3020	Shift Register Drivers (Partial)	12	1.76
3021*-3046*	Decoding Gate (Partial)	(3)	(3)
3081*	Decoding Gate	(3)	(3)
3047-1	DC-1 Switch (Partial)	5	.223
3047-2	DC-1 Switch (Partial)	7	1.35
3048-1	DC-2A Switch (Partial)	5	.223
3048-2	DC-2A Switch (Partial)	7	1.35
3049-1	DC-4A Switch (Partial)	5	.223
3049-2	DC-4A Switch (Partial)	7	1.35
3050-1	DC-5 Switch (Partial)	5	.223
3050-2	DC-5 Switch (Partial)	7	1.35

Note: (3) For number of component parts and unit failure rates, see Appendix A, section 2.

EXHIBIT 47 (Continued)

Unit Number	Name	Number of Components	Failure Rate, $\lambda \times 10^{-6}$/hour
Command Detection and Decoding (continued)			
3051-1	DC-6 Switch (Partial)	5	.223
3051-2	DC-6 Switch (Partial)	7	1.35
3052-1	DC-7 Switch (Partial)	5	.223
3052-2	DC-7 Switch (Partial)	7	1.35
3053-1	DC-8 Switch (Partial)	5	.223
3053-2	DC-8 Switch (Partial)	7	1.35
3054-1	DC-2B Switch (Partial)	11	.346
3054-2	DC-2B Switch (Partial)	12	1.76
3055-1	DC-3 Switch (Partial)	16	.506
3055-2	DC-3 Switch (Partial)	12	1.76
3057-1	DC-9 Switch (Partial)	16	.506
3057-2	DC-9 Switch (Partial)	12	1.76
3058-1	DC-10 Switch (Partial)	16	.506
3058-2	DC-10 Switch (Partial)	12	1.76
3059-1	DC-11 Switch (Partial)	16	.506
3059-2	DC-11 Switch (Partial)	12	1.76
3060-1	DC-12 Switch (Partial)	16	.506
3060-2	DC-12 Switch (Partial)	12	1.76
3061-1	DC-13A Switch (Partial)	11	.346
3061-2	DC-13A Switch (Partial)	12	1.76
3062-1	DC-13B Switch (Partial)	11	.346
3062-2	DC-13B Switch (Partial)	12	1.76
3063-1	DC-13C Switch (Partial)	11	.346
3063-2	DC-13C Switch (Partial)	12	1.76
3064-1	DC-14A Switch (Partial)	11	.346
3064-2	DC-14A Switch (Partial)	12	1.76
3065-1	DC-14B Switch (Partial)	11	.346
3065-2	DC-14B Switch (Partial)	12	1.76

EXHIBIT 47 (Continued)

Unit Number	Name	Number of Components	Failure Rate, $\lambda \times 10^{-6}$/hour
Command Detection and Decoding (continued)			
3066-1	DC-15 Switch (Partial)	16	.506
3066-2	DC-15 Switch (Partial)	12	1.76
3067-1	DC-16 Switch (Partial)	16	.506
3067-2	DC-16 Switch (Partial)	12	1.76
3068-1	DC-17 Switch (Partial)	16	.506
3068-2	DC-17 Switch (Partial)	12	1.76
3069-1	DC-18 Switch (Partial)	16	.506
3069-2	DC-18 Switch (Partial)	12	1.76
3070-1	DC-19 Switch (Partial)	16	.506
3070-2	DC-19 Switch (Partial)	12	1.76
3071-1	DC-20 Switch (Partial)	16	.506
3071-2	DC-20 Switch (Partial)	12	1.76
3072-1	DC-21 Switch (Partial)	16	.506
3072-2	DC-21 Switch (Partial)	12	1.76
3073-1	DC-23 Switch (Partial)	16	.506
3073-2	DC-23 Switch (Partial)	12	1.76
3074-1	DC-24 Switch (Partial)	16	.506
3074-2	DC-24 Switch (Partial)	12	1.76
3075-1	DC-25A Switch (Partial)	11	.346
3075-2	DC-25A Switch (Partial)	12	1.76
3076-1	DC-25B Switch (Partial)	11	.346
3076-2	DC-25B Switch (Partial)	12	1.76
3077-1	DC-26 Switch (Partial)	16	.506
3077-2	DC-26 Switch (Partial)	12	1.76
3078-1	DC-27 Switch (Partial)	16	.506
3078-2	DC-27 Switch (Partial)	12	1.76
3079	Transformer-Rectifier	19	3.44
3080	Amplifier and Sync Switch	14	2.08

EXHIBIT 47 (Continued)

Unit Number	Name	Number of Components	Failure Rate, $\lambda \times 10^{-6}$/hour
Command Detection and Decoding (continued)			
3082	Control Flip-Flop	22	1.36
3083	Event Logic and Switch	23	2.88
3084	CC and S Alert Logic and Switch	15	2.23
3085	CC and S Sync and QC Logic and Switches	35	5.33
Central Computer and Sequencer			
401	Transformer-Rectifier	23	4.60
402	Oscillator	80	7.82
403	1-pps, 25-pps, and 1-ppm Counter	322	25.44
404	Magnetic Divider (1/1000)	92	6.33
405	Launch Matrix	46	9.48
406	Driver	16	1.55
406a	Relay	2	.75
407	Driver	16	1.55
407a	Relay	2	.75
408	Driver	16	1.55
408a	Relay	2	.75
409	Input Decoder	268	23.64
410	Address Register	89	8.26
411	Maneuver Duration (Readin-Readout)	116	9.65
412	Pitch Maneuver Duration	87	7.81
413	Pitch Polarity Set	18	1.18
414	Roll Maneuver Duration	87	7.81
415	Roll Polarity Set	18	1.18
416	Velocity Maneuver Duration	89	7.97
417	Maneuver Clock	107	9.36

EXHIBIT 47 (Continued)

Unit Number	Name	Number of Components	Failure Rate, $\lambda \times 10^{-6}$/hour
Central Computer and Sequencer (continued)			
418	Driver	20	1.94
419	Relay Set Coil	2	.75
420	Driver	35	4.77
421	Relay Set Coil	2	.75
422	Relay Set Coil	2	.75
424	Start Pitch Duration Switch	19	1.33
425	Magnetic Divider (1/2000)	115	8.19
426	Master Time Matrix	73	10.09
427	Driver	20	1.94
427a	Relay	4	1.50
428	Driver	17	1.70
428a	Relay	2	.75
429	Driver	17	1.70
429a	Relay	2	.75
430	Driver	17	1.70
430a	Relay	2	.75
431	Driver	17	1.70
431a	Relay	1	.60
432	Driver	17	1.70
432a	Relay	1	.60
433	Driver	14	1.46
433a	Relay	1	.60
434	Driver	21	2.09
434a	Relay	2	1.20
435	Driver	17	1.70
435a	Relay	1	.60
436	Driver	17	1.70
436a	Relay	1	.60

EXHIBIT 47 (Continued)

Unit Number	Name	Number of Components	Failure Rate, $\lambda \times 10^{-6}$/hour
Central Computer and Sequencer (continued)			
437	Driver	25	2.20
438	Relay Set Coil	2	.75
439	Pitch and Roll Stop Logic and Driver	13	1.27
440	Relay Set Coil	2	.75
441	Relay Reset Coil	2	.75
442	Driver	34	4.60
443	Relay Set Coil	2	.75
444	Start Roll Duration Switch	19	3.75
445	Relay Reset Coil	2	.75
446	Driver	31	4.52
447	Relay Coil	1	.60
448	Start Velocity Duration Switch	43	3.13
449	Velocity Stop Logic and Driver	27	2.73
450	Relay Coil	1	.20
451	Driver	56	6.44
452	Relay Reset Coil	2	.75
453	Relay Reset Coil	2	.75
454	Driver	16	1.41
455	M/C Start-Stop Relay	6	.93
Power Supply			
501	Solar Panel Circuitry	117	29.36
502	Battery	20	14.05
503	Battery Charger/Share Protector	75	14.86
504	Power Distribution and Switching Unit	13	2.96
505	2.4-kc Sync	62	4.49
506	Booster Regulator No. 1	69	15.63

EXHIBIT 47 (Continued)

Unit Number	Name	Number of Components	Failure Rate, $\lambda \times 10^{-6}$/hour
Power Supply (continued)			
507	Booster Regulator No. 2	71	16.38
508	2.4-kc Main Inverter	44	11.44
509	2.4-kc Maneuver Load Inverter	44	11.44
510	Sync, 400 cycles, 1 phase	60	4.75
511	Sync, 400 cycles, 3 phase	26	2.76
512	400-Cycle, 1-Phase Inverter	36	5.59
513	400-Cycle, 1-Phase Inverter	25	10.87
515	Booster Backup Sensor	39	5.38
516	LC Oscillator	31	2.42
517	Sync Source Transfer	25	4.85
Attitude Control			
601	Time Delay Switch	1	.25
602	Acquisition Sun Sensors	8	3.04
603	Sun Gate Sensors and Relay	12	2.42
605	Attitude Control T/R	11	1.94
606	Gyro T/R	28	7.32
607	Gyro Control	55	8.66
608	Pitch and Yaw Gyros	104	52.94
610	Pitch and Yaw S. A. Compensation	21	2.33
611	Switch Amplifiers and Switches (Pitch and Yaw)	149	32.81
612	Valves and Nozzles and Gas Supply	(4)	(4)
613	Valves and Nozzles and Gas Supply	(4)	(4)

Note: (4) For number of component parts and unit failure rates, see Appendix A, section 2.

EXHIBIT 47 (Continued)

Unit Number	Name	Number of Components	Failure Rate, $\lambda \times 10^{-6}$/hour
Attitude Control (continued)			
614	Cruise Sun Sensors and Regulator	16	3.68
615	Solar Pressure Stabilization	(4)	(4)
616	Canopus Sensor and Electronics	169	21.96
617	Canopus Gate	83	8.89
618	Roll Gyro	51	26.25
619	Switching Amplifier and Power Switch (Roll)	72	10.22
620	Valves and Nozzles and Gas Supply (Roll)	(4)	(4)
621	Valves and Nozzles and Gas Supply (Roll)	(4)	(4)
622	Derived Rate Damping (Roll)	20	1.54
623	Turn Command Generator	34	5.12
624	CW One-Shot	21	2.43
625	CCW One-Shot	21	2.43
626	Relay	5	.92
627	Cone Angle Update Circuits	50	5.71
Trajectory Correction			
701	Autopilot and Vane Actuators	145	74.97
702	Midcourse Maneuver Motor, Tankage and Plumbing	7	206.40c(5)
Radio			
801	CS-2 CW Logic	(6)	1.44
802	CS-1 CW Logic	(6)	1.44

Notes: (4) For number of component parts and unit failure rates, see Appendix A, section 2.

(5) c = cycles.

(6) 161 components divided among 11 units.

EXHIBIT 47 (Continued)

Unit Number	Name	Number of Components	Failure Rate, $\lambda \times 10^{-6}$/hour
Radio (continued)			
803	CS-2 CCW Logic	(6)	1.44
804	Switching Transformer-Rectifier	1	2.47
805	CS-1 and CS-2 Magnetization Circuits	1	.10
806	Cyclic Switching Logic	(6)	1.44
807	Receiver Transformer-Rectifier	1	2.47
808	Preamp and Mixers and First IF	67	7.00
809	Second Mixer, IF and AGC	187	18.51
810	Receiver Multipliers and Divider	160	15.68
811	Range Detector	59	4.56
812	Video Amplifier	91	6.94
813	Isolation Amplifier	18	1.82
814	Multipliers and Amplifiers	133	14.12
815	Exciter Transformer-Rectifier	1	2.47
816	CS-5 CW Logic	(6)	1.44
817	Isolation Amplifier	18	1.82
818	Multipliers and Amplifiers	133	14.12
819	Exciter Transformer-Rectifier	1	2.47
820	CS-5 CCW Logic	(6)	1.44
821	CS-5 Magnetization Circuits	1	.05
823	Transfer Circuits	5	.31
824	Auxiliary Oscillator	14	2.65
825	Transfer Circuits	5	.31
826	Auxiliary Oscillator	14	2.65
827	PA-1 and Converter	59	21.23

Note: (6) 161 components divided among 11 units.

EXHIBIT 47 (Continued)

Unit Number	Name	Number of Components	Failure Rate, $\lambda \times 10^{-6}$/hour
Radio (continued)			
829	CS-3 CW Logic	(6)	1.44
830	CS-4 CW Logic	(6)	1.44
831	PA-2 and Converter	59	21.23
833	CS-3 CCW Logic	(6)	1.44
834	CS-4 CCW Logic	(6)	1.44
835	CS-3 and CS-4 Magnetization Circuits	1	.10
836	VCO, Phase Detector, and Loop Filter	155	16.54
837	CS-1 CCW Logic	(6)	1.44
Pyrotechnics			
901	Separation Switch	1	.12cs
902	Transformer	1	2.20
903	Control Rectifiers and Capacitor	6	.76
904	Power Rectifiers and Capacitor	8	.64
905	Power Rectifiers and Capacitor	8	.64
906	Separation Switch	1	.12cs
907	Transformer	1	2.20
908	Control Rectifiers and Capacitor	6	.76
909	Power Rectifiers and Capacitor	8	.64
910	Power Rectifiers and Capacitor	8	.64
911	Time Delay Switch	1	.25
912	Silicon-Controlled Rectifier	8	1.21
913	Silicon-Controlled Rectifier	9	1.43
914	Silicon-Controlled Rectifier	8	1.21
915	Silicon-Controlled Rectifier	9	1.43

Note: (6) 161 components divided among 11 units.

EXHIBIT 47 (Continued)

Unit Number	Name	Number of Components	Failure Rate, $\lambda \times 10^{-6}$/hour
Pyrotechnics (continued)			
916	Relay K2	2	.75
917	Relay K2'	2	.75
918	Relay K4	2	.75
919	Relay K4'	2	.75
920	Silicon-Controlled Rectifier, First Maneuver	8	1.21
921	Silicon-Controlled Rectifier, First Maneuver	8	1.21
922	Silicon-Controlled Rectifier, First Maneuver	7	.99
923	Silicon-Controlled Rectifier, First Maneuver	7	.99
924	Silicon-Controlled Rectifier, Second Maneuver	8	1.21
925	Silicon-Controlled Rectifier, Second Maneuver	8	1.21
926	Silicon-Controlled Rectifier, Second Maneuver	7	.99
927	Silicon-Controlled Rectifier, Second Maneuver	7	.99
928	Filter	3	.17
929	Filter	3	.17
930	Silicon-Controlled Rectifier	6	.20
931	Silicon-Controlled Rectifier	6	.20
932	Filter	3	.17
933	Filter	3	.17
934	Hinges	8	.16a
935	Spring Actuators	4	4.20a
936	Hydraulic Snubbers	4	0

EXHIBIT 47 (Continued)

Unit Number	Name	Probability
Operational Probabilities		
950	Probability of No Meteoritic Impact	.9
951	Probability of Solar Panels Not Degrading to the Extent That Battery Is Required	.75
952	Probability That Wrong Target Is Not Acquired	.9
953	Operational Probability of Adequate First Maneuver	.9782
954	Operational Probability of Adequate Second Maneuver	.9782

that are not primary objectives. Inquiries of this nature can be satisfied by computing the reliabilities of selected subsystems or events in a classical fashion, conditioned by the assumption that all remaining parts or subsystems are operating as scheduled. Mathematical models for performing such calculations on Mariner C subsystems were presented in the interim report.

Except for the effect of variable operating times, the most significant factor influencing a classical reliability prediction is the complexity of the equipment under consideration. An estimate of subsystem complexity can be gained by totaling the parts count, although this judgment must be tempered by knowledge of the parts replication or redundancy which characterizes the subsystem. In this view, it is of interest to list the total parts count, by subsystem, arrived at in this study.

Science subsystem	1,511 parts
Data encoder	6,282 parts
Command subsystem	2,284 parts
CC and S	2,241 parts
Power supply	757 parts
Attitude control	943 parts
Trajectory correction	157 parts
Radio	1,345 parts
Pyrotechnics	191 parts

The grand total is nearly 16,000 parts, and it must be remembered that this does not include the data automation system, the scientific instruments, the telemetry transducers, or isolation filters for GSE monitors. The list affords some insight into the results which can be expected.

Any interpretation of the classical reliabilities predicted here must recognize the conditions which surround each calculation. In general, it is assumed that all inputs and externally supplied services needed for the proper operation of a subsystem are available with a reliability of unity. In some instances, however, this assumption is not made because particular segments of one subsystem may function solely for the benefit of another subsystem and should, in reality, be charged to that subsystem from a reliability standpoint. The descriptions given in this subsection make all such conditions explicit.

The events and subsystem functions considered to be of most interest and importance are listed below, with an effort made to display the more independent functions first.

Solar panel deployment
Power supply
Command capability
Radio
Central computer and sequencer
Attitude control
Trajectory correction
Data encoder

1. Solar Panel Deployment

The unit configuration needed for this event is that which is illustrated in Exhibits 43 and 44. The reliability of the separation timer, unit 911, is included, and it is assumed that signal L-1 is not present. Basic spacecraft power is assumed to be available. The total operating time is only a few minutes, and this event can be considered as almost wholly dependent upon the one-shot units involved.

The calculated reliability is 0.999996, which can be viewed as a prediction that panel deployment will fail to occur only once in more than 100,000 trials.

The considerable use of redundancy in the implementation of this event makes it natural to inquire as to what reliability gains have been effected by this replication. To answer this question, a system was postulated which contained one set of eight squibs, a set of eight single pin latches, two silicon-controlled rectifiers, and one current storage branch. This effectively removes all redundancy, yielding a calculated reliability of 0.999200. Thus, the chance of failure has increased to about once in 1,000 trials. This event, which is so vital to any mission success, needs to be extremely reliable, and the extensive use of redundancy has truly effected a significant reliability improvement.

2. Power Supply

The operation of the spacecraft power supply is dependent, over the greater portion of the mission, upon successful solar panel deployment and correct attitude orientation in the pitch and yaw axes. It has been assumed that conditions have been satisfied except for scheduled acquisitions and maneuvers. The only units which enter these calculations, therefore, are the power supply units as configured in Exhibits 28, 29, and 30, together with units 401 and 402 from the CC and S, which are used to provide a redundant frequency reference. The battery is required during acquisitions and maneuvers and as a backup to the solar panels during encounter. The battery charger is considered as being needed during periods prior to maneuvers and in the first two weeks of cruise.

With these conditions established, the power supply reliability was computed for several points along the mission profile:

	Time (hours)	Predicted Reliability
First maneuver	44	0.996
Second maneuver	288	0.955
	750	0.954
Mariner R mission	2,600[1]	0.871
	4,500	0.792
Encounter	6,000	0.720
End playback	6,213	0.711

This can be compared with the estimated reliability of the Mariner R power supply, which was 0.716 for 2,600 hours.

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[1] Where predicted reliabilities are tabulated in the sequel, the mission time equivalent to a Mariner R mission (2,600 hours) is listed for comparative purposes. Qualifications for comparing the reliabilities of the two types of missions and spacecraft also are presented as appropriate.

3. Command Capability

This capability is determined by the operating condition of the command detector and decoder and of the radio receiver. Although receiver reliability is computed separately in a subsection to follow, it did not appear realistic simply to assume an operable receiver in any assessment of command reliability. This is justified on the basis that the receiver is truly needed only for doppler tracking and command reception, and, for most of the mission, this latter function is of great importance.

The computation made here answers the question, "What is the reliability of executing a typical command at various times during the mission?" To perform this execution, a variety of units are required. Radio units 801, 802, and 803 are required, as shown in Exhibit 38, along with receiver units 807, 808, 809, 836, and 810 in series, as depicted in Exhibit 39. The common units 3079, 3000, 3001-1, 3002, 3003, and 3080 from Exhibit 16 are required, and the units for DC-3 as a typical command are included. These are shown in Exhibit 17 and consist of units 3005, 3006, 3007, 3008-2, 3009, 3011, 3014, 3015, 3018, 3019, 3023, and 3055-2. These conditions assure that the resultant reliability applies to a specific command only and is not dependent upon units which are uniquely associated with any other command.

The predicted reliability of a typical command is as follows:

	Time (hours)	Predicted Reliability
First maneuver	44	0.992
Second maneuver	288	0.952
	750	0.879
Mariner R mission	2,600	0.634
	4,500	0.457
Encounter	6,000	0.352
End playback	6,213	0.340

This compares, although not directly, with the predicted command reliability for Mariner R which was 0.233 for 2,600 hours. The Mariner R result covers the execution of all commands rather than a typical command; hence, it would be expected to be somewhat lower than if it had been calculated on a basis comparable to that being used for Mariner C. However, the difference is not estimated to be large.

Extensive effort was expended in this analysis to identify those failure modes which would inadvertently cause continuous execution of a command. This is one form of false command failure, and the probability of such an occurrence has been computed. Two cases of interest were examined. The first is the probability that any one or more of the entire command complement might fail in this manner. The probability of such a failure is estimated to be 0.041 for the entire mission. The second case, recognizing that false execution of certain commands might be disastrous, covers the probability that a single (typical) command might be falsely executed. This is found to be less than 0.0008 for the entire mission. These false command probabilities were arrived at by calculating the failure probabilities of units such as 3055-1, shown in Exhibit 19.

4. Radio Functions

Obviously, the radio performs at least two well-defined functions, since it acts as a receiver and as a transmitter. The reliabilties of interest appear to be those which characterize the receiving function alone, the transmitting function alone, and the combination function. For the receiver only, the unit configuration shown in Exhibit 38 is required for antenna control, except that Canopus tracking and signal MT-6 are assumed to be available. In addition, the receiver units, as illustrated in Exhibit 39, are required, with the exception of units 811 and 812 which perform the ranging function. The predicted reliability of this combination of units, operating as scheduled on the profile, is listed on the following page.

	Time (hours)	Predicted Reliability
First maneuver	44	0.997
Second maneuver	288	0.982
	750	0.955
Mariner R mission	2,600	0.852
	4,500	0.754
Encounter	6,000	0.685
End playback	6,213	0.675

If, now, one examines Exhibit 40 for the transmitter, it is observed that three excitation sources can be called upon. One of these, the VCO, demands that the receiver be operating, but the two auxiliary oscillators are self-contained as far as the transmitter is concerned. The question to be answered regarding the transmitter is, "What is its predicted reliability, including the triple redundancy of the excitation sources?" For antenna control, the unit configuration in Exhibit 42 must be operable as scheduled, but unity reliability is assumed for Canopus tracking and for the signal MT-5. The exciter units displayed in Exhibit 40 are required, and presence of the VCO implies that the receiver must operate to supply this redundancy. (Note that the receiver is not considered in series, reliability-wise, with the transmitter. It is needed only for a redundant excitation source.) The required power amplifier is supplied by including the units diagrammed in Exhibit 41. The calculated reliability of the transmitter is tabulated as follows:

	Time (hours)	Predicted Reliability
First maneuver	44	~1.000
Second maneuver	288	~1.000
	750	~1.000
Mariner R mission	2,600	0.998
	4,500	0.982
Encounter	6,000	0.971
End playback	6,213	0.970

This can be compared to the predicted reliability of the noncoherent transmission mode of the Mariner R transponder which was 0.853 for 2,600 hours. The comparison is not entirely accurate because the Mariner C transmitter reliability estimate also includes the possibility of coherent transmission; however, it should be stated that the contribution of this coherent mode to transmitter reliability is relatively small. To be precise, if the coherent transmission mode is eliminated, the predicted reliability of the Mariner C transmitter for 6,213 hours is 0.932.

The combined receiver and transmitter, operating in the coherent mode only, is the normal or desired state of affairs during the mission. For this capability, it has been assumed that all units of the receiver and transmitter, configured as in Exhibits 38 through 42, will be required for the appropriate time periods with these exceptions: (1) Canopus tracking is assured; (2) signals MT-5 and MT-6 are available; (3) the auxiliary oscillators, units 823, 824, 825, and 826, are not needed; and (4) the ranging units 811 and 812 are not required. On this basis, the predicted reliability of the coherent radio subsystem is as listed below:

	Time (hours)	Predicted Reliability
First maneuver	44	0.997
Second maneuver	288	0.982
	750	0.953
Mariner R mission	2,600	0.844
	4,500	0.729
Encounter	6,000	0.651
End playback	6,213	0.640

This compares quite directly with the predicted reliability of the coherent transponder of the Mariner R (0.688 for 2,600 hours).

5. Central Computer and Sequencer

During the early portion of the mission, the CC and S functions to decode and store the quantitative commands and to issue the appropriate signals to accomplish one or two midcourse maneuvers. Although the number of component parts involved in this operation is large, the operating time is short.

For this calculation, the CC and S units shown in Exhibits 24 and 25 are needed. It is assumed that these units remain energized throughout the 288 hours required for two maneuvers, with the exception of one-shot devices, such as relays. It is also assumed that the quantitative commands are received with perfect reliability. The reliability of this complement of units is then calculated as 0.994 for 44 hours (first maneuver) and as 0.948 for 288 hours (second maneuver).

Throughout the entire mission, the CC and S also serves in the role of a sequencer, issuing signals at preprogrammed intervals to the various subsystems of the spacecraft. For a typical launch signal, the reliability of units 401, 402, 403, 404, 405, 408, and 408a was computed for 16 hours, the longest period over which the launch matrix must operate. For this short operating time, the predicted reliability is 0.9991.

The sequencing functions beyond midcourse maneuver are illustrated in Exhibits 26 and 27. They require units 401, 402, 403, 404, 425, and 426, together with a typical driver and relay such as units 427 and 427a. The predicted reliability of this chain of units at various points in the mission is as follows:

	Time (hours)	Predicted Reliability
	750	0.953
Mariner R mission	2,600	0.847
	4,500	0.750
Encounter	6,000	0.681
End playback	6,213	0.672

This cannot be properly compared to the CC and S reliability for Mariner R (predicted as 0.708 for 2,600 hours). The Mariner R reliability included all parts of the CC and S and covered the requirement that all signals would be given rather than a typical signal. Another fact which prevents any accurate comparison concerns the failure rate used for film resistors (see Appendix B). This was the only subsystem on Mariner R for which a substantial number of film resistors had been identified, and a very conservative rate was applied to them. The revised rate now in use would have raised the predicted reliability of the CC and S on Mariner R to some extent, although the exact improvement has not been calculated. The CC and S subsystems, at least for the sequencing functions, are very similar on the two versions of Mariner, and it would be expected that their reliabilities would be comparable if calculated on the same basis.

6. Attitude Control

This subsystem presents the opportunity of posing a number of interesting and significant questions regarding the reliability of its operation. Of first importance is its ability to acquire and track the sun, an operation which must be successful if any worthwhile functions are to be performed by the spacecraft. In calculating this reliability, allowance has been made for three sun acquisitions, an initial acquisition and one after each of two maneuvers. For these acquisitions, the unit configuration pictured in Exhibit 31 is used with the assumption that the signal L-2, which turns on the subsystem, has been received. For all other time periods, the connection of units shown in Exhibit 32 forms the basis for the calculations. The solar pressure stabilization system operates after the receipt of signal L-3, which is given unity reliability. The reliability tabulation given below starts with reliability as predicted for the period ending with acquisition after the first maneuver, and, therefore, includes the initial acquisition.

	Time (hours)	Predicted Reliability
First maneuver	44	0.996
Second maneuver	288	0.977
	750	0.958
Mariner R mission	2,600	0.889
	4,500	0.823
Encounter	6,000	0.774
End playback	6,213	0.767

Reference to the Mariner R reliability calculations reveals that the sun tracking function only was predicted to be 0.903 reliable for 2,600 hours. This did not include any acquisitions, however.

The acquisition of the star Canopus is an event of particular significance inasmuch as this capability has not been previously demonstrated. To compute its reliability, the necessity for initial sun acquisition and sun tracking during Canopus acquisition has been recognized. For roll axis orientation, the units shown in Exhibit 34 have been included, and no assumptions regarding reliability of commands DC-15 and DC-21 have been made. These are the gate override command and the roll override command, respectively. They have been included at their normal reliability, which means that 24 units from the command subsystem and 6 units from the radio subsystem have entered into this calculation. This is considered justifiable on the basis that these commands implement important redundant paths that, if ignored, would unduly penalize the subsystem reliability estimate. On the other hand, if they are introduced with a reliability of unity, they completely mask the reliability of several important parts of the acquisition function. Accordingly, it was deemed most appropriate to allow them to assume normal reliability with full dependence on the radio and the command detector and decoder. For these conditions, the Canopus acquisition event is accomplished with a predicted reliability of 0.9995 which reflects, of course, the short operating times involved. This is equivalent, in a reciprocal sense, to 5 failures in 10,000 trials.

Complete orientation of the spacecraft demands that both celestial references be acquired each time an acquisition is called for and that they be tracked throughout the mission. Thus, the complement of units illustrated in Exhibits 31, 32, 34, and 36 is needed in accordance with the schedule of the mission profile. In addition, unscheduled acquisitions may be required by failure of unit 950. The probability of this failure is the probability that tracking will not be disturbed by noncatastrophic impacts with meteorites.

Commands DC-15 and DC-21 are used with normal reliability as was explained in the calculation of Canopus acquisition reliability; however, command DC-17, cone angle update, was assumed to have unity reliability since it is redundant to a CC and S function and not to any part of the attitude control subsystem. The processing of these update signals is accomplished within the attitude control by the ring counter, unit 627, and the reliability of this equipment is calculated in the normal fashion.

The resultant reliability prediction, then, applies to the combined functions of acquiring and tracking both the sun and Canopus with allowance made for unscheduled reacquisitions. This predicted reliability for various mission times is as follows:

	Time (hours)	Predicted Reliability
First maneuver	44	0.994
Second maneuver	288	0.974
	750	0.946
Mariner R mission	2,600	0.824
	4,500	0.718
Encounter	6,000	0.644
End playback	6,213	0.635

It is possible to make a reasonable comparison of these results with the Mariner R results if it is kept in mind that slight differences arise because the Mariner R calculations were based on tracking only, with acquisition assured. The reliability of sun-earth tracking on Mariner R was predicted as 0.317 for 2, 600 hours.

The inertial roll control capability designed into Mariner C is a potentially valuable feature, and it is in order to inquire as to its reliability. This has been done for a specific set of conditions. First, it is required that the sun acquisition and tracking function be operable over the whole mission. Next, it is demanded that Canopus acquisition and tracking be operable through the time required for two maneuvers (288 hours). The free roll mode, commanded by DC-20, must be available at any time during cruise. Finally, the inertial control path shown in Exhibit 36 must be operable for the final phases of the mission beginning 50 hours before encounter. This last requirement implies that the radio receiver and transmitter, and commands DC-18 and DC-21, the incremental roll commands, are part of the attitude control subsystem for this operating mode. This is justified on the basis that the attitude control function takes the form of a combination radio/ inertial control when this mode is invoked.

It has been assumed throughout this study that inertial roll control, although available at any desired time, would not be used continuously until the important encounter phase was approached. The period of interest, then, is through encounter and tape playback.

	Time (hours)	Predicted Reliability
Encounter	6,000	0.460
End playback	6,213	0.441

7. Trajectory Correction

In considering the success of this event, it becomes clear that nearly all of the spacecraft subsystems must be functioning satisfactorily if an adequate maneuver is to be made. The units shown in Exhibit 37 are obviously required if any controlled maneuver is to be effected. In addition, the following conditions pertain:

a. The solar array must be deployed.

b. The power supply, including special equipment for the maneuver, must be operating.

c. The attitude control must track the sun and Canopus before and between maneuvers, and reacquire them after maneuvers.

d. The radio receiver and transmitter must be operating coherently.

e. Required commands, including quantitative commands, must be available.

f. CC and S signals, particularly the maneuver signals, must be present as required.

g. At least the high rate decks, together with all series elements of the data encoder, must function to provide a minimal monitoring capability.

A number of probabilities must be computed to arrive at a final reliability prediction for the maneuver. It must be recalled that a successful maneuver is defined as one in which no equipment failures occur but where operational errors cause the miss distance (in the sense of missing the aiming point) to be too great or too small. An adequate maneuver is successful in that no equipment failures occurred, and, in addition, the miss distance is satisfactorily small.[1] A failed manuever is one which suffers an equipment failure.

Because of pyrotechnic redundancy, it is possible to have a failed first maneuver and still be capable of performing the second maneuver. For the conditions established above, the applicable probabilities are calculated as follows:

a.	Probability of no equipment failure during first maneuver	0.962
b.	Probability of an adequate first maneuver	0.940
c.	Probability of a successful first maneuver and an adequate second maneuver	0.016

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[1] This definition is furnished by JPL.

d.	Probability of a failed first maneuver and an adequate second maneuver	0.004
e.	Probability of an adequate maneuver	0.961

This compares directly with an estimated 0.8 maneuver reliability for Mariner R, where the single maneuver is accomplished 190 hours after injection.

8. Data Encoder

This particular subsystem has posed the greatest problem in arriving at a satisfactory numerical assessment. It has been suggested that the classical reliability might be defined as the probability that some arbitrary fraction (say 9/10) of the data inputs are reliably commutated and encoded. An approach of this kind was attempted at great length; however, the enormous number of computations required to assess the subsystem made the task infeasible. To appreciate this problem, it should be noted that the encoder comprises over 250 units if all significant catastrophic failure modes are accounted for. It was hoped that properties such as symmetrical unit arrangements or large groups of identical failure consequences would manifest themselves. This has not proved to be the case, and it is conservatively estimated that literally thousands of unit configurations would have to be separately investigated to produce a numerical result. Accordingly, attention was focused on other approaches which would give at least some insight into the classical reliability of this subsystem.

Considering the very vital function of encoding the video and encounter science data, it can be observed from Exhibit 15 that the series circuits are required. These include redundant PN generators. Their reliability is computed at a time 50 hours prior to encounter and at the end of tape playback, as these times bracket the period of interest. Reliability at the beginning of the period is estimated at 0.629 for 5,950 hours, and, at 6,213 hours, the end of the period, it is 0.606.

To encode cruise science, the series units are needed as for any other function of the data encoder. In addition, the miscellaneous logic depicted in Exhibit 14 is required except for unit 2017, the medium speed drive. Because cruise science is subframed with engineering data, the 100-110 sequencers, units 2025 and 2026, are required in redundant fashion as illustrated in Exhibit 12. This complement of units is needed throughout the cruise phase of the mission, and its predicted reliability is listed below:

	Time (hours)	Predicted Reliability
Second maneuver	288	0.972
	750	0.932
Mariner R mission	2,600	0.784
	4,500	0.656
Encounter	6,000	0.568

The telemetry of engineering measurements, along with cruise science, will evidently be governed by the reliability of the units discussed above for cruise science measurements. Except for unit 2017, the medium speed drive, this same reliability figure would apply to the commutated digital engineering data. For commutated analog engineering data, however, the analog-to-digital conversion units are additionally required. These units are shown in their redundant configuration in Exhibit 13. This is a switchable redundancy, and it is assumed that command DC-6, which provides the switching action, is available with unity reliability. The calculated reliability applies to commutated analog data as follows:

	Time (hours)	Predicted Reliability
First maneuver	44	0.995
Second maneuver	288	0.972
	750	0.932
Mariner R mission	2,600	0.761
	4,500	0.624
Encounter	6,000	0.530

The foregoing predicted reliability for engineering data does not include the effects of commutation. The difficulties associated with developing a meaningful reliability for all of the commutating functions as a group have been discussed. It is possible, however, to predict the reliability of typical channels of engineering data. This has been done for both analog and digital data channels.

For analog data, consider channel 109, a high-rate channel, and channel 415, a low-rate channel. The unit configuration demanded for these channels will include, of course, the analog-to-digital converter, the miscellaneous logic, and the series circuits as calculated above. In addition, for the high-rate channel, two switches, units 2058 and 2144, must close in order to gate the channel information to the miscellaneous logic. All of the 100 sequencer, unit 2025, must be operating because this channel is controlled by the last stage. The redundancy furnished by the 110 sequencer is no longer applicable. Again, it is assumed that services such as power supply and radio are available. For these conditions, the typical high-rate channel reliability is predicted as shown below:

	Time (hours)	Predicted Reliability
First maneuver	44	0.995
Second maneuver	288	0.964
	750	0.912
Mariner R mission	2,600	0.725
	4,500	0.574
Encounter	6,000	0.474

The low-rate channel, 415, demands a large complement of units, including the analog-to-digital converter, the miscellaneous logic, and the series circuits. Individual units, required in an in-line capacity for this channel, are 2102, 2034, 2147, 2022, 2037, 2021, 2108, 2049, 2050, 2052, and 2144. Portions of sequencers needed in series, reliability-wise, are 2031-1··· 6 and 2025-1··· 3.

Sequencers needed in redundant configuration consist of two groups. The first is the quadruple redundancy formed by units 2030, 2031, 2033, and 2038, but with units 2031-1···6 excluded since they have already been specified as a series requirement. The second group is that formed by units 2025 and 2026, but with units 2025-1···3 excluded since they were counted above. The reliability of this combination of components for the data encoder is predicted as follows:

	Time (hours)	Predicted Reliability
First maneuver	44	0.993
Second maneuver	288	0.995
	750	0.890
Mariner R mission	2,600	0.668
	4,500	0.497
Encounter	6,000	0.392

The predicted reliability of this low-rate channel is noticeably less than that of a high-rate channel, which reflects the additional commutation equipment required. Each channel is somewhat different, in that the required sequencer arrangement varies. Moreover, bucking supplies are needed for some channels but not for others. However, the numbers listed above are typical of what can be expected.

There are far fewer digital channels than analog channels, and their reliabilities appear to lie between the values calculated for the analog channels. Two examples were selected for illustrative purposes.

Encoding of the command detector VCO monitor information requires the series circuits and miscellaneous logic but not the analog-to-digital converter. Specific individual units required are 2035, 2039, 2040, and 2046, together with the first five stages of the 100 sequencer, unit 2025.

Event register 1 requires the same complement of units, except that unit 2042 replaces unit 2046 and 2035 is not needed. In addition, the first six stages of the 110 sequencer, unit 2026, are needed, rather than portions of the 100 sequencer.

The predicted reliabilities of these two digital words were computed for three points on the mission profile as given below:

	Hours		
	288	2,600	6,213
Detector Monitor	0.954	0.663	0.374
Event Register 1	0.958	0.691	0.413

The large number of components which comprise the data encoder make this subsystem a likely candidate for some kind of random failure over the 6,000-hour mission. Specifically, a simple parts count reliability of the encoder has been calculated as approximately 0.02 for 6,000 hours. This number is not believed to be meaningful, however, because many of the failures which contribute to this low apparent reliability would involve the loss of only one, or at most a few, channels. For this reason, the analytical emphasis has been placed on the reliability prediction for the important segments of the encoder and for typical channels within the commutator.

9. Total System

The reliability of the total Mariner C system (excluding the data automation system) is a function of the level of performance arbitrarily selected as being the minimum which can be tolerated. In making such a selection, the worth function which has been assigned to each objective provides a certain degree of guidance. The worth assignments are discussed in the next subsection, and a study of them will afford some appreciation for the rationale on which the system reliability was based.

The conditions that were established as being required for a successful mission include the following:

a. An adequate midcourse maneuver must be completed. This involves a requirement for nearly all of the spacecraft subsystems through 288 hours.

b. The power supply must operate in a normal manner throughout the 6,213-hour mission.

c. The attitude control must acquire Canopus and track it throughout the mission. Inertial control is not considered a satisfactory operating path because it has been limited (in this study) to operation at encounter only, and cruise science would be lost or degraded in the free roll condition.

d. The radio transmitter must operate, either coherently or noncoherently, for all of the mission.

e. The data encoder must operate to the extent that the series units, miscellaneous logic, and analog-to-digital converter are working. In addition, the high-rate decks are required.

f. The tape recorder and planet scan functions must be available through the encounter phase.

g. After 288 hours, the CC and S and command functions are redundant. This implies that the radio receiver is needed only for this redundant purpose for most of the mission.

From the foregoing list of requirements, it can be deduced that some degradation from the normal path is allowed in this definition of a successful mission. The subcommuted engineering data is not required. Doppler tracking after 288 hours is not a requirement. This is not to say that these functions are not desirable, only that they are not essential. All other objectives are required in full.

Reliability for the spacecraft has been computed at two points in the mission for this complement of equipment, and the results are given below:

For 2,600 hours, predicted system reliability = 0.383
For 6,213 hours, predicted system reliability = 0.111

C. System Figure-of-Merit

Recognizing that the classical reliability of a mission, however it may be defined, is an incomplete measure of reliability for missions as complex as that of Mariner C, PRC's figure-of-merit (FOM) has been used in this study. The FOM provides for the use of every state of acceptable operation, from the perfect state of operation to the most degraded state that can contribute measurable achievement of any mission objective. To effect this type of analysis, specific values of worth are assigned to certain mission objectives. Each of these is actually a weighting function for the probabilities of operating in those states that will produce a given objective. The worth functions used here were assigned by the Systems Design Section of Jet Propulsion Laboratory. This assignment will be discussed before the application is detailed.

1. Objectives and Worth Assignments

There are eight main objectives defined for the Mariner C mission. If all eight were successfully accomplished, the value of the worth functions at end of tape playback would total 100 percent. The contribution to this total mission worth of each of the various objectives is shown in Exhibit 48.

The first three objectives shown accrue worth essentially over the entire length of the mission. Specifically, cruise science, assigned a worth of 12 percent, begins to accrue its worth upon injection of the spacecraft and continues to do so until 50 hours before encounter. Engineering telemetry, with a total possible worth of 3.5 percent, accrues almost a third of this in the first 43 hours of the mission; the remaining portion accrues over the next 5,957 hours. Orbit determination, including both the ranging and doppler functions, accrues its total worth of 4.5 percent in five different intervals over the 6,213 hours of the mission.

The remaining five objectives are considered "one-shot" since their total possible worth is accrued at specific instants in time. This is exactly the case for the first three. Star acquisition will add a worth step of 1 percent at the end of the first acquisition, or one-and-one-half hours after injection.[1] Encounter, with tracking, is another step function occurring at 6,000 hours, the time of closest approach to the planet. Trajectory correction is also a one-shot objective, with a total worth of

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[1] See mission profile times on Exhibit 46.

EXHIBIT 48 - WORTH FUNCTIONS FOR MISSION OBJECTIVES

	Worth (percent)		Time (hours)
	Element	Subtotal	
Continuous Objectives:			
Cruise Science	12.0		0-5,950
Engineering Telemetry	3.5		
		1.0	0-43
		2.5	43-6,000
Orbit Determination	4.5		
		1.8	0-43
		0.7	43-80
		1.0	80-750
		0.5	750-5,950
		0.5	5,950-6,213
One-Shot Objectives:			
Star Acquisition	1.0		1.5
Trajectory Correction	2.0		288.0
Encounter (with tracking)	6.0		6,000.0
Encounter Science	11.0		6,013.0(1)
Tape Playback:	60.0		
First two pictures		40.0	6,033.0(1)
Remainder		20.0	6,213.0(1)

Note: (1) Worth actually accrued over a relatively short interval of time at encounter.

2 percent. However, the model used in this study allows for two chances to correct the trajectory. The worth function for this objective, although scheduled at two different instants in time (as discussed below), is considered a step function at 288 hours.

It is of interest to explore in further detail the worth function associated with the correction maneuvers. If at the end of the first maneuver, occurring at 43 hours after injection, the trajectory is considered "adequate," the entire step function of 2 percent is accrued. An "adequate" maneuver is defined as one which insures that the miss distance at the planet will be within tolerance. If the first maneuver was not adequate, then it either was "successful" or it "failed." A successful maneuver is one performed according to command, but the predicted miss distance at the planet is too large or too small, and another maneuver is required. A "failed" maneuver results in this model only from hardware failure. Exhibit 45 indicates that the only hardware failure than can occur and still allow a second maneuver to be accomplished is a failure of the hardware associated with the maneuver pyrotechnics. Now, to return to the worth function, if the first maneuver was only successful, a step function of 0.6 percent is accrued, but not until the time for the second maneuver has passed (or at 288 hours). Additional worth is accrued at that time dependent on whether or not the second maneuver is adequate (1.4 percent), successful (1.0 percent), or failed. Finally, if the first correction failed, possible worth accrues at 288 hours, dependent again on the outcome of the second maneuver. However, since the value of the worth function of a failed first maneuver is zero, the worth function for the second maneuver changes in value: adequate, 2.0 percent; successful, 1.0 percent; and failed, 0.7 percent. It is at the end of the second maneuver, or 288 hours, that the worth is added for the possible outcomes of trajectory correction.

The last two "one-shot" objectives in Exhibit 48 are not strictly step functions. Relative to the length of the entire mission, it is convenient to summarize them as such. In the FOM calculations to follow, however, they actually accrue worth over short periods of time. Encounter science, for example, accrues its total possible worth of 11.0 percent during the 63 hours between 5,950 and 6,013 hours after injection. The function for tape playback is divided into two intervals. A value of 40 percent, associated with the first two pictures, is accrued over 20 hours, between 6,013 and 6,033 hours. The final 20 percent associated with the remaining pictures accrues between 6,033 and 6,213 hours, a period of 180 hours.

Exhibit 49 gives the worth accrual rates for each of the continuous objectives and these last two "one-shot" objectives. It is apparent from the table that within each interval the worth accrual rate of an objective is a constant. In actuality, the rates might well be a continuous function of time, e.g., cruise science might contribute a diminishing amount of worth per unit time during the long portion of the mission relative to the beginning, and then increase in the vicinity of the planet. In order to make the problem tractable, however, the mission was divided into the intervals shown, and the accrual rates are considered constant in each interval. It should also be noted that an attempt to eliminate some of the effects of this problem of manageability is made in the assignment of worth functions for Mariner C. That is, encounter science, which includes many of the same measurements as cruise science, accrues its worth in 63 hours around encounter. It contributes over half of the 23 percent of worth assigned to real-time science telemetry.

Three other considerations need to be pointed out here; each emphasizes differences from the assignment made in the Mariner R assessment. In the FOM calculations discussed below, (1) one-way doppler has zero worth, (2) loss of sync modulation in transmission has zero worth, and (3) noncoherent telemetry, or loss of phase lock, has full worth.

2. Accrual of Worth

In the figure-of-merit model, the probability of successfully achieving each objective is weighted by the worth function of that objective. As stated earlier, the FOM model considers not only the perfect state of hardware operation of the spacecraft that produces a given objective, but various degraded states of hardware operation that would also accrue the worth assigned for that same objective.

EXHIBIT 49 - WORTH ACCRUAL RATES (x 10^{-3})

	0-43	43-80	80-750	750-5,950	5,950-6,013	6,013-6,033	6,033-6,213
Cruise Science	.00202	.00202	.00202	.00202	.00202	.00202	.00202
Engineering Telemetry	.0233	.00042	.00042	.00042	.00042	.00042	.00042
Orbit Determination	.0419	.01891	.00149	.000096	.00190		
Encounter Science					.175		
Tape Playback:							
First two pictures						2.00	
Remainder							.111
Totals	.0671	.0214	.00393	.002536	.175934	2.00244	.11344

For the one-shot objectives, the average of expected worth of a mission objective is simply the product of the value of the worth function assigned to that objective, and the probability that the objective is met. Therefore, $\overline{W}_a$, the average worth for a single one-shot objective, a, is

$$\overline{W}_a = w_a P_a \tag{1}$$

where w_a is the assigned worth for objective a.

For objectives which accrue worth continuously, the <u>average</u> rate $\overline{w}_\beta(t)$ of worth accrual at time t for objective β is

$$\overline{w}_\beta(t) = w_\beta(t) P_\beta(t) \tag{2}$$

where $w_\beta(t)$ is the assigned worth accrual rate for β.

The total average worth, $\overline{W}_\beta$, accrued during the mission for objective β is

$$\overline{W}_\beta = \int w_\beta(t) P_\beta(t) dt \tag{3}$$

where the integration is taken over the complete mission with $w_\beta(t) = 0$ for all t where β is not applicable.

The average worth for a complete mission, $\overline{W}_M$, is obtained by combining the average worths for each objective. Thus, the total mission figure-of-merit, $\overline{W}_M$, is given by

$$\overline{W}_M = \sum_a \overline{W}_a + \sum_\beta \overline{W}_\beta \tag{4}$$

where $\overline{W}_M$ is an expected value in the statistical sense.

The total average worth for each of the objectives listed in Exhibit 48 will be discussed below; this will be followed by the compilation of the figure-of-merit for the entire mission. The detail will be concerned with describing the states of hardware operability that will accomplish each objective, a tabulation of the resulting probability of success in these states, and, finally, the average worth accrued, $\overline{W}_{\alpha}$ or $\overline{W}_{\beta}$, dependent on the type of objective.

a. Continuous Objectives

(1) Cruise Science

There is only one major state of the hardware units that will accrue worth for cruise science over the 5,950 hours assigned to this objective. Certainly none of the video data units, planetary scan, or tape record/playback are necessary. Only portions of the data encoder are required; the series circuits (Exhibit 15) are required, as well as the miscellaneous logic (Exhibit 14), except for the 10, 11, and medium-speed drive (unit 2017). Also needed are the 100 sequencer and the 110 sequencer in a simple redundant configuration. The power supply units are needed as scheduled on the normal mission chart (Exhibit 46). The attitude control units are needed as shown on the normal chart with all of the redundancies shown in Exhibits 31 to 36, with one exception. In all of the calculations of the FOM model, inertial roll control is not considered as a possible operating path until t_{25}, or 5,950 hours. Since cruise science stops accruing worth at this point, inertial roll control is not applicable to this objective. The transmitter may be either in a coherent or noncoherent mode of operation; the receiver must be operational only for commands. No midcourse maneuver is required, since cruise science worth may be accrued whether the miss distance at the planet is within tolerance or not. Pyrotechnic units are needed for solar panel deployment only.

The command detector and decoder must be up for two types of redundancies, In the series circuits of the data encoder, one PN generator is in a standby redundancy to a second, with discrete command 6 acting as the switch. A second type of discrete command requiring the command detector and decoder is DC-17, which backs up the central computer and sequencer signals that initiate the Canopus cone angle update sequences. This makes the command detector and decoder redundant to the CC and S throughout much of the time interval for this objective. As was pointed out, whenever a command is required, even in a redundant capacity, the radio receiver must be operational.

The valve and nozzle redundancy of the attitude control subsystem enters the computation as shown in the attitude control diagrams; however, certain other assumptions concerning this redundancy are outlined here. The considerations apply each time the valves and nozzles are required in the following calculations. The pitch and yaw associated valves are assumed to experience 200 actuations per valve for the redundant system during sun acquisition. During cruise, the same system experiences four actuations per valve per hour before t_4 and three actuations per valve per hour after t_4, the time of activation of the solar pressure stabilization system. The duty cycle of each of the four stepping motors[1] of unit 615 is assumed to be 5 percent for the time required for the system to effect stabilization within the limit cycle. This stabilized state is assumed to be reached 333 hours after t_{16}, the time of the final maneuver. The redundant system of valves, nozzles, and gas that supplies the roll torques is assumed to experience 200 actuations per valve during star acquisition and four actuations per valve per hour during cruise. Unlike those supplying the pitch and yaw torques, these continue to operate throughout the remainder of any mission during which star tracking is required.

The reliability of the complete cold gas system (units 612, 613, 615, 620, and 621) does not degrade below 0.999 until after $t_{16} + 333$ hours due to the extremely low failure rates of the valves and nozzles and to the assumption of the 5 percent duty cycle for the motors. After 621 hours, the configuration reduces to the simple redundancy of units 620 and 621, with four actuations per valve per hour, and enters into the calculations as

$$\left\{1 - (1 - e^{-5.6 \times 10^{-6} t})^2\right\}$$

The tabulation of the probability that the configuration of spacecraft units described above will survive various time intervals of the mission

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[1] See Appendix A, Section 1.

is shown below. The intervals correspond to intervals in the worth function with two exceptions. First, 2,600 hours corresponds to the Mariner R total mission time, and second, 4,500 hours is arbitrarily picked as a convenient tabulation point during the long cruise period after 2,600 hours and before encounter.

Probability of Obtaining Cruise Science Data

Hours	Probability
44.5	0.979
288	0.904
750	0.849
2600	0.530
4500	0.307
5950	0.192

These probabilities are used at the various intervals to determine the expected rate during these intervals. Both the assigned and expected rates for these intervals are shown in Exhibit 50. The time integrals of these curves are given in Exhibit 51. In the latter, the curves represent the total cruise science worth accrued to time t . The expected contribution of cruise science to the figure-of-merit is seen to be 6.3 percent.

(2) Engineering Telemetry

The worth assigned to engineering telemetry can be obtained in either of two states of hardware operability. In the first, the power supply and attitude control units must be in the normal configurations shown in the reliability diagrams of Section III and energized as shown on the normal mission chart (Exhibit 46). Solar panel deployment is required but no trajectory correction is needed since engineering telemetry worth may be accrued without consideration of the miss distance at the planet. The transmitter may be either coherent or noncoherent. The receiver must be operable in a redundant capacity, along with the command detector and decoder, whenever a command is needed under the stated conditions. These are redundant, of course, to signals from the CC and S.

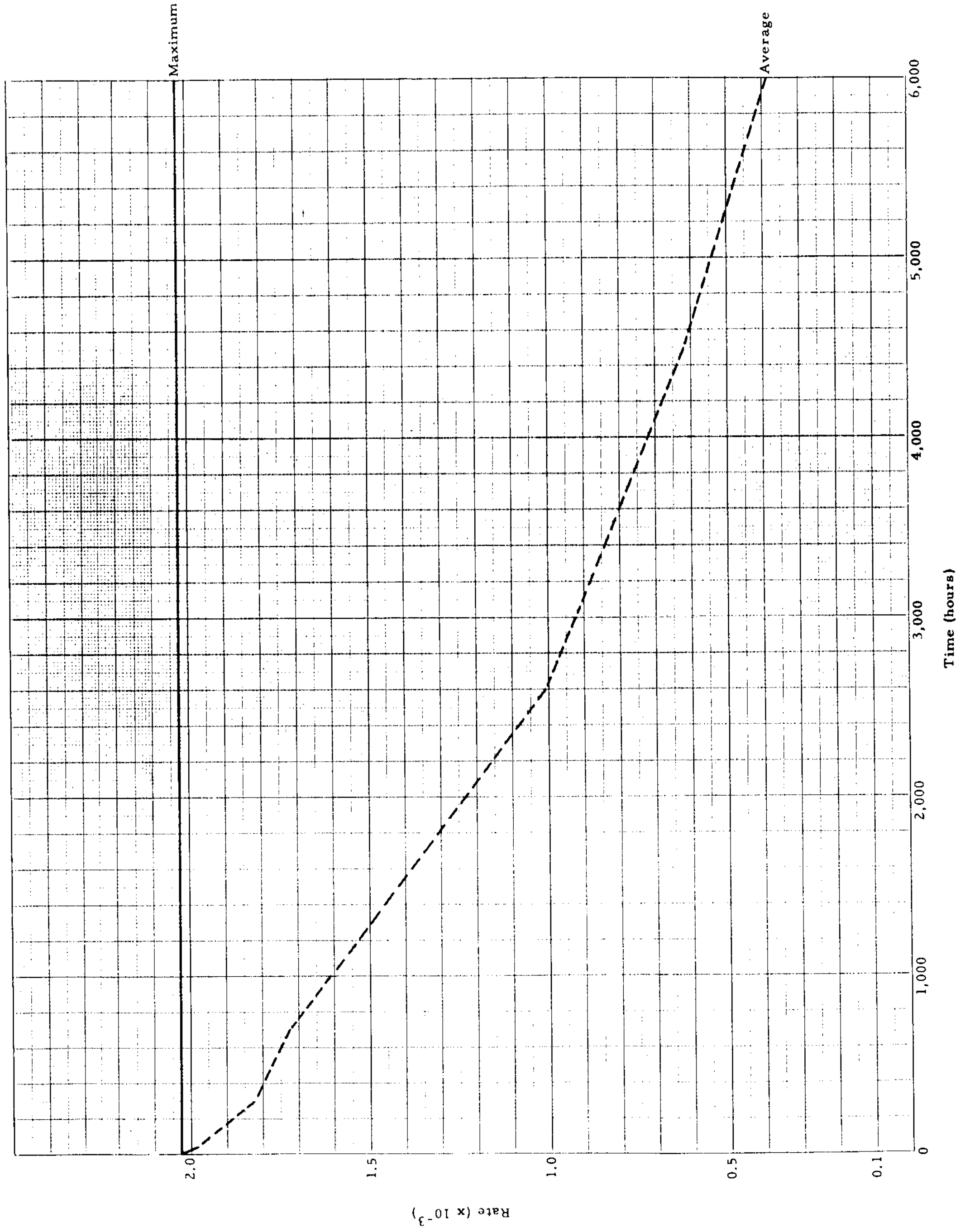

EXHIBIT 50 - CRUISE SCIENCE WORTH ACCRUAL RATE

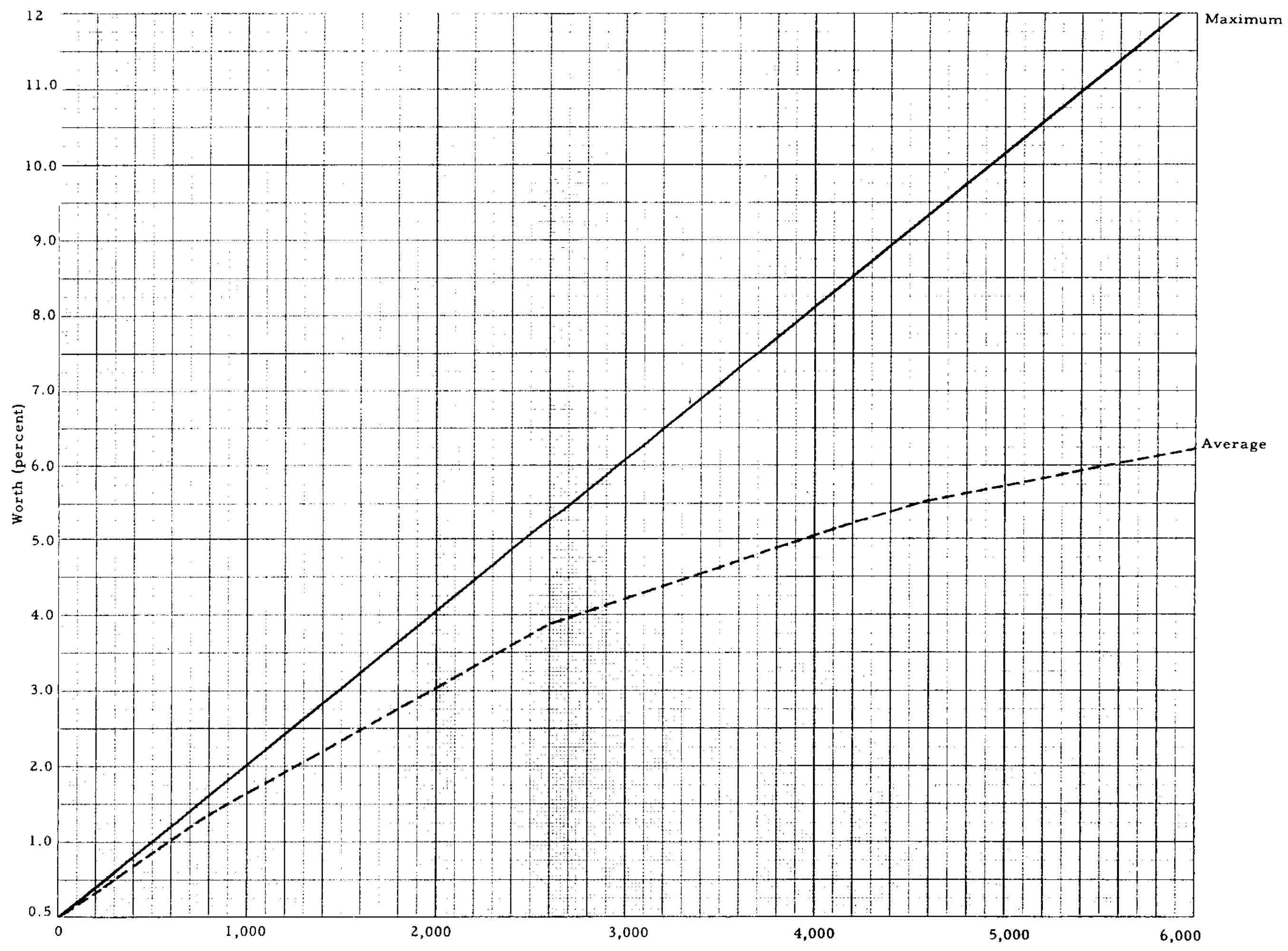

EXHIBIT 51 - CRUISE SCIENCE ACCRUED WORTH

In addition, the complete data encoder must be operable: the series circuits, the miscellaneous logic, the analog-to-digital converter, and the high-, medium-, and low-rate decks. For the purposes of this study, however, the many hundreds of thousands of degraded states within the subcommutating portion of the data encoder were not considered. This was an arbitrary decision, and tends to inflate the resulting contribution to the figure-of-merit. However, the relatively low worth assigned to this objective is one justification for the approximation. Hence, using only common portions of the encoder and the high-rate decks, the hardware configuration is complete for this state.

In the second hardware condition of the spacecraft that enables engineering telemetry worth to be accumulated, just as in the first, a midcourse correction is not required. In addition, up until t_{19}, the limit of the low-gain antenna, star acquisition and tracking may be ignored. This degraded path requires the data encoder, the radio, and the solar panel deployment as above. The required attitude control units reduce to those in Exhibits 31 and 32; the power supply units reduce to those required to support the spacecraft with these attitude control functions, i. e., those shown in Exhibit 28 for one sun acquisition (since a midcourse maneuver is not required) and those shown in Exhibit 29.

The probability of surviving the first state, together with the probability of success in the second, weighted by the worth function for this objective gives the contribution to the FOM. The probabilities of the two states are shown below for the time intervals of interest.

Probability of Obtaining Engineering Telemetry

Hours	Probability
43	0.972
288	0.844
750	0.750
2600	0.383
4500	0.155
6000	0.078

The expected accrual rate resulting from these probabilities is plotted in Exhibit 52. Two points should be noted; (1) the maximum rate of accrual changes at t=43 hours, with one-third of the assigned worth being accrued by that time, and (2) there is an expected communication blackout between t_{19} and t_{20}, during which no worth is accrued.

The integral of this rate curve is shown in Exhibit 53. Recalling that this is a slightly optimistic approximation to the expected worth, it should be noted that the probabilities involved also indicate that on a system level the investigation of the many degraded paths in the subcommutation portion of the data encoder is not warranted since the expected FOM contribution is 2.0 percent (assigned = 3.5 percent). The inclusion of the subcommutator would not appreciably affect the accrual of 0.9 percent during the first 43 hours of the mission. They could only affect the remaining 1.1 percent computed for the balance of the mission.

(3) Orbit Determination

The hardware configurations for orbit determination serve two objectives, ranging and doppler tracking. Considering ranging first, one possible configuration requires the attitude control and power supply units to operate in the normal path up to t=80 hours, the end of accrual of worth for this objective. Solar panel deployment and either a coherent or noncoherent radio complete this requirement. A second configuration is similar, except that it drops the requirement for star acquisition and tracking and the associated power supply units. This is the same degraded path described for engineering telemetry; its maximum duration in this application is, of course, 80 hours. The third path differs primarily in that the receiver VCO is omitted as shown in Exhibit 39, except for units 807, the receiver transformer rectifier, and 808, preamp 1st IF and mixer. The ranging function always requires unit 811, the range code detector, and unit 812, the video amplifier.

The two paths for the doppler function are essentially the same as the first two for ranging. The degraded path that terminates at t_{19} (no requirement for star acquisition and tracking) is configured in the same manner, but with a maximum time of 2,376 hours rather than 80

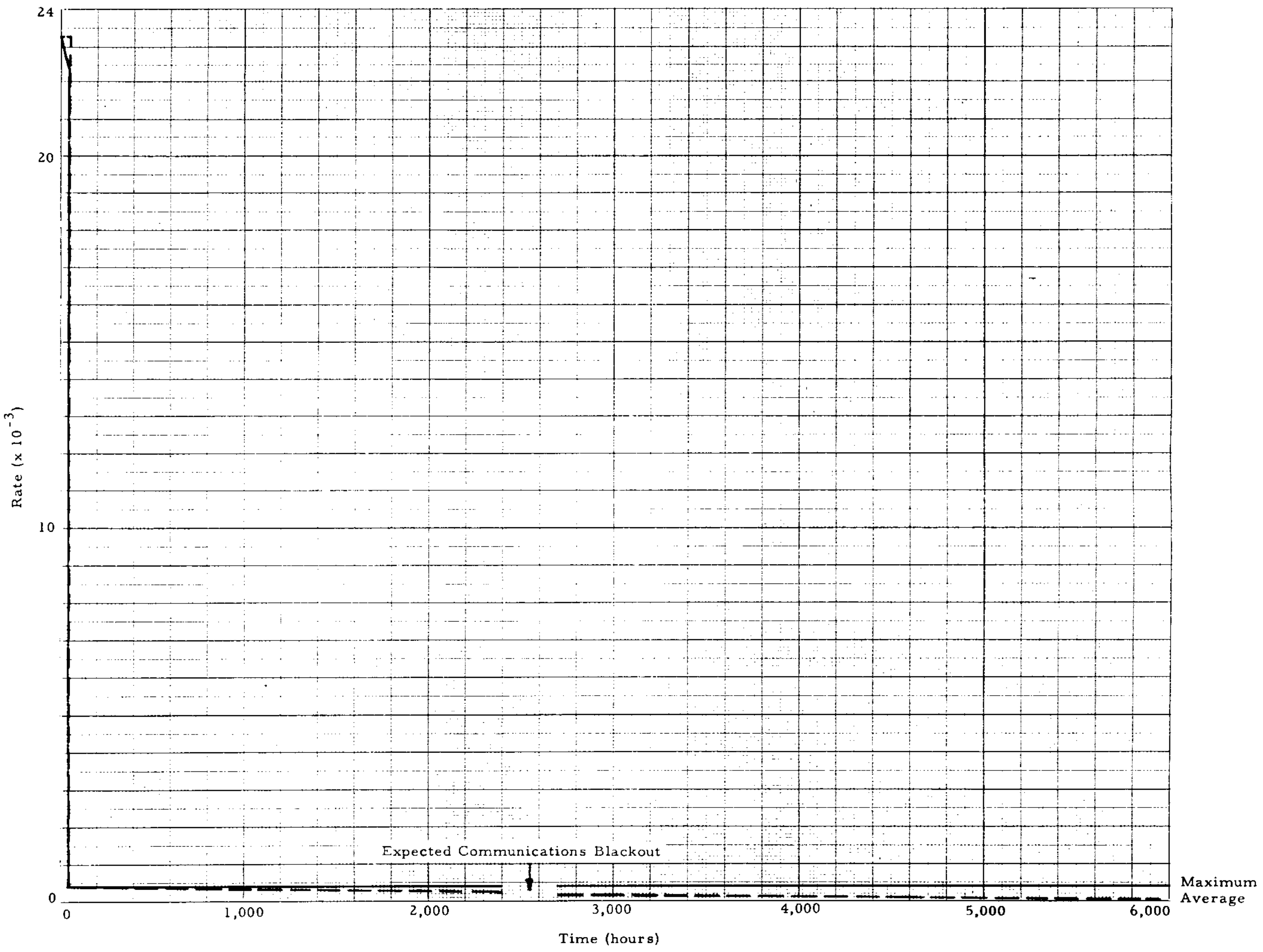

EXHIBIT 52 - ENGINEERING TELEMETRY WORTH ACCRUAL RATE

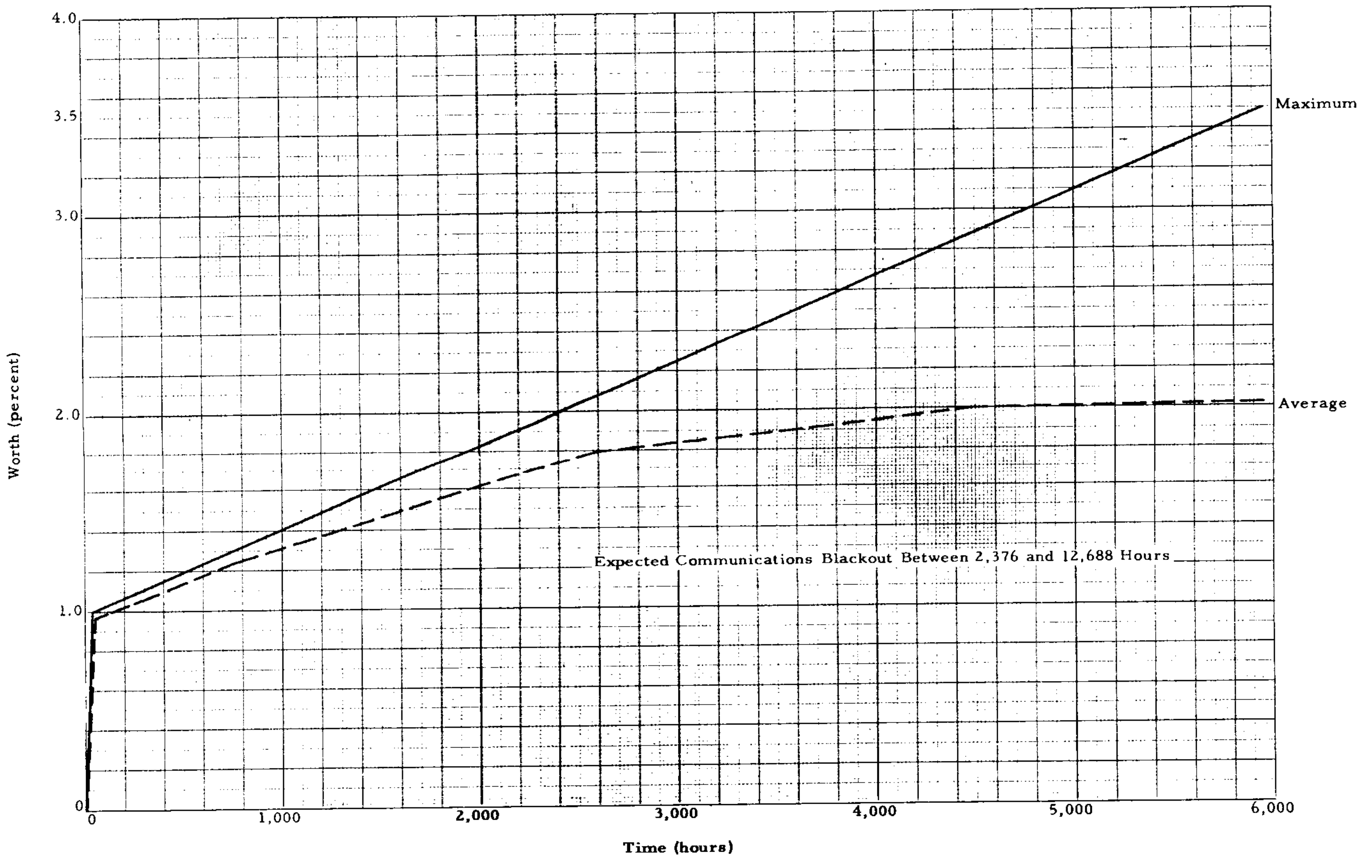

EXHIBIT 53 - ENGINEERING TELEMETRY ACCRUED WORTH

hours. A midcourse correction is not required in order to accrue the worth assigned to this function. The second doppler path does differ, in that after t_{25} the redundant path including inertial roll control is allowed. The units involved here are shown in Exhibit 36.

The probabilities computed for these hardware states are listed below for the pertinent intervals of the worth function for the orbit determination objective.

Probabilities Involved in Orbit Determination

	Hours	Probabilities
Ranging		
	43	0.991
	80	0.985
Doppler		
	43	0.988
	80	0.979
	750	0.860
	5,950	0.367
	6,213	0.320

The total expected accrual rate for this objective is plotted together with the assigned accrual rate in Exhibit 54. It is evident that more than half of the possible worth to be accrued can be obtained in the first 80 hours and only 20 percent of the total assigned worth is expected after the first month (t=750 hours). The probabilities involved assure that the expected worth accrual will be close to the maximum. Exhibit 55, giving the integrated curves for orbit determination, shows the total contribution of this objective to the system FOM to be 3.6 percent, where the maximum is 4.5 percent.

b. One-Shot Objectives

(1) Star Acquisition

The worth for this objective has been assigned as a step function. It occurs at the end of the first 1.5 hours after

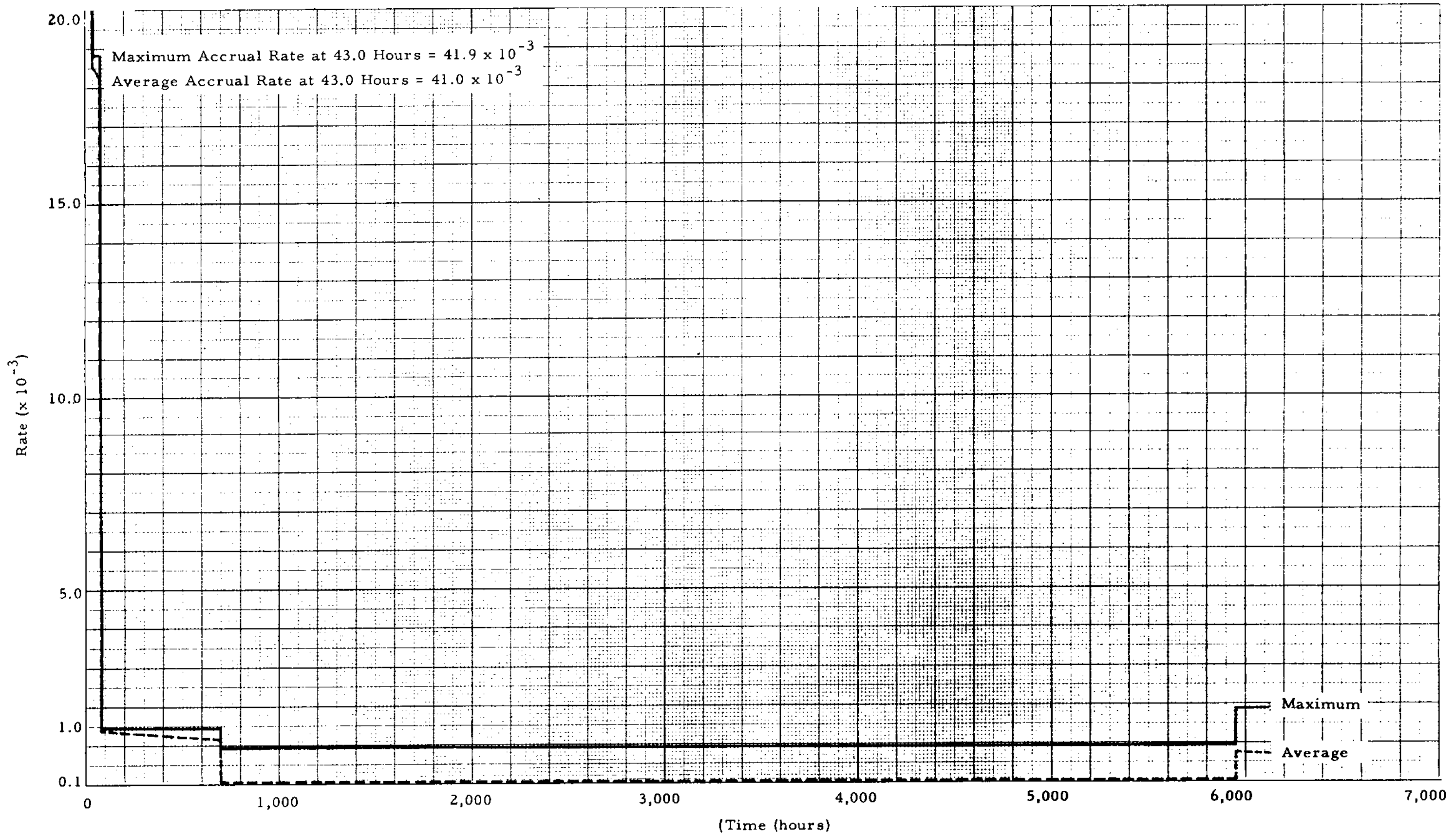

EXHIBIT 54 - ORBIT DETERMINATION WORTH ACCRUAL RATE

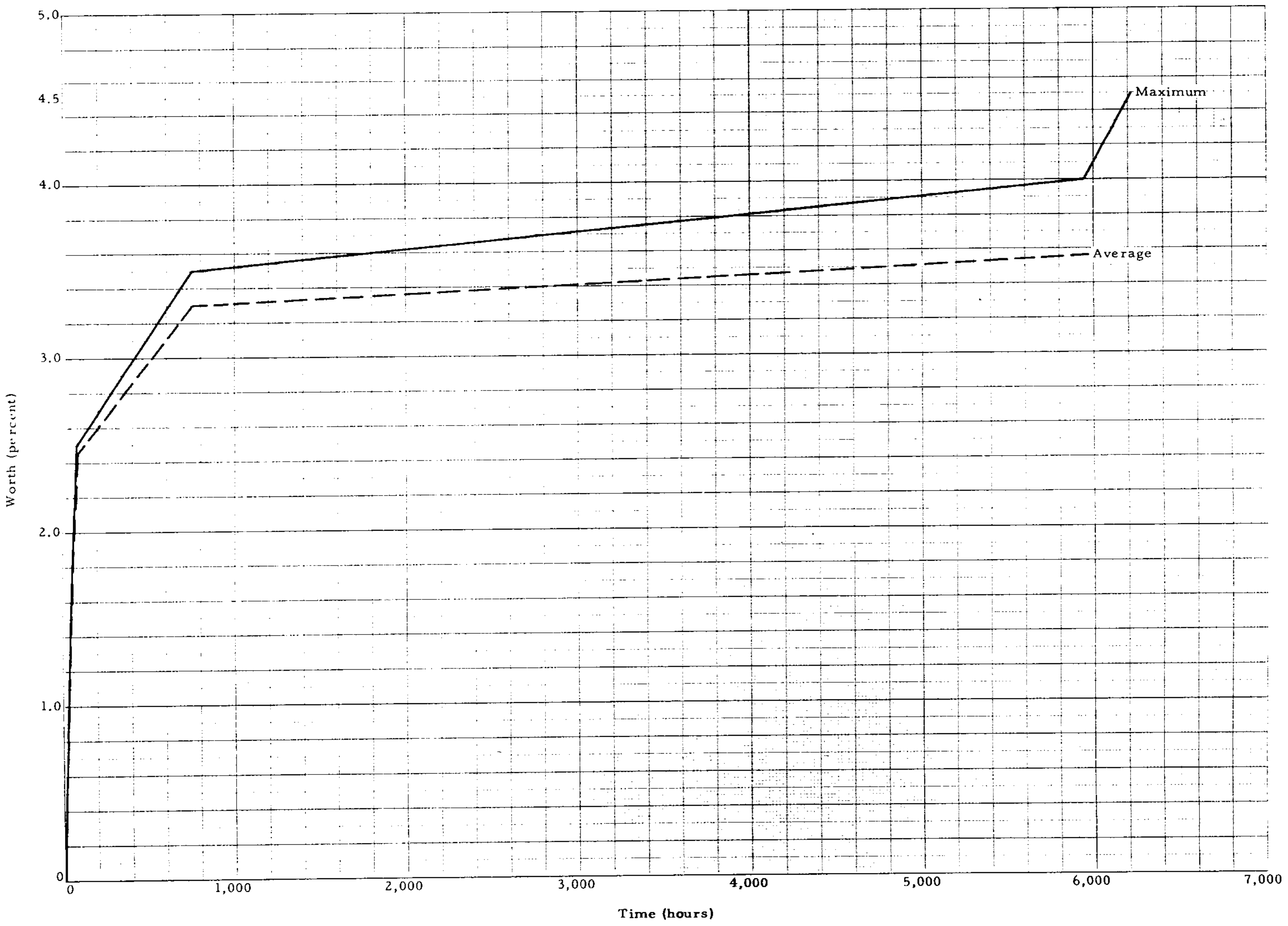

EXHIBIT 55 - ORBIT DETERMINATION ACCRUED WORTH

injection. The exceedingly small time interval implies almost certain accrual of worth.[1]

There is only one hardware configuration considered here: the power supply units as shown in Exhibit 28; attitude control as in Exhibits 31, 32, and 34; a coherent or noncoherent radio; the command detector and decoder in a redundant configuration as shown in Exhibit 34; the central computer and sequencer as in Exhibit 23; and, finally, the data encoder series units, miscellaneous logic, A-D coverter, and one engineering channel to assure that the star has indeed been acquired.

The probability of successfully performing this objective is 0.999. The contribution of star acquisition to the total FOM is, then, 0.9 percent since the assigned worth function at t=1.5 hours is 1.0 percent.

(2) Trajectory Correction

The worth function for trajectory correction allows for the maximum worth to be accrued at 43 hours for an adequate first maneuver or at 288 hours if the first maneuver was not adequate but the second is. The probabilities computed for this objective are (1) the necessary hardware successfully survives 43 hours, (2) the maneuver is made with only one possibility of redundant hardware failure, and (3) the hardware survives the next 245 hours (including the second maneuver). The one redundant hardware failure possibility is in the pyrotechnics required for the first maneuver. As Exhibit 27 shows, there is a redundant set available if the first fails.

The complete hardware configuration for these conditions is as follows. The power supply units are in maneuver and cruise modes, as shown in Exhibits 28 and 29, except the probability of meteoric impact is not considered. The attitude control units are required to acquire the star and sun and to track both (as in normal mission requirement). The radio may be either in a coherent or noncoherent mode. The central

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[1] The reader is reminded of the assumption regarding the exponential failure law given in the Introduction.

computer and sequencer is required during both data insertion periods as shown in Exhibit 24, in acqusiition periods as in Exhibit 23, and during the maneuver periods as in Exhibit 25. The command detector and decoder is required in this objective, since the quantitative commands and DC-27 and DC-23 are not backed by CC and S signals. Pyrotechnic units for solar panel deployment and for maneuver capability are required.

The probability that this hardware configuration survives the corrections must be modified by the operational probability than an adequate first and/or an adequate second maneuver is performed. These probabilities are both 0.978. The conditional probabilities involved in obtaining the probability that the maximum worth will be accrued at 288 hours are shown below:

Probabilities Involved in Trajectory Correction

Hours	Probability	Condition
43	0.952	First maneuver is adequate.
	0.022	First maneuver is successful.
	0.005	First maneuver fails in such a way that the second is possible.
288	0.825	Second maneuver is adequate.
288	0.974	First maneuver is adequate, or, if not, the second is.

The total contribution to the system FOM for the trajectory correction objective based on these probabilities and the assigned worth function is 1.9 percent.

(3) Encounter With Tracking

This one-shot objective requires an adequate trajectory correction, either one of the two shown above. After 288 hours, however, there are two hardware configurations to consider. First, the power supply units are as shown on the normal mission profile, including those units required for encounter (see Exhibit 30), the attitude control units are as listed on the normal mission profile, and either a coherent or noncoherent radio is operating. The command detector and decoder and the central computer and sequencer are needed in their redundant capacities.

The second configuration differs from the first in that star tracking may be down after t_{16} (the end of trajectory correction) and inertial roll control initiated at t_{25}, which is 50 hours prior to encounter. This means, in addition, that the command detector and decoder must be available at t_{25} to invoke the inertial roll control. Although it is recognized that if such conditions do occur, the inertial roll control equipment would be exercised at intervals between t_{16} and t_{25}. This model allows for no equipment failures during such exercises.

The total probability for these two paths is 0.491; the maximum value of the worth function for this objective at 6,000 hours is 6.0 percent. Therefore, the total contribution of encounter with tracking to the system FOM is 2.9 percent.

(4) Encounter Science

Encounter science is tabulated as a one-shot objective; its expected worth calculation was actually made by allowing it to accrue the worth over 63 hours, beginning at 5,950 hours after injection.

As was mentioned earlier, many of these measurements are essentially the same as those for cruise science; the real-time science worth function, in effect, increases in the vicinity of encounter. There are two hardware states to be considered. The first is the same as the cruise science path, except that the engineering subframe has been dropped, and, therefore, the 100 and 110 sequencer redundancy does not enter into the calculations. The degraded path is the same as one described earlier.[1] It involves the loss of star tracking after maneuver, and the use of the inertial roll control capability after t_{25} (5,950 hours).

The probability that encounter science can be transmitted at 5,950 hours is 0.248, degrading only slightly over the next 63 hours. The assigned accrual rate of 0.175 per hour during this interval is modified by the probabilities to obtain the expected accrual rate. Integrating this

---

[1] The second path for the encounter objective.

accrual rate over the 63-hour interval gives the total contribution to the system FOM for encounter science of 2.4 percent.

(5) Tape Playback

This objective is also one which accrues its worth during a relatively short period after encounter. It has two discrete intervals in its worth function, with almost 70 percent of its assigned worth accruing in 20 hours, between 6,013 and 6,033 hours after injection. The remaining worth is accrued in the next 180 hours, ending at 6,213 hours.

This objective can be achieved with two hardware configurations, similar to those already discussed. There is one major difference; the planetary instrument scan and video data recording and playback units, as shown in Exhibits 1 and 2, are now required. For the first configuration, in addition to the video data units, the power supply and attitude control are required in a normal path after 288 hours. A successful midcourse correction is required, as well as the series circuits of the data encoder (see Exhibit 15) over the entire 6,213 hours. The radio may again be either coherent or noncoherent, with the receiver being required whenever commands are necessary, either in-line or redundant to CC and S signals.

The applicable degraded state involves the attitude control units; i.e., star tracking may be lost after the trajectory correction, with inertial roll control being employed at t_{25}. Again, this requires that the command detector and decoder be operable at t_{25} and that the radio be coherent.

The probability that the hardware demanded under these conditions survives to 6,213 hours is 0.216. Integrating the expected accrual rate over the relatively small time interval gives a total FOM contribution of 14.1 percent for the tape playback objective.

c. Total Mission Worth Accrual

As discussed above, worth is accrued during a mission in two ways. Cruise science, engineering telemetry, and orbit determination accrue worth over a period of time, while star acquisition, trajectory correction, encounter with tracking, encounter science, and tape playback are assumed to accrue worth at specific times. Exhibit 56 shows the average and maximum (assigned) value accrual rates for the continuous objectives.

The expected worth contributions of the five one-shot objectives and the three time-dependent objectives (at their final values) are tabulated in Exhibit 57. The integration of the curves in Exhibit 56, together with the addition of the one-shot objectives, are presented in Exhibit 58. The maximum curve, it will be recalled, is a plot of assigned worths and represents a perfect mission, while the average (expected) curve represents the accrual of worth for an average mission, theoretically determined over a series of many identically defined missions.

Therefore, given the assumptions discussed throughout this report, the expected worth accrued for a mission--determined over a totality of many missions which differ stochastically only due to equipment failures--is equal to 34 percent of the desired worth, or that worth which would accrue if all equipment were functioning properly through encounter and post-encounter.

The comparable figure for Mariner R was 42 percent. It must be remembered, however, that the Mariner C mission is more than twice as long, and more important, the Mariner C worth assignments have heavily emphasized those objectives which are achieved late in the mission when reliability is necessarily reduced. On the other hand, the result given here for Mariner C was arrived at without consideration of the data automation system, and the inclusion of this complex system would undoubtedly subtract to some extent from the figure-of-merit.

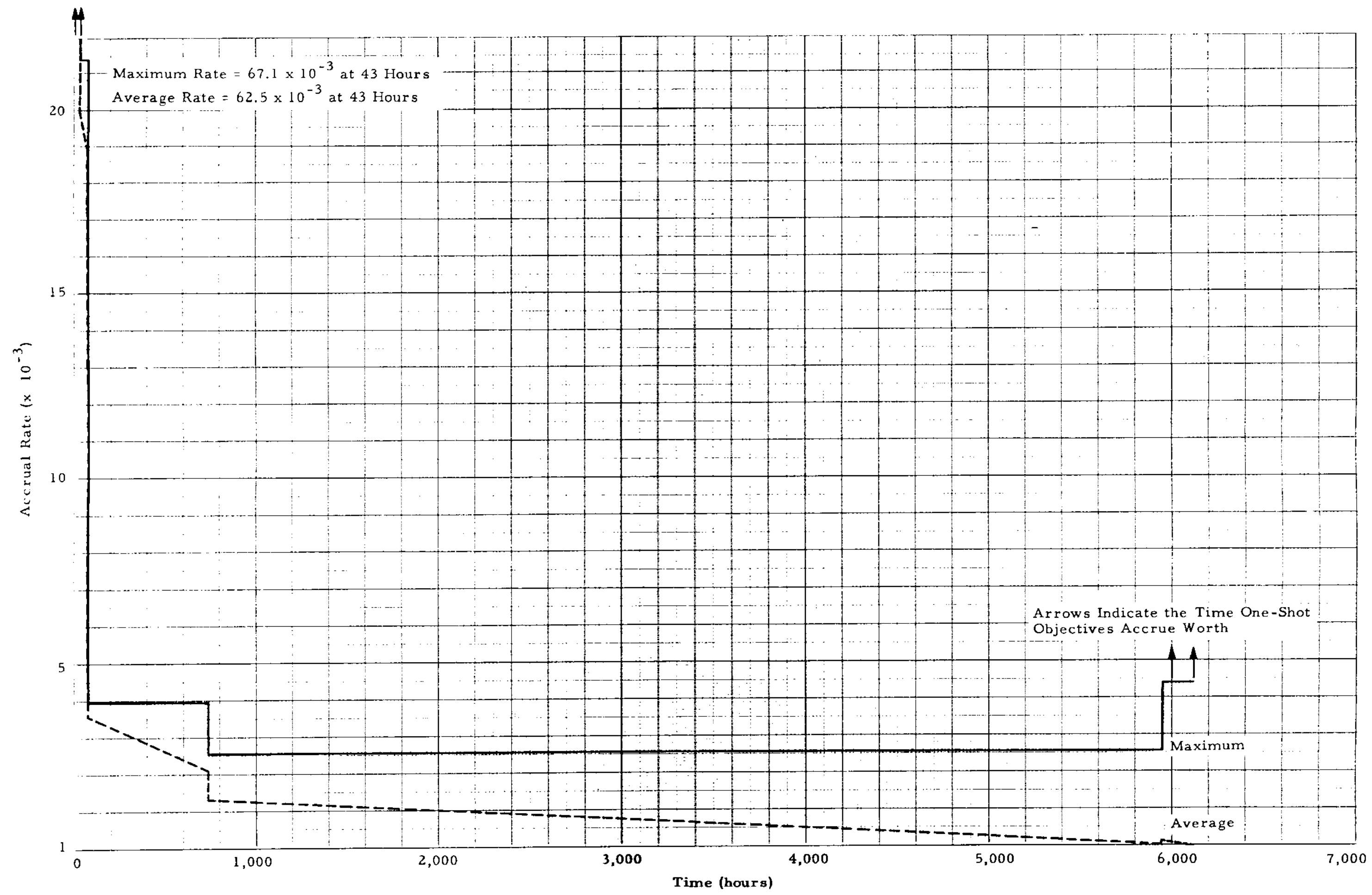

EXHIBIT 56 - TOTAL MISSION WORTH ACCRUAL RATE

EXHIBIT 57 - ACCRUED WORTH FOR MISSION OBJECTIVES

	Maximum	Expected Worth
Continuous Objectives:		
Cruise Science	12.0	6.3
Engineering Telemetry	3.5	2.0
Orbit Determination	4.5	3.6
One-Shot Objectives:		
Star Acquisition	1.0	0.9
Trajectory Correction	2.0	1.9
Encounter	6.0	2.9
Encounter Science	11.0	2.6
Tape Playback	60.0	14.1
Totals	100.0	34.3

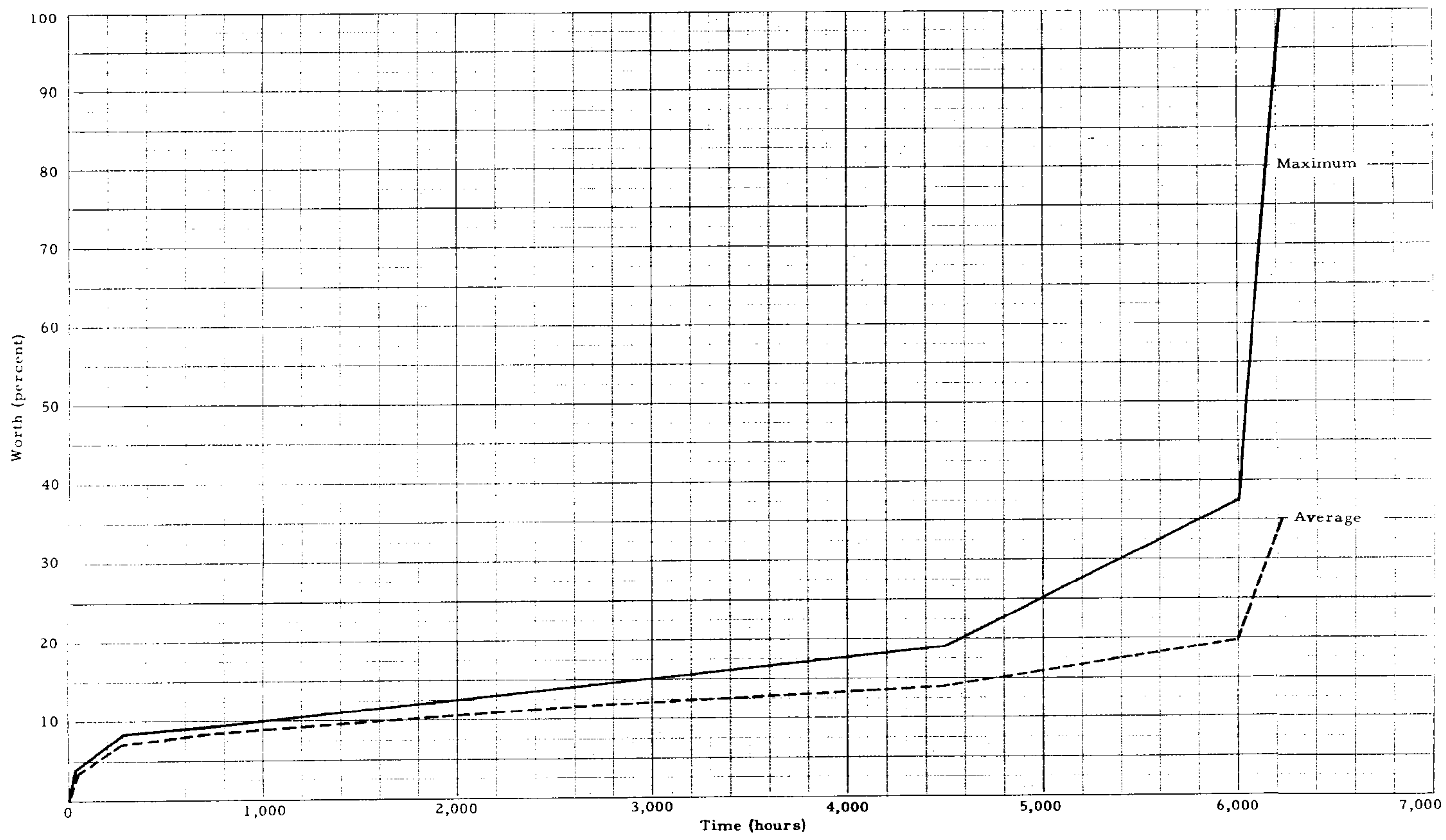

EXHIBIT 58 - TOTAL MISSION ACCRUED WORTH

V. ASSESSMENT CONCLUSIONS

The ability to draw meaningful conclusions from a reliability assessment is limited to a significant degree by the availability of a background of experience upon which judgments can be based. Clearly, no such background exists if comparisons are restricted to flyby missions aimed at the vicinity of Mars. The extremely successful Mariner R 1962 program does provide a point of reference that possesses many of the same design requirements and objectives as the program under consideration here. Despite the fact that the single Venus probe does not constitute a statistically valid sample, comparisons to it are inevitable and have been made freely throughout this report. Such comparisons enter into many of the conclusions discussed in this section.

A. General Conclusions

1. The most significant general conclusion that can be made about the Mariner C spacecraft is that its reliability is considerably higher than would be estimated by extrapolating the predictions made for Mariner R. The possibilities for random failures are certainly much greater if total mission length is extended two and one-half times, which is the approximate ratio between the Mariner C and Mariner R missions. Moreover, the distinct emphasis that has been deliberately placed on end-of-the-mission objectives operates to bring the figure-of-merit down to the level of an overall classical reliability. Despite these factors, the figure-of-merit and the predicted reliability which it implies have remained relatively high.

2. The predicted classical reliability of 0.111 must be recognized as applying to a somewhat arbitrarily defined "successful" mission in which most, but not all, objectives are completely fulfilled. The exclusion of thousands of data encoder parts, justified by the knowledge that they serve a secondary objective, greatly influenced the calculated reliability. Had these parts been included, it is certain that the predicted reliability of the remainder of the spacecraft would have been almost totally obscured.

3. Neither measure of spacecraft reliability, FOM or classical, includes the potentially degrading effects of the data automation system. This system must inevitably add several thousand components to the spacecraft parts complement and, if it were conventionally constructed, would lower the predicted reliability to a very noticeable extent. If the system were comparable to the science data conditioning system of Mariner R, it would reduce the predicted reliability by a factor in the order of 0.5. Improved fabrication techniques being employed in its construction may well operate to prevent any such degradation of reliability.

4. A broad view of the spacecraft subsystems shows a reasonably good balance in the individual reliability predictions. There is no outstandingly "poor" subsystem and, conversely, there is no disproportionately reliable subsystem. For this reason, no obvious recommendation can be made that attention be focused on any particular area. Individual subsystems should, of course, be examined at any time for reliability weaknesses, but it appears that this kind of activity need not be directed at specially selected functional areas.

5. Regardless of the interpretation placed on the reliability predictions resulting from this study, the inherent reliability of the parts and designs should be conserved by proper packaging and wiring techniques and by close control of fabrication and testing processes. These factors are included in this study only to the extent that they can be introduced into individual part failure rates. Reliability cannot be improved, but only degraded, by assembly and testing operations.

B. Subsystem Conclusions

Consideration of each of the individual subsystems has not necessarily brought to light a significant body of pertinent conclusions in each case. Nevertheless, certain observations can be made in many instances.

1. Data Encoder

The overall design philosophy of the Mariner C data encoder tends toward higher reliability than similar data sampling and encoding systems, such as Mariner R. This is discernible in several ways, the most noticeable of which is the provision for A-D converter and PN generator groups that are redundant by command. Use of complementary flip-flops in the sequencers (shift registers) tends to insure that the consequences of failure will be a direct function of where the failure occurs. That is, a complementary flip-flop has a tendency to fail "off," while a conventional flip-flop is just as likely to fail "on" and "off." Therefore, the consequence of complementary flip-flop failure in a shift register is that the associated channel or those following it will no longer be selectable. Failure of a conventional flip-flop could have the same result, but in addition--and with equal probability--it could fail "on," resulting in the switching of more than one input at a time to the common output, thus in turn resulting in loss of all of the inputs.

Increased reliability is also obtained by shifting through two (and in one case three) sequencers simultaneously, thus tending to insure that failure of an entire sequencer will not affect any channels other than those associated with the failed sequencer. In addition, diode redundancy is used in the logic throughout the subsystem. Although comparative numerical gains that can be and have been made with such design philosophies cannot be determined in a study of this scope, it is evident that considerable thought has been given to reliable design.

Some negative conclusions can also be made without regard to calculated numbers, however. For example, the probability of getting any particular digital engineering word can be increased by changing the logic of a typical selection signal from 10 x 115 (for event registers 1 and 2) to 10 x (115 + 105). Then, if logic signal 115 were unavailable because of failure in the sequencer stage associated with it or in any stage preceding it, the event register could still be read out by logic signal 105.

In the single-pole electronic switch, one transformer secondary winding and the resistor across it serve no functional purpose. Although it is difficult within the scope of the present study to make exact determinations at this level, it would seem that a normal, two-winding transformer could be found for this application.

Eight decks of telemetry channels are found to be dependent on unit 2144 (10 switch), while only two are dependent on unit 2145 (11 switch).

Thus, failure "off" of the 10 switch would result in a much greater subsystem loss than the same failure of the 11 switch. This situation could be alleviated by some reassignment of the channels. As was stated previously, the gains resulting from such changes would require more detailed study and perhaps some comparative analyses; for comparative purposes, calculations would be required for the various alternatives.

Note that in the previous paragraph it was necessary to refer to "subsystem loss." The figure-of-merit approach to reliability requires that some consideration be given to success. Considering the subsystem independently, it could reasonably be stated that, since there will be two A-D converters and two PN generators aboard, increased reliability could possibly be attained by allowing both PN generators to operate with one A-D converter and, if possible, with both A-D converters. This would depend on the availability of at least one command, which, to the knowledge of the analyst, is available. However, on an overall system mission basis the engineering data has relatively little worth (3.5 out of 100). Therefore, consideration should perhaps be given to eliminating the redundant A-D converter so that its power and weight requirements could be devoted to higher worth portions of the system.

2. Command Detector and Decoder

It is quite evident that the spacecraft is well protected against the false execution of commands from outside influence when all of the command equipment is unfailed. That is, when operating in a completely unfailed state, a sync subcarrier must be available to lock up the command detector before a command can be executed. This action must then be followed by 26 "0's" and the three decoder start bits, "1," "1," "0." Then, if the next six bits contain an even number of "1's," indicating an actual command, the command will be executed. Thus the protection against false execution of commands is extensive.

The design does not include any hardware redundancy, and appears to be straightforward with respect to design simplicity considering the complexity of what is being accomplished in the command detector.

The effect of any failures in this subsystem can be looked upon as causing a command either to be unexecutable or to be executed continuously. With respect to the latter, the ultimate result of the failure depends on the use of the output at the receiving end.

It is interesting to note that the consequences of subsystem command failure indicated with an IS switch differ from those involving an IP switch. Over a long time period it can be said that any failure on the input side of the transformer associated with a command indicated by an IP switch results in further inability to execute that command. It is recognized that, depending on the particular mode of failure, a single execution indication would falsely appear. However, in many (if not all) cases, the effect of such an execution could be offset by the proper execution of another command. For example, if the low bit rate were required and such a failure as described above caused the bit rate to change to the high rate, a proper command of low bit rate to the spacecraft would rectify the situation. For those commands indicated by an IS switch, the results of some failures are the same as for the IP switch. In addition, though, there are failures that cause a continuous output. This situation could be helped by a-c coupling the input to the switch if this can be tolerated in the circuit design. This would at least alleviate the consequences due to such modes of failure originating in the active portion of the decoding gates.

3. Central Computer and Sequencer

The basic design concepts applying to this subsystem do not differ extensively from those previously employed. The combined requirement for both short- and long-term sequencing functions dictates the necessity for long chains of countdown circuitry. Much of this equipment serves no primary purpose, after short-term requirements are met, except to provide an input to the long-term dividers. The number of parts involved raises the hazard of a random failure and loss of the timing functions at encounter, when they are so important. Replication of the dividers would be complex and costly, but a standby long-term clock is desirable. An astronomical or optical device, actuated by the transit of selected celestial references, might be implemented with less complexity. This would require study and development.

4. Power Supply

The division of the principal power supply elements into two groups and the redundancy afforded by this move represent a major effort to improve reliability at minimum cost and weight. Advantage has been taken of the mission profile characteristics, and the design is probably close to optimum for the type of power source available. The solar array itself is the area which should be examined if further reliability improvement is sought. The isolation and overvoltage protection constitutes the largest single contributor to the unreliability of this subsystem.

5. Attitude Control

Elimination of the antenna hinge function has provided a substantial reliability gain within the attitude control subsystem. The solar pressure stabilization system, if it performs according to the operational regime that has been calculated for it, will produce a dramatic reduction in valve duty cycle for two of the control axes. This subsystem shows an encouragingly high reliability when compared with the Mariner R subsystem; however, the acquisition of Canopus may, for operational reasons, depend upon the availability of commands and, while this has been accounted for in the predicted reliability, it emphasizes the necessity for devoting sufficient attention to interface problems. Consideration of the inertial control operating mode reinforces this recommendation. Signals from the command subsystem should be transmitted in the most fail-safe manner.

6. Trajectory Correction

The trajectory correction operation shows a relatively high predicted reliability. The principal reason for this is the short operating time, but higher reliabilities of the subsystems involved have contributed significantly to the apparently favorable result. The estimated figure for operational probability of success is encouraging and suggests a reexamination of the reasons for two maneuvers. This capability has been obtained with only a modest increase in parts, but the propellant storage problem raises some question as to the hazard involved in carrying high-pressure tankage for the full mission.

7. Radio Subsystem

An obvious conclusion concerning the radio subsystem is that the reliability of the transmitter is very high for this class of equipment, primarily due to the extensive application of redundancy. On the other hand, the receiver, which is more complex, is not marked by any type of redundancy, either at the component level or in the functional sense. Replication of the receiver would indeed be costly, particularly in terms of weight, and is probably not justified because there is no direct dependence on the receiver after the maneuvers. The receiver is required for command capability, however, and in this redundant sense its role continues to be important throughout the mission, especially at encounter.

8. Pyrotechnic Subsystem

The classical reliabilities predicted for solar array deployment and maneuver propulsion timing reflect the high level of reliability of the pyrotechnic subsystem. The redundancy incorporated into the design is quite complete and should assure proper initiation of these pyrotechnic events. Attention in these areas should be focused on the mechanical devices themselves, as these are more likely to fail than the initiating circuitry.

APPENDIX A

APPENDIX A

UNIT FAILURE RATES

The piece parts count and resultant failure rate for each reliability unit used in the assessment of the Mariner C spacecraft are listed on the following pages. It was necessary in establishing accurate representations of the spacecraft subsystems to contrive some units which account for various modes of failure of the component parts. The simple listing of the parts complement of such a unit is not sufficient to show the manner in which the appropriate failure rates of the unit are derived. Therefore, a section has been included with this appendix which presents all details of these specialized unit failure rate computations.

In some instances, parts counts were based on parts lists submitted with the documentation; otherwise they were taken from applicable schematic diagrams. Wherever diagrams were used to establish a parts count, the identification of the parts may have been incomplete and occasionally it was necessary to estimate the exact classification of some parts. This was not generally the case, and it is felt that the parts counts presented here are quite adequate for the purposes of the study.

1. Unit Parts Complements

	Unit	Number of Components	Individual Component Failure Rate[1]
101:	Cover Latch		
	Latch	1	.02
102:	Hinge and Actuating Spring		
	Hinge	1	.02a[2]
	Actuator	1	1.05a
		2	1.07a
103:	Motor and Gearing		
	Motor, electrical	1	3.00
	Gear box	1	6.30
	Potentiometer	1	1.08
		3	10.38
104:	Scan Electronics		
	Capacitors, tantalum	40	.08
	Capacitors, ceramic	8	.01
	Resistors, wirewound	4	.22
	Resistors, carbon composition	100	.01
	Diodes, zener	7	.26
	Diodes	20	.15
	Transistors	28	.30
	Transformers, 4 terminals	2	.80
	Transformers, rectifier	4	2.47
	Thermistors	2	.30
	Neon lamps	4	1.00
	Photo diodes	4	.38
		223	35.98

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[1] Failure rate given is to be multiplied by 10^{-6}. Unit is "per hour" unless otherwise noted.

[2] a = actuations.

	Unit	Number of Components	Individual Component Failure Rate	
			During Mission	At Encounter
105:	Recorder Mechanism			
	Drive belts	4	.10	10.0
	Bearing assemblies	2	.50	2.0
	Pulley shaft assemblies	2		.01
	Shaft bearings (ball)	4	.50	2.00
	Input bearings (ball)	4	.50	2.00
	Clutches, spring type	2		2.50
	Input pulleys	2		.01
	Tape drive belt	1	.10	10.0
	Springs	2	.01	
	Pivoted sleeves	2	.10	
	Bearings	2	.50	2.0
	Ball bearings, pair	1	.05	2.0
	Housing and center shaft	1	.01	
	Hub assembly, rotating	1	.01	
	Tape roller assemblies	6	.50	2.0
	Endless magnetic tape (Mylar)	1	.01	
	During mission	31	9.80	
	At encounter only	30		93.04

			Individual Component Failure Rate
106:	Record Electronics		
	Capacitors	8	.01
	Capacitors, glass	6	.01
	Resistors, metal film	48	.01
	Resistors, film	8	.01
	Diodes, silicon	28	.15
	Transistors	18	.30
	Transformer	1	.80
	Relay	1	.60
	Record heads	2	.20
	Record motor	1	3.00
		121	15.10

Unit	Number of Components	Individual Component Failure Rate
107: Playback Electronics		
Capacitors, tantalum	50	.08
Capacitor, film	1	.01
Capacitors, glass	120	.01
Resistors, metal film	228	.01
Resistors, carbon composition	2	.01
Resistor, variable	1	.01
Resistors, film	333	.01
Resistors, wirewound	2	.22
Potentiometer	1	1.08
Diodes, silicon	156	.15
Diodes, zener	11	.26
Diodes, power	10	.01
Transistors	168	.30
Transformers, 4 terminals	3	.80
Transformer, 8 terminals	1	1.60
Transformer, 11 terminals	1	2.20
Relay, magnetic latching	1	.60
Chokes	3	.20
Switches, silicon controlled	2	.30
Rectifiers	2	1.20
Playback heads	2	.20
Playback motors	2	3.00
	1100	70.16
2001: Rate Generator		
Capacitors, tantalum	5	.08
Capacitors, glass/ceramic	28	.01
Resistors, carbon film	90	.01
Diodes, silicon	33	.15
Transistors	25	.30
Transformer, 4 terminals	1	.80
Relay, latching	1	.60
Rectifiers	2	1.20
	185	16.03[1]

---

[1] This is the failure rate for the series components only; 12 of the 33 diodes are arranged in configurations as shown in (a), (b), (c), and (d). (See Appendix A, section 2, p. 232.) The reliability of unit 2001 is thus

$$R_{2001} = R_s R_a R_b R_c R_d$$

where

$$R_s = e^{-16.03 \times 10^{-6} t} .$$

Similar notation will be used for other units of the Data Encoder where appropriate.

Unit	Number of Components	Individual Component Failure Rate
2002: Mode Selector		
Capacitors, tantalum	23	.08
Resistors, carbon film	32	.01
Diodes	19	.15
Transistors	15	.30
Transformers, 4 terminals	3	.80
Rectifiers	4	1.20
Relays, latching	3	.60
	99	17.55[1]
2003-1: Switching Circuits (Partial)		
Relays, latching	6	.60
	6	3.60
2003-2: Switching Circuits (Partial)		
Capacitors, tantalum	4	.08
Capacitors, glass	12	.01
Resistors, film	57	.01
Diodes, silicon	22	.15
Transistors	16	.30
Relays, latching	3	.60
Rectifiers	2	1.20
	116	11.51[2]
2003-3: Switching Circuits (Partial)		
No parts		

---

[1] Failure rate of series components only; 12 capacitors are in the (j) configuration. (See Appendix A, section 2, p. 232.)

$$R_{2002} = R_sR_j \; .$$

[2] Failure rate of series components only; 12 diodes are arranged as in (a), (b), (c), (d). (See Appendix A, section 2, p. 232.)

$$R_{2003-2} = R_sR_aR_bR_cR_d \; .$$

Unit	Number of Components	Individual Component Failure Rate
2003-4: Switching Circuits (Partial)		
No parts		
2004-1: PNG "OR" (Partial)		
Unit 2004		
Capacitors, glass	25	.01
Capacitor, tantalum	1	.08
Resistors, film	88	.01
Diodes, silicon	43	.15
Transistors	25	.30
	182	10.66
Unit 2004-1 = 1/2 unit 2004	91	5.33[1]
2004-2: PNG "OR" (Partial)		
Same as unit 2004-1		
2005: PNG "A"		
Capacitor, tantalum	1	.08
Capacitors, glass/ceramic	21	.01
Resistors, carbon film	76	.01
Diodes, silicon	71	.15
Transistors	19	.30
	188	8.70[2]
2006: PNG "B"		
Same as 2005		

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[1] Series components only; 30 of the diodes are arranged as follows: 12 as in (c), 6 as in (a), and 12 as in (d). (See Appendix A, section 2, p. 232.)

$$R_{2004-1} = R_s \, 1/2 \, (R_c)^3 \, (R_a)^3 \, (R_d)^3 \ .$$

[2] Series components only; 58 of the diodes are arranged as follows: 2 as in (b), 4 as in (a), 4 as in (e), 40 as in (g), and 8 as in (h). (See Appendix A, section 2, p. 232.)

$$R_{2005} = R_s R_b R_e R_h (R_a)^2 \, (R_g)^5 \ .$$

	Unit	Number of Components	Individual Component Failure Rate
2007:	Power Supply		
	Capacitors, tantalum	15	.08
	Capacitors, paper	2	.01
	Capacitors, glass/ceramic	4	.01
	Resistors, wirewound	35	.22
	Resistors, carbon film	21	.01
	Diodes	26	.15
	Diodes, power	8	.01
	Transistors	15	.30
	Transformer, 8 terminals	1	1.60
		127	19.25
2008:	Modulator		
	Capacitors, glass	30	.01
	Resistors, film	112	.01
	Diodes, silicon	22	.15
	Transistors	28	.30
		192	13.12
2010:	Mixer Amplifier		
	Resistors	12	.01
	Transistors	5	.30
		17	1.62
2011:	Data Selector		
	Capacitors, glass	30	.01
	Resistors, carbon film	100	.01
	Diodes, silicon	40	.15
	Transistors	24	.30
		194	10.00[1]

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[1] Series components only; 30 of the diodes are arranged as follows: 8 as in (a), 4 as in (b), 8 as in (f), 6 as in (i), and 4 as in (c). (See Appendix A, section 2, p. 232.)

$$R_{2011} = R_s R_c (R_a)^4 (R_b)^2 (R_f)^2 (R_i)^2 \quad .$$

Unit	Number of Components	Individual Component Failure Rate
2012-1: ADC "OR" (Partial)		
Unit 2012:		
Capacitors, glass	4	.01
Resistors, film	14	.01
Diode, silicon	8	.15
Transistors	4	.30
	30	2.58
Unit 2012-1 = 1/2 unit 2012	15	1.29
2012-2: ADC "OR" (Partial)		
Same as 2012-1		
2013: ADC "A"		
Capacitors, glass	2	.01
Resistors, film	8	.01
Diodes	2	.15
Transistors	6	.30
	18	2.20
2014: ADC "B"		
Same as 2013		
2015: Isolation Amplifier "A"		
Capacitors	2	.01
Resistors, film	10	.23
Diodes, zener	3	.26
Transistors	8	.30
	23	5.50
2016: Isolation Amplifier "B"		
Same as 2015		

	Unit	Number of Components	Individual Component Failure Rate
2017:	10, 11 and Medium-Speed Drive		
	Capacitors, glass	12	.01
	Resistors, film	48	.01
	Diodes, silicon	14	.15
	Transistors	12	.30
		86	6.30
2018:	Science Selection Circuits		
	Capacitors, glass	8	.01
	Resistors, film	24	.01
	Diodes, silicon	11	.15
	Transisors	6	.30
		49	3.77
2019:	Master Counter		
	Capacitors, glass	18	.01
	Resistors, film	48	.01
	Diodes, silicon	11	.15
	Transistors	12	.30
		89	5.91
2020:	100 Synchronizer		
	Capacitors, glass	5	.01
	Resistors	11	.01
	Diodes	10	.15
	Transistors	3	.30
		29	2.56
2021:	200 Synchronizer		
	Same as 2020		
2022:	300 Synchronizer		
	Same as 2020		

Unit	Number of Components	Individual Component Failure Rate
2023: Word Sync Amplifier		
Capacitors, glass	2	.01
Resistors, film	8	.01
Diodes	2	.15
Transistors	2	.30
	14	1.00
2025: 100 Sequencer		
Capacitors, glass	12	.01
Resistors, film	30	.01
Diode, zener	1	.26
Diodes	12	.15
Transistors	22	.30
	77	9.08
2025-1: 100 Sequencer (Partial)		
Capacitors, glass	3	.01
Diode, zener	1	.26
Diodes	2	.15
Resistors, film	13	.01
Transistors	4	.30
	23	1.92
2025-2: 100 Sequencer (Partial)		
Capacitor, glass	1	.01
Resistors, film	2	.01
Diodes	1	.15
Transistors	2	.30
	6	.78
2025-3, ···, -10: 100 Sequencer (Partial)		
Same as 2025-2		
2026: 110 Sequencer		
Same as 2025		

Unit	Number of Components	Individual Component Failure Rate
2027: 200 Sequencer		
Same as 2025		
2028: 212 Sequencer		
Same as 2025		
2029: 1.5-Volt Bucking Supply		
Capacitor	1	.01
Resistors	4	.01
Diodes	2	.15
Diode, zener	1	.26
Transformer, 14 terminals[1]	1	.70
	9	1.31
2030: 300 Sequencer		
Same as 2025		
2031: 401 Sequencer		
Same as 2025		
2032: 1.5-Volt Bucking Supply		
Same as 2029		
2033: 423 Sequencer		
Same as 2025		
2034: 0.5-Volt Bucking Supply		
Capacitors	2	.01
Resistors	6	.01

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[1] Failure rate divided among four units. This transformer also serves units 2032, 2034, and 2049.

Unit		Number of Components	Individual Component Failure Rate
2034:	0.5-Volt Bucking Supply (Cont.)		
	Diodes	2	.15
	Diode, zener	1	.26
	Transformer, 14 terminal[1]	1	.70
		12	1.34
2035:	Driver		
	Capacitors, glass	2	.01
	Resistors, film	8	.01
	Diode, silicon	1	.15
	Transistors	2	.30
		13	.85
2037:	40, 41, 42, 43 Drive		
	Capacitors, glass	4	.01
	Resistors, carbon film	6	.01
	Resistors, film	8	.01
	Diodes, silicon	2	.15
	Transistors	4	.30
		24	1.68
2038:	Low-Speed Deck Position Indicator		
	Capacitors, glass	28	.01
	Resistors, film	81	.01
	Diodes, silicon	20	.15
	Transistors	20	.30
		149	10.09
2039:	Transfer Register		
	Capacitors, glass	10	.01
	Resistors, film	68	.01
	Diodes, silicon	26	.15
	Transistors	14	.30
		118	8.88

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[1] Failure rate divided among four units. This transformer also serves units 2029, 2032, and 2049.

	Unit	Number of Components	Individual Component Failure Rate
2040:	Digital Word Programmer		
	Capacitors, glass	46	.01
	Resistors, film	192	.01
	Diodes, silicon	50	.15
	Transistors	54	.30
		342	26.08
2041:	Sync Circuits		
	Capacitors, glass	8	.01
	Resistors, film	32	.01
	Diodes, silicon	16	.15
	Transistors	8	.30
		64	5.20
2042:	Event Register, No. 1		
	Capacitor, tantalum	1	.08
	Capacitors, glass	3	.01
	Resistors, film	13	.01
	Diode	1	.15
	Transistors	4	.30
		22	1.59
2043:	Event Register, No. 2		
	Same as 2042		
2044:	Event Register, No. 3		
	Same as 2042		
2045:	Event Register, No. 4		
	Same as 2042		
2046:	Command Detector Monitor (VCO)		
	Capacitors, glass	23	.01
	Resistors, film	134	.01
	Diodes, silicon	45	.15
	Transistors	30	.30
		232	17.32

Unit	Number of Components	Individual Component Failure Rate
2047: Command Detector Monitor (In/Out Lock)		
Capacitors, glass	8	.01
Resistors, film	24	.01
Diodes, silicon	6	.15
Transistors	4	.30
	42	2.42
2048: Event Timer		
Capacitors, glass	49	.01
Capacitors	4	.01
Resistors	13	.01
Resistors, film	146	.01
Diodes, silicon	43	.15
Transistors	28	.30
	283	16.97
2049: 0.5-Volt Bucking Supply		
Same as 2034		
2050: Low-Level Amplifier		
Capacitors, tantalum	8	.08
Capacitors, glass	5	.01
Capacitor, paper	1	.01
Resistors, film	25	.01
Diodes	2	.15
Transistors	13	.30
Transformer, 14 terminal	1	2.80
Transformer, 5 terminal	1	1.00
Choke	1	.20
	57	9.15
2051: 101 Switch, Single Pole		
Capacitors, tantalum	3	.08
Capacitors, glass	4	.01
Resistors, film	9	.23
Diodes	2	.15
Transistors	3	.30
Transformer	1	1.20
	22	4.75

Unit	Number of Components	Individual Component Failure Rate
2052-2053: 102-103 Switches, Single Pole		
Same as 2051		
2054-2063: 105-114 Switches, Single Pole		
Same as 2051		
2064-2066: 117-119 Switches, Single Pole		
Same as 2051		
2068-2076: 202-210 Switches, Single Pole		
Same as 2051		
2077-2080: 213-216 Switches, Single Pole		
Same as 2051		
2081-2089: 221-229 Switches, Single Pole		
Same as 2051		
2090-2099: 300-309 Switches, Single Pole		
Same as 2051		
2100: 403 Switch (T), Double Pole		
Capacitors, tantalum	3	.08
Capacitors, glass	5	.08
Resistors, film	11	.01
Diodes	3	.15
Transistors	4	.30
Transformer	1	1.20
	27	3.25
2101: 406 Switch (T), Double Pole		
Same as 2100		

Unit	Number of Components	Individual Component Failure Rate
2102-2104: 415-417 Switches, Single Pole Same as 2051		
2105: 422 Switch, Single Pole Same as 2051		
2106: 425 Switch, Single Pole Same as 2051		
2107: 427 Switch, Single Pole Same as 2051		
2108-2109: 211-212 Switches (T), Double Pole Same as 2100		
2110-2112: 217-219 Switches (T), Double Pole Same as 2100		
2113-2114: 401-402 Switches (T), Double Pole Same as 2100		
2115-2116: 404-405 Switches (T), Double Pole Same as 2100		
2117-2124: 407-414 Switches (T), Double Pole Same as 2100		
2125-2128: 418-421 Switches (T), Double Pole Same as 2100		

Unit	Number of Components	Individual Component Failure Rate
2129-2130: 423-424 Switches (T), Double Pole		
Same as 2100		
2131: 426 Switch (T), Double Pole		
Same as 2100		
2132-2143: 428-439 Switches (T), Double Pole		
Same as 2100		
2144-2145: 10-11 Switches, Single Pole		
Same as 2051		
2146-2149: 40-43 Switches, Single Pole		
Same as 2051		
2151: Current Generator		
Resistors	6	.01
Diode	1	.15
Diode, zener	1	.26
Transistors	4	.30
	12	1.67
3000: Command Detector (Partial)		
Capacitors	8	.01
Capacitors, tantalum	33	.08
Capacitors, glass	108	.01
Diodes	128	.15
Diodes, zener	2	.26
Resistors, composition	168	.01
Resistors, film	222	.01
Resistors	13	.01
Transistors	104	.30
Transformers, 4 terminal	4	.80
Inductor	2	.20
	792	62.35

Unit	Number of Components	Individual Component Failure Rate
3001-1: Command Detector (Partial)		
Capacitors, tantalum	3	.08
Capacitors, glass	3	.01
Diodes	4	.15
Resistors	16	.01
Transistors	4	.30
	30	2.23
3002: Programming Logic and Counter		
Capacitors	15	.01
Capacitors, glass	48	.01
Diodes	79	.15
Resistors	64	.01
Resistors, film	2	.01
Resistors, composition	80	.01
Transistors	33	.30
	321	23.84
3003: Shift Register, Stages 1 and 2		
Capacitors, glass	12	.01
Diode	8	.15
Resistors, composition	20	.01
Transistors	2	.30
	42	2.12
3004-1: In Lock Switch (Partial)		
For component parts, see Appendix A, section 2, p. 234. Unit failure rate is equal to $\lambda_{ON} + 1/2\,\lambda_{IND'T}$ for IS.	11	.346
3004-2: In Lock Switch (Partial)		
For component parts, see Appendix A, section 2, p. 234. Unit failure rate equals $\lambda_{OFF} + 1/2\,\lambda_{IND'T}$ for IS.	12	1.76

Unit	Number of Components	Individual Component Failure Rate
3005-1: Shift Register (Partial)		
Capacitors, glass	3	.01
Diodes	2	.15
Resistors	5	.01
Transistor	1	.30
	11	.68

3005-2: Shift Register (Partial)

Same as 3005-1

3006-1: Shift Register (Partial)

Same as 3005-1

3006-2: Shift Register (Partial)

Same as 3005-1

3007-1: Shift Register (Partial)

Same as 3005-1

3007-2: Shift Register (Partial)

Same as 3005-1

3008-1: Shift Register (Partial)

Same as 3005-1

3008-2: Shift Register (Partial)

Same as 3005-1

3009-1: Shift Register Drivers (Partial)

Same as 3004-2

3010-1: Shift Register Drivers (Partial)

Same as 3004-2

Unit	Number of Components	Individual Component Failure Rate
3011-1: Shift Register Drivers (Partial)		
Same as 3004-2		
3012-1: Shift Register Drivers (Partial)		
Same as 3004-2		
3013-1: Shift Register Drivers (Partial)		
Same as 3004-2		
3014-1: Shift Register Drivers (Partial)		
Same as 3004-2		
3015-1: Shift Register Drivers (Partial)		
Same as 3004-2		
3016-1: Shift Register Drivers (Partial)		
Same as 3004-2		
3017-1: Shift Register Drivers (Partial)		
Same as 3004-2		
3018-1: Shift Register Drivers (Partial)		
Same as 3004-2		
3019-1: Shift Register Drivers (Partial)		
Same as 3004-2		
3020-1: Shift Register Drivers (Partial)		
Same as 3004-2		

Unit	Number of Components	Individual Component Failure Rate
3021*: Decoding Gate For component parts, see Appendix A, section 2. Reliability equation derived on p. 235.		
3022*: Decoding Gate (Partial) For component parts, see Appendix A, section 2. Reliability equation derived on p. 236.		
3022-A1*: Decoding Gate (Partial) For component parts, see Appendix A, section 2. Reliability equation derived on p. 236.		
3023*-3028*: Decoding Gate Same as 3021*		
3029*-3033*: Decoding Gate (Partial) Same as 3022*		
3033-A2*: Decoding Gate (Partial) Same as 3022-A1*		
3034*: Decoding Gate (Partial) Same as 3022*		
3034-A2*: Decoding Gate (Partial) Same as 3022-A1*		
3035*-3044*: Decoding Gate (Partial) Same as 3022*		
3044-A4*: Decoding Gate (Partial) Same as 3022-A1*		

Unit	Number of Components	Individual Component Failure Rate
3045*-3046*: Decoding Gate (Partial)		
Same as 3022*		
3081*: Decoding Gate		
Same as 3021*		
3047-1: DC-1 Switch (Partial)		
For component parts, see Appendix A, section 2, p. 234. Unit failure rate equals $\lambda_{ON} + 1/2 \lambda_{IND'T}$ of IP.	5	.223
3047-2: DC-1 Switch (Partial)		
For component parts, see Appendix A, section 2, p. 234. Unit failure rate equals $\lambda_{OFF} + 1/2 \lambda_{IND'T}$ of IP.	7	1.35
3048-1: DC-2A Switch (Partial)		
Same as 3047-1		
3048-2: DC-2A Switch (Partial)		
Same as 3047-2		
3049-1: DC-4A Switch (Partial)		
Same as 3047-1		
3049-2: DC-4A Switch (Partial)		
Same as 3047-2		
3050-1: DC-5 Switch (Partial)		
Same as 3047-1		
3050-2: DC-5 Switch (Partial)		
Same as 3047-2		

Unit	Number of Components	Individual Component Failure Rate
3051-1: DC-6 Switch (Partial) Same as 3047-1		
3051-2: DC-6 Switch (Partial) Same as 3047-2		
3052-1: DC-7 Switch (Partial) Same as 3047-1		
3052-2: DC-7 Switch (Partial) Same as 3047-2		
3053-1: DC-8 Switch (Partial) Same as 3047-1		
3053-2: DC-8 Switch (Partial) Same as 3047-2		
3054-1: DC-2B Switch (Partial) For component parts, see Appendix A, section 2, p. 234. Unit failure rate equals $\lambda_{ON} + 1/2\,\lambda_{IND'T}$ of IS.	11	.346
3054-2: DC-2B Switch (Partial) For component parts, see Appendix A, section 2, p. 234. Unit failure rate equals $\lambda_{OFF} + 1/2\,\lambda_{IND'T}$ of IS.	12	1.76
3055-1: DC-3 Switch (Partial) For component parts, see Appendix A, section 2, p. 234. Unit failure rate equals $\lambda_{ON} + 1/2\,\lambda_{IND'T}$ of Decoding Gate plus $\lambda_{ON} + 1/2\,\lambda_{IND'T}$ of IS.	16	.506

Unit	Number of Components	Individual Component Failure Rate
3055-2: DC-3 Switch (Partial) For component parts, see Appendix A, section 2, p. 234. Unit failure rate equals $\lambda_{OFF} + 1/2 \lambda_{IND'T}$ of IS.	12	1.76
3057-1: DC-9 Switch (Partial) Same as 3055-1		
3057-2: DC-9 Switch (Partial) Same as 3055-2		
3058-1: DC-10 Switch (Partial) Same as 3055-1		
3058-2: DC-10 Switch (Partial) Same as 3055-2		
3059-1: DC-11 Switch (Partial) Same as 3055-1		
3059-2: DC-11 Switch (Partial) Same as 3055-2		
3060-1: DC-12 Switch (Partial) Same as 3055-1		
3060-2: DC-12 Switch (Partial) Same as 3055-2		
3061-1: DC-13A Switch (Partial) Same as 3054-1		

Unit	Number of Components	Individual Component Failure Rate
3061-2: DC-13A Switch (Partial)		
Same as 3054-2		
3062-1: DC-13B Switch (Partial)		
Same as 3054-1		
3062-2: DC-13B Switch (Partial)		
Same as 3054-2		
3063-1: DC-13C Switch (Partial)		
Same as 3054-1		
3063-2: DC-13C Switch (Partial)		
Same as 3054-2		
3064-1: DC-14A Switch (Partial)		
Same as 3054-1		
3064-2: DC-14A Switch (Partial)		
Same as 3054-2		
3065-1: DC-14B Switch (Partial)		
Same as 3054-1		
3065-2: DC-14B Switch (Partial)		
Same as 3054-2		
3066-1: DC-15 Switch (Partial)		
Same as 3055-1		
3066-2: DC-15 Switch (Partial)		
Same as 3055-2		

Unit	Number of Components	Individual Component Failure Rate
3067-1: DC-16 Switch (Partial)		
Same as 3055-1		
3067-2: DC-16 Switch (Partial)		
Same as 3055-2		
3068-1: DC-17 Switch (Partial)		
Same as 3055-1		
3068-2: DC-17 Switch (Partial)		
Same as 3055-2		
3069-1: DC-18 Switch (Partial)		
Same as 3055-1		
3069-2: DC-18 Switch (Partial)		
Same as 3055-2		
3070-1: DC-19 Switch (Partial)		
Same as 3055-1		
3070-2: DC-19 Switch (Partial)		
Same as 3055-2		
3071-1: DC-20 Switch (Partial)		
Same as 3055-1		
3071-2: DC-20 Switch (Partial)		
Same as 3055-2		
3072-1: DC-21 Switch (Partial)		
Same as 3055-1		

Unit	Number of Components	Individual Component Failure Rate
3072-2: DC-21 Switch (Partial)		
Same as 3055-2		
3073-1: DC-23 Switch (Partial)		
Same as 3055-1		
3073-2: DC-23 Switch (Partial)		
Same as 3055-2		
3074-1: DC-24 Switch (Partial)		
Same as 3055-1		
3074-2: DC-24 Switch (Partial)		
Same as 3055-2		
3075-1: DC-25A Switch (Partial)		
Same as 3054-1		
3075-2: DC-25A Switch (Partial)		
Same as 3054-2		
3076-1: DC-25B Switch (Partial)		
Same as 3054-1		
3076-2: DC-25B Switch (Partial)		
Same as 3054-2		
3077-1: DC-26 Switch (Partial)		
Same as 3055-1		
3077-2: DC-26 Switch (Partial)		
Same as 3055-2		

Unit	Number of Components	Individual Component Failure Rate
3078-1: DC-27 Switch (Partial)		
Same as 3055-1		
3078-2: DC-27 Switch (Partial)		
Same as 3055-2		
3079: Transformer-Rectifier		
Capacitors, tantalum	4	.08
Diodes, power	6	.01
Resistors	6	.01
Transformer, 13 terminals	1	2.60
Inductors	2	.20
	19	3.44
3080: Amplifier and Sync Switch		
Capacitor	1	.01
Diodes	2	.15
Resistors	7	.01
Transistors	3	.30
Transformer, 4 terminals	1	.80
	14	2.08
3082: Control Flip-Flop		
Capacitors, glass	6	.01
Diodes	4	.15
Resistors	10	.01
Transistors	2	.30
	22	1.36
3083: Event Logic and Switch		
Capacitors	2	.01
Diodes	5	.15
Resistors	11	.01
Transistors	4	.30
Transformer, 4 terminals	1	.80
	23	2.88

Unit	Number of Components	Individual Component Failure Rate
3084: CC and S Alert Logic and Switch		
Capacitor	1	.01
Diodes	3	.15
Resistors	7	.01
Transistors	3	.30
Transformer, 4 terminals	1	.80
	15	2.23
3085: CC and S Sync and QC Logic and Switches		
Capacitors	3	.01
Diodes	9	.15
Resistors	15	.01
Transistors	6	.30
Transformer, 4 terminals	1	.80
Transformer, 6 terminals	1	1.20
	35	5.33
401: Transformer-Rectifier		
Capacitors, tantalum	2	.08
Capacitor, paper	1	.01
Diodes, silicon	16	.15
Resistors, carbon	3	.01
Transformer, 10 terminals	1	2.00
	23	4.60
402: Oscillator		
Capacitor, tantalum	1	.08
Capacitors, glass	15	.01
Diodes, silicon	10	.15
Resistors, glass film	39	.01
Transistors	13	.30
Transformer, 4 terminals	1	.80
Crystal	1	1.00
	80	7.82

	Unit	Number of Components	Individual Component Failure Rate
403:	1-pps, 25-pps, and 1-ppm Counter		
	Resistors, glass	51	.01
	Resistors, wirewound	11	.22
	Resistors, glass film	106	.01
	Resistor, carbon	1	.01
	Transistors	46	.30
	Capacitors, glass	26	.01
	Capacitors, tantalum	6	.08
	Diodes, silicon	42	.15
	Cores	30	0
	Inductors	3	.20
		322	25.44
404:	Magnetic ÷ 1000		
	Resistors, glass	30	.01
	Resistors, wirewound	9	.22
	Transistors	12	.30
	Diodes, silicon	3	.15
	Cores	38	0
		92	6.33
405:	Launch Matrix		
	Capacitors, tantalum	2	.08
	Capacitor, glass	1	.01
	Diodes, silicon	15	.15
	Transistors	12	.30
	Resistor, composition	1	.01
	Resistors, glass	15	.23
		46	9.48
406:	Driver		
	Capacitors, tantalum	2	.08
	Resistors, glass	8	.01
	Diodes, silicon	3	.15
	Diode, zener	1	.26
	Transistors	2	.30
		16	1.55

	Unit	Number of Components	Individual Component Failure Rate
406a:	Relay		
	Diode, silicon	1	.15
	Relay, latching	1	.60
		2	.75
407:	Driver		
	Capacitors, tantalum	2	.08
	Resistors, glass	8	.01
	Diodes, silicon	3	.15
	Diode, zener	1	.26
	Transistors	2	.30
		16	1.55
407a:	Relay		
	Diode, silicon	1	.15
	Relay, latching	1	.60
		2	.75
408:	Driver		
	Capacitors, tantalum	2	.08
	Resistors, glass	8	.01
	Diodes, silicon	3	.15
	Diode, zener	1	.26
	Transistors	2	.30
		16	1.55
408a:	Relay		
	Diode, silicon	1	.15
	Relay, latching	1	.60
		2	.75
409:	Input Decoder		
	Resistors, glass	130	.01
	Capacitors, glass	19	.01
	Capacitors, tantalum	3	.08

	Unit	Number of Components	Individual Component Failure Rate
409:	Input Decoder (Cont.)		
	Capacitor, paper	1	.01
	Diodes, silicon	84	.15
	Transistors	31	.30
		268	23.64
410:	Address Register		
	Capacitors, glass	4	.01
	Capacitors, tantalum	2	.08
	Resistors, glass	41	.01
	Diodes, silicon	33	.15
	Transistors	9	.30
		89	8.26
411:	Maneuver Duration (Readin-Readout)		
	Capacitors, glass	15	.01
	Capacitor, tantalum	1	.08
	Resistors, film	58	.01
	Diodes, silicon	24	.15
	Diodes, zener	4	.26
	Transistors	14	.30
		116	9.65
412:	Pitch Maneuver Duration		
	Capacitors, film	3	.01
	Resistors, film	13	.01
	Diodes, silicon	45	.15
	Transistors	3	.30
	Cores	23	0
		87	7.81
413:	Pitch Polarity Set		
	Capacitors, glass	2	.01
	Resistors, glass	11	.01
	Diodes, silicon	3	.15
	Transistors	2	.30
		18	1.18

	Unit	Number of Components	Individual Component Failure Rate
414:	Roll Maneuver Duration		
	Capacitors, film	3	.01
	Resistors, film	13	.01
	Diodes, silicon	45	.15
	Transistors	3	.30
	Cores	23	0
		87	7.81
415:	Roll Polarity Set		
	Capacitors, glass	2	.01
	Resistors, glass	11	.01
	Diodes, silicon	3	.15
	Transistors	2	.30
		18	1.18
416:	Velocity Maneuver Duration		
	Capacitors, film	3	.01
	Resistors, film	14	.01
	Diodes, silicon	46	.15
	Transistors	3	.30
	Cores	23	0
		89	7.97
417:	Maneuver Clock		
	Capacitors, tantalum	2	.08
	Capacitor, glass	1	.01
	Resistors, wirewound	6	.22
	Resistors, glass	37	.01
	Diodes, silicon	14	.15
	Transistors	18	.30
	Cores	29	0
		107	9.36
418:	Driver		
	Capacitors, tantalum	3	.08
	Resistors, glass	9	.01
	Diode, zener	1	.26

	Unit	Number of Components	Individual Component Failure Rate
418:	Driver (Cont.)		
	Diodes, silicon	5	.15
	Transistors	2	.30
		20	1.94
419:	Relay Set Coil		
	Diode, silicon	1	.15
	Relay, latching	1	.60
		2	.75
420:	Driver		
	Capacitors, tantalum	2	.08
	Capacitor, glass	1	.01
	Resistors, glass	13	.01
	Sensistor, silicon	1	.01
	Diodes, silicon	12	.15
	Diode, zener	1	.26
	Transistors	4	.30
	Transformer, 6 terminals	1	1.20
		35	4.77
421:	Relay Set Coil		
	Diode, silicon	1	.15
	Relay, latching	1	.60
		2	.75
422:	Relay Set Coil		
	Diode, silicon	1	.15
	Relay, latching	1	.60
		2	.75
424:	Start Pitch Duration Switch		
	Capacitors, glass	2	.01
	Resistors, film	11	.01
	Diodes, silicon	4	.15
	Transistors	2	.30
		19	1.33

	Unit	Number of Components	Individual Component Failure Rate
425:	Magnetic ÷ 2000		
	Resistors, glass	40	.01
	Resistors, wirewound	10	.22
	Capacitor, tantalum	1	.08
	Diodes, silicon	5	.15
	Diode, zener	1	.26
	Transistors	15	.30
	Cores	43	0
		115	8.19
426:	Master Time Matrix		
	Resistors, glass	19	.01
	Diodes, silicon	42	.15
	Transistors	12	.30
		73	10.09
427:	Driver		
	Capacitors, tantalum	3	.08
	Resistors, glass film	9	.01
	Diodes, silicon	5	.15
	Diode, zener	1	.26
	Transistors	2	.30
		20	1.94
427a:	Relay		
	Diodes, silicon	2	.15
	Relay, latching	2	.60
		4	1.50
428:	Driver		
	Capacitors, tantalum	2	.08
	Resistors, glass film	8	.01
	Diodes, silicon	4	.15
	Diode, zener	1	.26
	Transistors	2	.30
		17	1.70

Unit	Number of Components	Individual Component Failure Rate
428a: Relay		
Diode, silicon	1	.15
Relay, latching	1	.60
	2	.75
429: Driver		
Capacitors, tantalum	2	.08
Resistors, glass film	8	.01
Diodes, silicon	4	.15
Diode, zener	1	.26
Transistors	2	.30
	17	1.70
429a: Relay		
Diode, silicon	1	.15
Relay, latching	1	.60
	2	.75
430: Driver		
Capacitors, tantalum	2	.08
Resistors, glass film	8	.01
Diodes, silicon	4	.15
Diode, zener	1	.26
Transistors	2	.30
	17	1.70
430a: Relay		
Diode, silicon	1	.15
Relay, latching	1	.60
	2	.75
431: Driver		
Resistors, glass	8	.01
Capacitors, tantalum	2	.08
Diodes, silicon	4	.15

Unit		Number of Components	Individual Component Failure Rate
431:	Driver (Cont.)		
	Diode, zener	1	.26
	Transistors	2	.30
		17	1.70
431a:	Relay		
	Relay, latching	1	.60
		1	.60
432:	Driver		
	Resistors, glass	8	.01
	Capacitors, tantalum	2	.08
	Diodes, silicon	4	.15
	Diode, zener	1	.26
	Transistors	2	.30
		17	1.70
432a:	Relay		
	Relay, latching	1	.60
		1	.60
433:	Driver		
	Resistors, glass	7	.01
	Capacitor, tantalum	1	.08
	Diodes, silicon	3	.15
	Diode, zener	1	.26
	Transistors	2	.30
		14	1.46
433a:	Relay		
	Relay	1	.60
		1	.60

Unit	Number of Components	Individual Component Failure Rate
434: Driver		
Resistors, glass	9	.01
Capacitors, tantalum	3	.08
Diodes, silicon	6	.15
Diode, zener	1	.26
Transistors	2	.30
	21	2.09
434a: Relay		
Relays, latching	2	.60
	2	1.20
435: Driver		
Resistors, glass	8	.01
Capacitors, tantalum	2	.08
Diodes, silicon	4	.15
Diode, zener	1	.26
Transistors	2	.30
	17	1.70
435a: Relay		
Relay, latching	1	.60
	1	.60
436: Driver		
Resistors, glass	8	.01
Capacitors, tantalum	2	.08
Diodes, silicon	4	.15
Diode, zener	1	.26
Transistors	2	.30
	17	1.70
436a: Relay		
Relay, latching	1	.60
	1	.60

Unit	Number of Components	Individual Component Failure Rate
437: Driver		
Capacitors, glass	2	.01
Capacitors, tantalum	2	.08
Resistors, glass	11	.01
Diodes	7	.15
Diode, zener	1	.26
Transistors	2	.30
	25	2.20
438: Relay Set Coil		
Diode	1	.15
Relay, latching	1	.60
	2	.75
439: Pitch and Roll Stop Logic and Driver		
Capacitors, glass	2	.01
Resistors, film	5	.01
Diodes	4	.15
Transistors	2	.30
	13	1.27
440: Relay Set Coil		
Same as 422		
441: Relay Reset Coil		
Same as 438		
442: Driver		
Capacitors, tantalum	3	.08
Capacitor, glass	1	.01
Resistors, glass	13	.01
Sensistor, silicon	1	.01
Diodes	9	.15
Diode, zener	1	.26
Transistors	4	.30
Transformer, 6 terminals	1	1.20
Inductor	1	.20
	34	4.60

Unit	Number of Components	Individual Component Failure Rate
443: Relay Set Coil		
Diode	1	.15
Relay, latching	1	.60
	2	.75
444: Start Roll Duration Switch		
Capacitors, glass	2	.01
Resistors, film	11	.23
Diodes	4	.15
Transistors	2	.30
	19	3.75
445: Relay Reset Coil		
Same as 443		
446: Driver		
Capacitor, glass	1	.01
Capacitor, tantalum	1	.08
Resistors, glass	11	.01
Sensistor, silicon	1	.01
Diodes	11	.15
Diode, zener	1	.26
Transistor	4	.30
Transformer, 6 terminals	1	1.20
	31	4.52
447: Relay Coil		
Relay	1	.60
	1	.60
448: Start Velocity Duration Switch		
Capacitors, glass	4	.01
Resistors, film	24	.01
Diodes	11	.15
Transistors	4	.30
	43	3.13

	Unit	Number of Components	Individual Component Failure Rate
449:	Velocity Stop Logic and Driver		
	Capaciors, glass	9	.01
	Capacitor, tantalum	1	.08
	Resistor, film	5	.01
	Diodes	7	.15
	Diode, zener	1	.26
	Transistors	4	.30
		27	2.73
450:	Relay Coil		
	Relay	1	.20
		1	.20
451:	Driver		
	Capacitors, tantalum	7	.08
	Capacitor, glass	1	.01
	Resistors, glass	24	.01
	Sensistor, silicon	1	.01
	Diodes	14	.15
	Diodes, zener	2	.26
	Transistors	6	.30
	Transformer, 6 terminals	1	1.20
		56	6.44
452:	Relay Reset Coil		
	Same as 421		
453:	Relay Reset Coil		
	Same as 419		
454:	Driver		
	Capacitors, tantalum	2	.08
	Resistors, film	9	.01
	Diode, zener	1	.26
	Diodes	2	.15
	Transistors	2	.30
		16	1.41

	Unit	Number of Components	Individual Component Failure Rate
455:	M/C Start-Stop Relay		
	Capacitor, tantalum	2	.08
	Resistors, film	2	.01
	Diode	1	.15
	Relay, latching	1	.60
		6	.93
501:	Solar Panel Circuitry[1]		
	Diodes	16	.15
	Diodes, zener	96	.26
	Transformers, 2 terminals	5	.40
		117	29.36
502:	Battery		
	Battery cells, silver zinc	18	.75
	Transformer, 2 terminals	1	.40
	Diode	1	.15
		20	14.05
503:	Battery Charger/Share Protector		
	Capacitor, paper	1	.01
	Capacitors, tantalum	5	.08
	Diodes	26	.15
	Diodes, glass	2	.15
	Diode, zener	1	.26
	Resistors, composition	19	.01
	Resistors, wirewound, power	5	.22
	Transistors	9	.30
	Relay	2	.60
	Choke	2	.20
	Transformers, 6 terminals	2	1.20
	Magnetic amplifier, 10 terminals	1	2.00
		75	14.86

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[1] See Appendix A, section 2, p. 237, for method of calculating reliability of unit.

	Unit	Number of Components	Individual Component Failure Rate
504:	Power Distribution and Switching Unit		
	Capacitors, tantalum	2	.08
	Diodes	8	.15
	Transformer, 6 terminals	1	1.20
	Chokes	2	.20
		13	2.96
505:	2.4-kc Sync		
	Capacitors, ceramic	12	.01
	Capacitors, tantalum	2	.08
	Resistors, composition	31	.01
	Diodes	8	.15
	Transistors	9	.30
		62	4.49
506:	Booster Regulator No. 1		
	Resistors, film	2	.01
	Resistors, wirewound	17	.22
	Resistors, composition	12	.01
	Capacitor, paper	1	.01
	Capacitors, tantalum	8	.08
	Diodes	6	.15
	Diodes, zener	5	.26
	Transistors	13	.30
	Transformers, 5 terminals	2	1.00
	Transformer, 6 terminals	1	1.20
	Transformer, 8 terminals	1	1.60
	Choke	1	.20
		69	15.63
507:	Booster Regulator No. 2		
	Capacitor, paper	1	.01
	Capacitors, tantalum	8	.08
	Resistors, film	2	.01
	Resistors, wirewound	17	.22
	Resistors	12	.01
	Diodes, zener	5	.26
	Diodes, silicon	7	.15
	Transistors	13	.30

Unit	Number of Components	Individual Component Failure Rate
507: Booster Regulator No. 2 (Cont.)		
Transformers, 5 terminals	2	1.00
Transformer, 6 terminals	1	1.20
Transformer, 8 terminals	1	1.60
Relay, latching	1	.60
Choke	1	.20
	71	16.38
508: 2.4-kc Main Inverter		
Resistors, composition	7	.01
Resistors, wirewound	7	.22
Resistors, film	5	.01
Capacitors, tantalum	6	.08
Diode	8	.15
Choke	1	.20
Transistors	5	.30
Transformers, 5 terminals	2	1.00
Transformer, 6 terminals	1	1.20
Transformers, 8 terminals	2	1.60
	44	11.44
509: 2.4-kc Maneuver Load Inverter		
Resistors, composition	7	.01
Resistors, wirewound	7	.22
Resistors, film	5	.01
Capacitors, tantalum	6	.08
Diodes	8	.15
Transistors	5	.30
Choke	1	.20
Transformers, 5 terminals	2	1.00
Transformer, 6 terminals	1	1.20
Transformers, 8 terminals	2	1.60
	44	11.44
510: Sync, 400 Cycles, 1 Phase		
Resistors, composition	29	.01
Capacitors, ceramic	11	.01
Diodes	11	.15
Transistors	9	.30
	60	4.75

	Unit	Number of Components	Individual Component Failure Rate
511:	Sync, 400 Cycles, 3 Phases		
	Capacitors, glass	2	.01
	Resistors, composition	12	.01
	Diodes	6	.15
	Diodes, zener	2	.26
	Transistors	4	.30
		26	2.76
512:	400-Cycle, 1-Phase Inverter		
	Capacitors, paper	8	.01
	Capacitors, tantalum	4	.08
	Diode	1	.15
	Resistors, composition	12	.01
	Resistor, wirewound accurate	1	.22
	Transistors	3	.30
	Chokes	5	.20
	Transformers, 7 terminals	2	1.40
		36	5.59
513:	400-Cycle, 1-Phase Inverter		
	Capacitors, tantalum	5	.08
	Resistors, carbon	3	.01
	Resistors, composition	4	.01
	Transistors	6	.30
	Transformers, 5 terminals	3	1.00
	Transformers, 9 terminals	3	1.80
	Choke	1	.20
		25	10.87
515:	Booster Backup Sensor		
	Resistors	12	.01
	Capacitors, tantalum	2	.08
	Transistors	6	.30
	Diodes	18	.15
	Relay	1	.60
		39	5.38

Unit	Number of Components	Individual Component Failure Rate
516: LC Oscillator		
Capacitors, tantalum	4	.08
Capacitors, mica	3	.01
Capacitor, Mylar	1	.01
Resistors, film	12	.01
Resistor, wirewound	1	.22
Resistors, composition	2	.01
Diodes	4	.15
Transistors	3	.30
Choke	1	.20
	31	2.42
517: Source Transfer		
Capacitors, tantalum	2	.08
Capacitors, paper	2	.01
Resistors, composition	5	.01
Resistor, wirewound	1	.22
Diodes	10	.15
Transistor	1	.30
Transformer, 4 terminals	1	.80
Transformer, 5 terminals	1	1.00
Relay, latching	1	.60
Choke	1	.20
	25	4.85
601: Time Delay Switch		
Time delay switch, 1 cs	1	.25
602: Acquisition Sun Sensors		
Sun Sensors	8	.38
	8	3.04
603: Sun Gate Sensors and Relay		
Resistors, fixed carbon	4	.01
Capacitor	1	.01
Transistors	2	.30
Diode	1	.15

	Unit	Number of Components	Individual Component Failure Rate
603:	Sun Gate Sensors and Relay (Cont.)		
	Diode, zener	1	.26
	Relay	1	.60
	Sun gate sun sensors	2	.38
		12	2.42
605:	Attitude Control T/R		
	Capacitors	4	.01
	Diodes	6	.15
	Transformer, 5 terminals	1	1.00
		11	1.94
606:	Gyro T/R		
	Capacitors, tantalum	4	.08
	Diodes, silicon	8	.15
	Diodes, zener	2	.26
	Resistors	8	.01
	Transistors	4	.30
	Transformers, 10 terminals	2	2.00
		28	7.32
607:	Gyro Control		
	Capacitors	9	.01
	Capacitor, tantalum	1	.08
	Diodes, zener	4	.26
	Diodes, silicon	14	.15
	Transistors	4	.30
	Resistors	15	.01
	Relays, latching	6	.60
	Inductors	2	.20
		55	8.66
608:	Pitch and Yaw Gyros		
	Diodes	18	.15
	Diodes, zener	4	.26
	Resistors	42	.01
	Resistors, wirewound	2	.22
	Capacitors	10	.01

	Unit	Number of Components	Individual Component Failure Rate
608:	Pitch and Yaw Gyros (Cont.)		
	Capacitors, tantalum	8	.08
	Transistors	12	.30
	Inductor	2	.20
	Transformers, 5 terminals	2	1.00
	Transformers, 6 terminals	2	1.20
	Gyros	2	19.60
		104	52.94
610:	Pitch and Yaw S.A. Compensation		
	Resistors	5	.01
	Diodes	8	.15
	Diodes, zener	4	.26
	Capacitors	4	.01
		21	2.33
611:	Switching Amplifiers and Switches (Pitch and Yaw)		
	Capacitors, glass	2	.01
	Capacitors, tantalum	20	.08
	Diodes	28	.15
	Diodes, zener	14	.26
	Resistors	65	.23
	Transistors	16	.30
	Transformers, 4 terminals	2	.80
	Transformers, 5 terminals	2	1.00
		149	32.81
612:	Valves and Nozzles and Gas Supply[1]		
	Valves and nozzles	4	
613:	Valves and Nozzles and Gas Supply[1]		
	Same as 612		

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[1] See Appendix A, section 2, p. 238, for failure rate computation.

Unit		Number of Components	Individual Component Failure Rate
614:	Cruise Sun Sensors and Regulator		
	Cruise sun sensors	8	.38
	Resistors, fixed, carbon	2	.01
	Capacitors	2	.01
	Diodes, zener	4	.15
		16	3.68
615:	Solar Pressure Stabilization[1]		
	Partial components		
	Resistors	21	.01
	Diodes	11	.15
	Diodes, zener	2	.26
	Capacitors	17	.01
	Transistors	4	.30
	Motor, stepping	4	3.70
	Gear box	4	6.30
		63	43.75
	Series units		
	Diodes	3	.15
	Relay	1	.60
	Resistor	1	.01
		5	1.06
616:	Canopus Sensor and Electronics		
	Diodes	34	.15
	Diode, zener	1	.26
	Resistors	57	.01
	Resistors, wirewound	2	.22
	Transistors	11	.30
	Capacitors, glass	4	.01
	Capacitors, ceramic	17	.01
	Capacitors, silver mica	8	.01
	Capacitors, tantalum	25	.08
	Inductor	5	.20
	Transformer, 12 terminals	1	2.40
	Transformer, 5 terminals	2	1.00

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[1] See Appendix A, section 2, p. 237, for failure rate computation.

	Unit	Number of Components	Individual Component Failure Rate
616:	Canopus Sensor and Electronics (Cont.)		
	Transformer, 4 terminals	1	.80
	Photomultiplier tube	1	3.80
		169	21.96
617:	Canopus Gate		
	Capacitors	2	.01
	Capacitors, ceramic	2	.01
	Capacitor, silver mica	1	.01
	Capacitors, tantalum	6	.08
	Diodes	14	.15
	Diode, zener	1	.26
	Transistors	14	.30
	Resistors	39	.01
	Resistor, molded metal	1	.01
	Inductor	1	.20
	Relay, latching	2	.60
		83	8.89
618:	Roll Gyro		
	Resistors	21	.01
	Diodes	9	.15
	Diodes, zener	2	.26
	Capacitors	5	.01
	Capacitors, tantalum	4	.08
	Transistors	6	.30
	Transformer, 5 terminals	1	1.00
	Transformer, 6 terminals	1	1.20
	Inductor	1	.20
	Gyro	1	19.60
		51	26.25
619:	Switching Amplifier and Power Switch (Roll)		
	Capacitor, glass	1	.01
	Capacitors, tantalum	10	.08
	Diodes	14	.15
	Diodes, zener	7	.26
	Resistors	29	.01
	Transistors	8	.30

Unit	Number of Components	Individual Component Failure Rate
619: Switching Amplifier and Power Switch (Roll) (Cont.)		
Transformer, 4 terminals	1	.80
Transformers, 5 terminals	2	1.00
	72	10.22
620: Valves and Nozzles and Gas Supply (Roll)[1]		
Valves and nozzles	2	
621: Valves and Nozzles and Gas Supply (Roll)[1]		
Same as 620		
622: Derived Rate Damping (Roll)		
Resistors	10	.01
Diodes	6	.15
Diodes, zener	2	.26
Capacitors	2	.01
	20	1.54
623: Turn Command Generator		
Resistors	11	.01
Diodes	9	.15
Diodes, zener	3	.26
Transistors	5	.30
Capacitors	2	.01
Capacitors, tantalum	2	.08
Relays, latching	2	.60
	34	5.12
624: CW One-Shot		
Resistors	10	.01
Diodes	3	.15
Diodes, zener	2	.26
Transistors	4	.30
Capacitors, tantalum	2	.08
	21	2.43

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[1] See Appendix A, section 2, p. 238, for unit failure rate computation.

	Unit	Number of Components	Individual Component Failure Rate
625:	CCW One-Shot		
	Same as 624		
626:	Relay		
	Diodes	2	.15
	Capacitor	1	.01
	Resistor	1	.01
	Relay, latching	1	.60
		5	.92
627:	Cone Angle Update Circuits		
	Resistors	13	.01
	Resistors, film	4	.01
	Capacitors, tantalum	13	.08
	Diodes	16	.15
	Transistor	1	.30
	Relays, latching	3	.60
		50	5.71
701:	Autopilot and Vane Actuators		
	Capacitors, composition	17	.01
	Capacitors, tantalum	8	.08
	Resistors	70	.01
	Diodes	10	.15
	Diodes, zener	6	.26
	Transistors	28	.30
	Transformer, 5 terminals	1	1.00
	Relay	1	1.00
	Vane actuators, torque motors	4	15.00
		145	74.97
702:	Midcourse Maneuver Motor, Tankage and Plumbing		
	Engine, rocket (thrust chamber)	1	2.0c[1]
	Tank and bladder, propellant	1	200.0c
	Jet vanes	4	0
	Regulator, nitrogen	1	4.4c
		7	206.40c

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[1] c = cycles.

	Unit	Number of Components	Individual Component Failure Rate
801:	CS-2 CW Logic		
	Capacitors, glass	15	.01
	Capacitors, tantalum	14	.08
	Resistors, carbon	69	.01
	Diodes, silicon	42	.15
	Transistors	16	.30
	Relays	3	.60
	Transformer, 4 terminals	1	.80
	Choke	1	.20
		161	(15.86)
			1.44[1]
802:	CS-1 CW Logic		
	See unit 801 for parts count		1.44
803:	CS-2 CCW Logic		
	See unit 801 for parts count		1.44
804:	Switching Transformer-Rectifier		
	T-R unit	1	2.47
805:	CS-1 and CS-2 Magnetization Circuits		
	Coil	1	.10
806:	Cyclic Switching Logic		
	See unit 801 for parts count		1.44
807:	Receiver Transformer-Rectifier		
	T-R unit	1	2.47

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[1] Failure rate of control logic divided among following units: 801, 802, 803, 806, 816, 820, 829, 830, 833, 834, 837.

	Unit	Number of Components	Individual Component Failure Rate
808:	Preamp and Mixers and First IF		
	Capacitors, glass	25	.01
	Resistors, film	2	.01
	Resistors, composition	19	.01
	Diodes	2	.15
	Transistors	4	.30
	Transformers, 4 terminals	2	.80
	Transformer, 5 terminals	1	1.00
	Chokes	10	.20
	Filters	2	.22
		67	7.00
809:	Second Mixer, IF and AGC		
	Capacitors, glass	68	.01
	Resistors, composition	77	.01
	Diode, zener	1	.26
	Diodes	6	.15
	Transistors	16	.30
	Chokes	4	.20
	Transformers, 5 terminals	6	1.00
	Transformers, 4 terminals	4	.80
	Filters	5	.22
		187	18.51
810:	Receiver Multipliers and Divider		
	Capacitors, glass	66	.01
	Resistors, composition	50	.01
	Diode, zener	1	.26
	Diodes	6	.15
	Transistors	7	.30
	Chokes	18	.20
	Transformers, 4 terminals	6	.80
	Transformers, 5 terminals	2	1.00
	Filters	3	.22
	Cavity	1	.20
		160	15.68
811:	Range Detector		
	Capacitors, tantalum	16	.08
	Capacitors, glass	2	.01
	Resistors, composition	28	.01

Unit	Number of Components	Individual Component Failure Rate
811: Range Detector (Cont.)		
Diodes	4	.15
Transistors	5	.30
Filters	4	.22
	59	4.56
812: Video Amplifier		
Capacitors, glass	26	.01
Capacitors, tantalum	5	.08
Resistors, composition	36	.01
Resistors, film	2	.01
Diodes	2	.15
Transistors	8	.30
Chokes	11	.20
Transformer, 5 terminals	1	1.00
	91	6.94
813: Isolation Amplifier		
Capacitors, glass	6	.01
Resistors	6	.01
Diodes	4	.15
Transistor	1	.30
Transformer, 4 terminal	1	.80
	18	1.82
814: Multipliers and Amplifiers		
Capacitor, tantalum	1	.08
Capacitors, glass	52	.01
Resistors, composition	38	.01
Diodes, zener	2	.26
Diodes	8	.15
Transistors	6	.30
Varicaps	2	.01
Chokes	15	.20
Transformers, 5 terminals	2	1.00
Transformers, 4 terminals	4	.80
Transformers, 3 terminals	2	.60
Cavity	1	.20
	133	14.12

	Unit	Number of Components	Individual Component Failure Rate
815:	Exciter Transformer-Rectifier		
	T-R unit	1	2.47
816:	CS-5 CW Logic		
	See unit 801 for parts count		1.44
817:	Isolation Amplifier		
	Same as 813		
818:	Multipliers and Amplifiers		
	Same as 814		
819:	Exciter Transformer-Rectifier		
	T-R unit	1	2.47
820:	CS-5 CCW Logic		
	See unit 801 for parts count		1.44
821:	CS-5 Magnetization Circuits		
	Coil	1	.05[1]
823:	Transfer Circuits		
	Capacitor, glass	1	.01
	Capacitor, tantalum	1	.08
	Resistors	2	.01
	Choke	1	.20
		5	.31
824:	Auxiliary Oscillator		
	Capacitors, glass	6	.01
	Resistors	3	.01

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[1] One-half the rate of unit 805.

	Unit	Number of Components	Individual Component Failure Rate
824:	Auxiliary Oscillators (Cont.)		
	Diode, zener	1	.26
	Transistor	1	.30
	Transformer, 4 terminals	1	.80
	Choke	1	.20
	Crystal	1	1.00
		14	2.65
825:	Transfer Circuits		
	Same as 823		
826:	Auxiliary Oscillator		
	Same as 824		
827:	PA-1 and Converter		
	Capacitors, tantalum	7	.08
	Capacitors, glass	2	.01
	Resistors	16	.01
	Diodes, zener	4	.26
	Diodes	16	.15
	Klystron	1	10.00
	Relay, latching	1	.60
	Transistors	5	.30
	Chokes	4	.20
	Transformer, 15 terminals	1	3.00
	Transformer, 5 terminals	1	1.00
	Magnetic amplifier	1	.15
		59	21.23
829:	CS-3 CW Logic		
	See unit 801 for parts count		1.44
830:	CS-4 CW Logic		
	See unit 801 for parts count		1.44

	Unit	Number of Components	Individual Component Failure Rate
831:	PA-2 and Converter		
	Same as 827		
833:	CS-3 CCW Logic		
	See unit 801 for parts count		1.44
834:	CS-4 CCW Logic		
	See unit 801 for parts count		1.44
835:	CS-3 and CS-4 Magnetization Circuits		
	Coil	1	.10
836:	VCO, Phase Detector, and Loop Filter		
	Capacitors, tantalum	2	.08
	Capacitors, glass	69	.01
	Varicap	1	.01
	Resistors, composition	48	.01
	Diodes	2	.15
	Diode, zener	1	.26
	Transistors	10	.30
	Transformers, 4 terminals	6	.80
	Transformer, 5 terminals	1	1.00
	Transformers, 6 terminals	2	1.20
	Chokes	10	.20
	Filters	2	.22
	Crystal	1	1.00
		155	16.54
837:	CS-1 CCW Logic		
	See unit 801 for parts count		1.44
901:	Separation Switch		
	Separation switch, 2 cs[1]	1	.12 cs

---

[1] Redundant contacts.

	Unit	Number of Components	Individual Component Failure Rate
902:	Transformer		
	Transformer, 11 terminals	1	2.20
903:	Control Rectifiers and Capacitor		
	Capacitor	1	.01
	Diodes[1]	5	.15
		6	.76
904:	Power Rectifiers and Capacitors		
	Capacitors	3	.01
	Diodes[2]	4	.15
	Resistor, composition	1	.01
		8	.64
905:	Power Rectifiers and Capacitor		
	Same as 904		
906:	Separation Switch		
	Switch	1	.12 cs
907:	Transformer		
	Transformer, 11 terminals	1	2.20
908:	Control Rectifiers and Capacitor		
	Same as 903		
909:	Power Rectifiers and Capacitor		
	Same as 904		

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[1] Four of the diodes are redundant in pairs.

[2] The four diodes are arranged in redundant pairs. Only short failure considered.

Unit	Number of Components	Individual Component Failure Rate
910: Power Rectifiers and Capacitor		
Same as 904		
911: Time Delay Switch		
Time delay switch, 1 cs	1	.25
912: Silicon-Controlled Rectifier		
Capacitor	1	.01
Resistors, composition	2	.01
Resistors, wirewound	4	.22
Silicon-controlled rectifier	1	.30
	8	1.21
913: Silicon-Controlled Rectifier		
Capacitor	1	.01
Resistors, composition	2	.01
Resistors, wirewound	5	.22
Silicon-controlled rectifier	1	.30
	9	1.43
914: Silicon-Controlled Rectifier		
Same as 912		
915: Silicon-Controlled Rectifier		
Same as 913		
916: Relay K2		
Relay, latching	1	.60
Diode	1	.15
	2	.75
917: Relay K2'		
Same as 916		

	Unit	Number of Components	Individual Component Failure Rate
918:	Relay K4		
	Same as 916		
919:	Relay K4'		
	Same as 916		
920:	Silicon-Controlled Rectifier, First Maneuver		
	Capacitor	1	.01
	Resistors, composition	2	.01
	Resistors, wirewound	4	.22
	Silicon-controlled rectifier	1	.30
		8	1.21
921:	Silicon-Controlled Rectifier, First Maneuver		
	Same as 920		
922:	Silicon-Controlled Rectifier, First Maneuver		
	Capacitor	1	.01
	Resistors, composition	2	.01
	Resistors, wirewound	3	.22
	Silicon-controlled rectifier	1	.30
		7	.99
923:	Silicon-Controlled Rectifier, First Maneuver		
	Same as 922		
924:	Silicon-Controlled Rectifier, Second Maneuver		
	Same as 920		

	Unit	Number of Components	Individual Component Failure Rate
925:	Silicon-Controlled Rectifier, Second Maneuver		
	Same as 920		
926:	Silicon-Controlled Rectifier, Second Maneuver		
	Same as 922		
928:	Filter		
	Capacitor	1	.01
	Resistor	1	.01
	Diode	1	.15
		3	.17
929:	Filter		
	Same as 928		
930:	Silicon-Controlled Rectifier		
	Capacitor	1	.01
	Resistor, film	1	.01
	Resistors, composition	3	.01
	Diodes	1	.15
		6	.20
931:	Silicon-Controlled Rectifier		
	Same as 930		
932:	Filter		
	Capacitor	1	.01
	Resistor, composition	1	.01
	Diode	1	.15
		3	.17

	Unit	Number of Components	Individual Component Failure Rate
933:	Filter		
	Same as 932		
934:	Hinges		
	Hinges	8	.02
		8	.16
935:	Spring Actuators		
	Actuators	4	1.05
		4	4.20
936:	Hydraulic Snubbers		
	Snubbers	4	0
Unnumbered Components			
	Latches and pinpullers	8	.02 a
	Squibs	16	106.00 a
	Valves, first maneuver	5	106.00 a
	Bridgewires, first maneuver	10	106.00 a
	Valves, second maneuver	5	106.00 a
	Bridgewires, second maneuver	10	106.00 a
	Total	54	

950: Probability of No Meteoritic Impact: .9

951: Probability of Solar Panels Not Degrading: .75

952: Probability That Wrong Target Is Not Acquired: .9

953: Operational Probability of Adequate First Maneuver: .9782

954: Operational Probability of Adequate Second Manuever: .9782

2. Special Failure Rate Computations

Several of the units defined in the first section of this appendix are of sufficient complexity to be described in somewhat more detail. These units are involved in four subsystems: (1) the data encoder, (2) the command detection and decoding, (3) the power supply, and (4) the attitude control. Each of these subsystems is discussed below.

a. Data Encoder

Many of these units are composed of various quantities of NAND and NOR gates, R-S flip-flops, universal flip-flops, relay drivers, and noninverting drivers or amplifiers. The parts counts used for these are listed below:

(1) NAND Gates

High-Speed NAND

4- or 2-input:

Capacitors, glass	2
Resistors, film	8
Diodes, silicon[1] (2-input)	4
Diodes, silicon (4-input)	6
Transistors	2

8-input:

Capacitor, glass	1
Resistors	4
Diodes, silicon[2]	9
Transistor	1

Low-Speed NAND

4- or 2-input:

Capacitors, glass	2
Resistors, film	8
Diodes, silicon (2-input)	2
Diodes, silicon (4-input)	4
Transistors	2

---

[1] Two diodes of the 2-input gate and four diodes of the 4-input gate are arranged in various combinations of redundancies.

[2] Eight of the nine diodes are involved in redundant configurations.

8-input:

Capacitor, glass	1
Resistors, film	4
Diodes, silicon	8
Transistor	1

(2) NOR Gates

Low-Speed NOR

4- or 2-input:

Capacitors, glass	2
Resistors, film	6
Diodes, silicon (2-input)	2
Diodes, silicon (4-input)	4
Transistors	2

(3) R-S Flip-Flops

High-Speed

Capacitors, glass	4
Resistors, film	10
Diodes	4
Transistors	2

Low-Speed

Capacitors, glass	4
Resistors, film	8
Diodes, silicon	2
Transistors	2

(4) Universal Flip-Flops

High-Speed

Capacitors, glass	6
Resistors, film	14
Diodes, silicon	8
Transistors	2

Low-Speed

Capacitor, glass	1
Resistors, film	10
Diodes, silicon	4
Transistors	2

(5) Relay Drivers

Capacitors, tantalum	2
Resistors, film	7
Rectifier	1
Transistors	3

(6) Noninverting Drivers (Amplifiers)

High-Speed

Capacitor, tantalum	1
Capacitors, glass	3
Resistors, film	10
Diodes	3
Transistors	3

Low-Speed

Resistors, film	4
Transistors	4

These parts were entered at the appropriate amount and so listed in section 1. However, the reliability of the redundant configurations of the NAND gate diodes has been computed according to the following equations. (For convenience, the equation for a redundant group of tantalum capacitors is also included here.)

(7) Redundant Configurations in NAND and NOR Gates

2-input gates:

(a) Both diodes in parallel

$$R_a(t) = \left\{1 - (1 - e^{-.15 \times 10^{-6} t})^2\right\}$$

(b) Both diodes in series

$$R_b(t) = (e^{-.15 \times 10^{-6} t})^2 = e^{-.3 \times 10^{-6} t}$$

4-input gates:

(c) All four in parallel

$$R_c(t) = \left\{1 - (1 - e^{-.15 \times 10^{-6} t})^4\right\}$$

(d) Two parallel pairs

$$R_d(t) = \left\{1 - (1 - e^{-.15 \times 10^{-6} t})^2\right\}^2$$

(e) Two in series; two in parallel

$$R_e(t) = (e^{-.3 \times 10^{-6} t})\left\{1 - (1 - e^{-.15 \times 10^{-6} t})^2\right\}$$

(f) Four in series

$$R_f(t) = e^{-.6 \times 10^{-6} t}$$

8-input gates:

(g) Two in series; three parallel pairs

$$R_g(t) = (e^{-.3 \times 10^{-6} t})\left\{1 - (1 - e^{.15 \times 10^{-6} t})^2\right\}^3$$

(h) Four in series; two parallel pairs

$$R_h(t) = (e^{-.6 \times 10^{-6} t})\left\{1 - (1 - e^{-.15 \times 10^{-6} t})^2\right\}^2$$

3-input gates:

(i) All three in series

$$R_i(t) = e^{-.45 \times 10^{-6} t}$$

Six parallel pairs of tantalum capacitors

(j) $R_j(t) = \left\{1 - (1 - e^{-.08 \times 10^{-6} t})^2\right\}^6$

b. Command Detection and Decoding

A great many of the units in the command subsystem are described by component parts whose modes of failure directly affect the failure rate of the unit. Consider, for example, the components listed below under the heading IS. The failure rate of unit 3004-1 is made up of the failure rate of two transistors failing short, one resistor failing open, plus one-half of the sum of the failure rates shown in the column "IND'T." The failure rate of unit 3004-2 is made up of the sum of the rates shown under the column headed "OFF" and one-half of the column headed "IND'T." Thus, between the two units all modes of catastrophic failure of IS are accounted for.

Listed below are the four combinations of component parts involved in this manner in the command subsystem units.

	λ_{ON}		λ_{OFF}		$\lambda_{IND'T}$	
Component Types	Cause of Failure	Failure Rate $\lambda \times 10^{-6}$ hours	Cause of Failure	Failure Rate $\lambda \times 10^{-6}$ hours	Cause of Failure	Failure Rate $\lambda \times 10^{-6}$ hours
IS Switch						
Capacitor, tantalum			Short	.064	Open	.004
Diodes, silicon			Open	.135	Short	.015
			Open	.135	Short	.015
			Open	.135	Short	.015
			Open	.135	Short	.015
Transistor	Short	.15	Open	.15		
	Short	.15	Open	.15		
Resistor,						
film			Open	.008	Short	.0005
carbon	Open	.008			Short	.0005
film			Open	.008	Short	.0005
carbon					Any failure	.01
Transformer, 4-terminal			Any failure	.800		
Total		.308		1.720		.0755
IP Switch						
Diode, silicon			Short	.015	Open	.135
Transistor			Any failure	.30		
Transistor	Short	.15	Open	.15		
Resistor,						
carbon					Any failure	.01
film			Open	.008	Short	.0005
carbon			Open	.008	Short	.0005
Transformer, 4 taps			Any failure	.800		
Total		.15		1.281		.1460

	λ_{ON}		λ_{OFF}		$\lambda_{IND'T}$	
Component Types	Cause of Failure	Failure Rate $\lambda \times 10^{-6}$ hours	Cause of Failure	Failure Rate $\lambda \times 10^{-6}$ hours	Cause of Failure	Failure Rate $\lambda \times 10^{-6}$ hours
	AID (Shift Register Driver)					
Transistor	Open	.15	Short	.15		
Resistor,						
film	Open	.008			Short	.0005
film					Any failure	.01
film					Any failure	.01
carbon			Open	.008	Short	.0005
Total		.158		.158		.021
	Decoding Gate, Series Components					
Capacitor, glass					Any failure	.01
Transistor	Short	.15	Open	.15		
Resistor,						
film			Open	.008	Short	.0005
film			Open	.008	Short	.0005
film					Any failure	.01
Total		.15		.166		.021

The reliability of the decoding gates is not simply the reliability of its series components listed above. There are three types of decoding gates defined on the reliability diagrams; two contain six diodes in an arrangement such that at least two of the six must fail in an open condition for the unit to fail. The equations of the three types are as follows:

(1) Decoding gate of the type defined as unit 3021*

The reliability of the gate is given by

$$R_{DG_1} = R_S \left[R_{DO}^6 + 6R_{DO}^5 (1 - R_{DO}) \right]$$

where R_S = reliability of the series components (use decoding gate, $\lambda_{ON} + \lambda_{OFF} + \lambda_{IND'T}$)

R_{DO} = probability a diode does not fail open

$$R_{DG_1} = e^{-.337t}\left[e^{-(.135)^6 t} + 6\,e^{-(.135)^5 t}(1 - e^{-.135t})\right]$$

(2) Decoding gate of the type defined as unit 3022*

This type is the same as that of 3021* except that $R_S = \lambda_{OFF} + \frac{1}{2}\lambda_{IND'T}$.

$$R_{DG_2} = e^{-.1765t}\left[e^{-(.135)^6 t} + 6\,e^{-(.135)^5 t}(1 - e^{-.135t})\right]$$

(3) Decoding gate of the type defined as unit 3022-A1*

This type is similar, except that $R_S = \lambda_{ON} + \frac{1}{2}\lambda_{IND'T}$ and there are no diodes as in the other two.

$$R_{DG_3} = e^{-.1605t}$$

Returning for a moment to the four major combinations of components and the apportionment of the failure rate between open and short modes of failure, the basis on which the catastrophic failure rate was apportioned was first used by PRC in another study.[1] Unfortunately, not much data is available to support such an apportionment; it is felt, however, that this apportionment properly combines engineering judgment with the available data (see References 1, 2, 3, 4, and 5 on page 239).

Failure Modes of Electronic Component Parts

Item	Common Cause of Failure	Percent of Total Failure
Resistors	Short	5
	Open	80
Capacitors	Short	80
	Open	5
Transformers	Short	70
	Open	10

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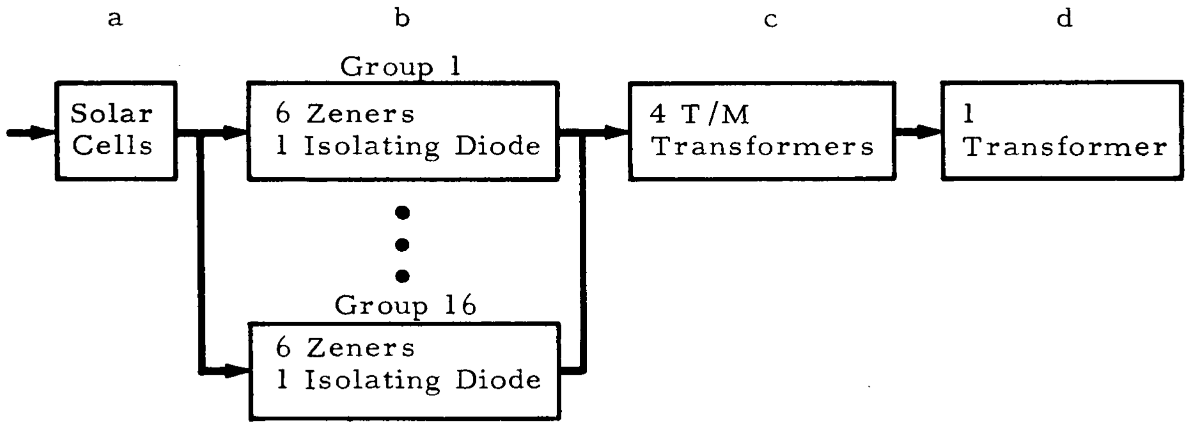
[1] Preliminary Reliability Assessment for the Orbiting Geophysical Observatories, PRC R-243, 1 February 1962.

Failure Modes of Electronic Component Parts (Continued)

Item	Common Cause of Failure	Percent of Total Failure
Relays	Open	50
Diodes	Short	10
	Open	90
Transistors	Short	50
	Open	50

c. Power Supply Subsystem

Only one unit of this subsystem needs to be discussed, unit 501. The components of unit 501 are arranged as shown in the following diagram:

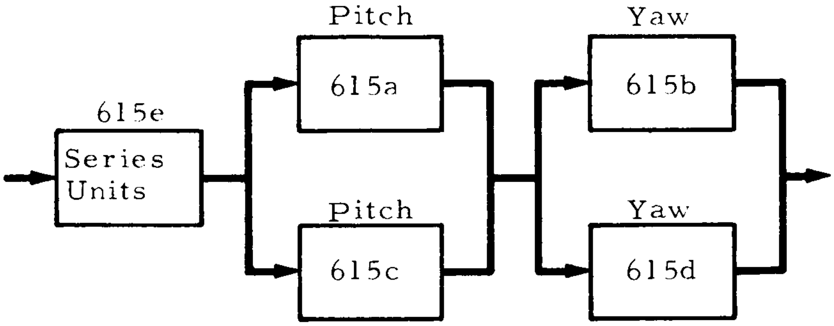


The failure rate of block a is assumed to be zero. For the normal path, it is assumed that 14 of the 16 groups of diodes in block b must contain no shorts during the cruise periods and no opens during maneuvers. Also, it is assumed that all four transformers of block c must function for the normal path. A degraded path occurs when it is assumed that a 50-percent loss of block c is not catastrophic up to one-half the length of the mission. The reliability of 501 is given by

$$R_{501} = R_{501a} R_{501b} R_{501c} R_{501d} \quad .$$

d. Attitude Control Subsystem

The solar pressure stabilization unit, 615, exhibits a simple redundancy. The parts count shown in section 1 is actually one-fourth of the total number of parts. The four sections are arranged as follows:



Therefore, the reliability of 615 is given by

$$R_{615} = R_e \quad 1 - (1 - R_{615a})^{2} \; {}^{2}$$

where R_e = series components
$R_a = R_b = R_c = R_d$

The redundant and cross-coupled valves, nozzles, and gas supply have been fully covered in the text. See the discussion of cruise science under "System Figure-of-Merit" (subsection IV.C.2.a(1)) for all the assumptions involved in the computation. It should be pointed out here, however, that there are four valves and nozzles in each of units 612 and 613 (supplying the pitch and yaw torques) and two in each of units 620 and 621. The component failure rate used was $.7 \times 10^{-6}$ actuations.

REFERENCES
(Appendix A)

1. Workmanship and Design Practices for Electronic Equipment. OP2230, First Revision. Bureau of Ordnance, United States Department of the Navy, 22 April 1959.

2. Shwop, John E., and Harold J. Sullivan. Semiconductor Reliability. Elizabeth, New Jersey: Engineering Publishers, 1961.

3. Granberg, M. Leland. "Failure Modes in Electronic Components," Proceedings of the Sixth National Symposium on Reliability and Quality Control in Electronics, January, 1960, p. 167.

4. "Design Guidelines for Air and Spaceborne Electronics" (Technical Reference Series, Part II), Space/Aeronautics, December, 1961, p. 69.

5. Von Alven, W. H. Semiconductor Reliability, Vol. II. Elizabeth, New Jersey: Engineering Publishers, 1962.

6. Earles, D. R., and M. F. Eddins. "Failure Therblig Failure Rates." Presented at the Western Electronic Show and Convention, Los Angeles, August 21-24, 1962.

7. Reliability Analysis Data for Systems and Component Design Engineers. TR A-873-74. General Electric Company, 1 September 1961.

APPENDIX B

APPENDIX B

COMPONENT PART FAILURE RATES

This reliability assessment of Mariner C (Mars) was undertaken with an agreement to use the same failure rates that PRC used for the Mariner R reliability assessment. This permits a valuable comparison, not often made, between the two spacecrafts. Since the assumptions regarding failure rates are exactly the same in the two studies, a detailed discussion of them is not included here. It is considered sufficient merely to list a few of the major assumptions:[1]

1. The severity of space environment is equivalent to that experienced by ground support equipment.
2. The failure rates of some mechanical components were modified from the data source to adjust for a less stringent operating mode.
3. All components have been applied at 25 percent of their rated operating loads.
4. All components are assumed to operate in an ambient environment of 35°C.

The component failure rates used in this study are considered to be conservative in magnitude due to the unknown effects of the several assumptions made. These component failure rates are tabulated and identified by source in Exhibit 59. The seven sources from which the failure rates in Exhibit 59 were obtained are as follows:

Source 1: Reliability Stress Analysis for Electronics Equipment, Proposed MIL Handbook 217 (WEPS), 31 December 1961

Source 2: Minuteman Parts Reliability, Autonetics Report No. EM-2496-3

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[1] For a complete discussion, see PRC R-293, Reliability Assessment of the Mariner Spacecraft, 17 December 1962.

Source 3: Reliability Application and Analysis Guide, M160-54 (Rev. 1), The Martin Company, July 1961

Source 4: Compilation and Analysis of Reliability Data on Selected Flight Control Components, PRC R-235, Planning Research Corporation, Confidential, December 1961

Source 5: Reliability Application and Analysis Guide, Avco Corporation, April 1962

Source 6: Reliability Analysis Data for Systems and Component Design Engineers, TRA-873-74, General Electric, September 1961

Source 7: Gyro Reliability Data, Jet Propulsion Laboratory Interoffice Memorandum, 28 June 1963

It should be noted that in two instances the failure rates of components were changed for this study. The gyro failure rate used in the assessment of Mriner R was obtained from a study of data compiled in the operating records of the Agena equipment. The quantity of data so obtained was limited and, accordingly, the failure rate was considered to be high for this reason rather than because of poor operating experience. A discussion was held with members of the Guidance and Control Division of JPL, and from this discussion it was agreed to incorporate the substantial body of bench test data which had been generated at JPL on this gyro type. The inclusion of these test results has lowered the gyro failure rate substantially, but the impact of this on the study results is not considered to be disproportionate since gyro operating time is low in any case.

The other instance of change in component failure rate involves the rate used for film resistors. Relating few film resistors were identified in the Mariner R study, and the failure rate that was used was based on data obtained through 1960. Unlike carbon composition resistors, film resistors have been under continuous development since that time, and it is recognized that definite improvements in material control and manufacturing processes have been made. A large number of film resistors

EXHIBIT 59 - ESTIMATES OF COMPONENT FAILURE RATES

Item	Failure Rate, $\lambda \times 10^{-6}$	Source
Accelerometer	28.00 hours	3
Actuators, bimetallic	.40 hour	3
Actuators, spring	1.05 actuations	3
Battery cells	.75 hour	6
Bearings	5.00 hours	5
Bearings, ball	9.00 hours	5
Bearings, sleeve-type	.40 hour	3
Cadmium sulfide cells	.38 hour	6
Capacitors, ceramic	.01 hour	1
Capacitors, glass	.01 hour	1
Capacitors, mica	.01 hour	1
Capacitors, paper	.01 hour	1
Capacitors, tantalum, solid	.08 hour	1
Cavities	.20 hour	6
Chokes	.20 hour	3
Clutch	3.00 hours	5
Coil	.10 hour	5
Cores	.00 hour	-
Crystals	1.00 hour	3
Diodes, power	.01 hour	1
Diodes, silicon	.15 hour	1
Diodes, zener	.26 hour	2
Engine, rocket, thrust chamber	2.00 cycles	6
Gears	1.20 hours	5
Gear box	6.30 hours	5
Gears, helical	.50 hour	5
Gears, compound	6.30 hours	5
Gears, anti-backlash	9.00 hours	5
Gears, spur	6.30 hours	4

EXHIBIT 59 - (Continued)

Item	Failure Rate, $\lambda \times 10^{-6}$	Source
Hinge	.02 actuations	3
Jet vane	.00 hour	-
Joint, rotary coaxial	75.00 hours	5
Inductors	.20 hour	3
Klystron	10.00 hours	6
Lamps, neon	1.00 hour	5
Latch	.02 actuations	3
Louvers	.00 hour	-
Magamps, windings and cores (per pair)	.15 hour	1
Motor, electrical	3.00 hours	5
Motor with gear and brake	16.00 hours	5
Motor, stepping	3.70 hours	5
Photo multiplier tube	3.80 hours	6(1)
Photo diode	.38 hour	6
Pinion	1.20 hours	5
Potentiometer	1.08 hours	3
Rate gyros	19.60 hours	7
Rectifiers	1.20 hours	3
Regulator, nitrogen	4.40 cycles	6
Relays (1 actuation per hour or less)	.60 hour	3
Resistors, composition	.01 hour	1
Resistors, film, signal	.23 hour	1
Resistors, film, power	1.08 hours	1
Resistors, wirewound, accurate	1.03 hours	1
Resistors, wirewound, power	.22 hour	1
Servo motors	15.00 hours	5
Solar panel	(see text)	
Solenoids	7.60 hours	4

EXHIBIT 59 - (Continued)

Item	Failure Rate, $\lambda \times 10^{-6}$	Source
Squibs	106.00 actuations	4
Switch, time delay	.25 hour	3
Switch, separation	.12 hour	3
Tank and bladder, propellant	200.00 cycles	6
Thermistor	.30 hour	1
Transformer	2.00 hours	3
Transformer-rectifier	2.47 hours	5
Transistors	.30 hour	1
Torque motors	15.00 hours	5
Valve, ignition cartridge	106.00 actuations	6
Valve, nitrogen	106.00 actuations	6
Valve, propellant, start	106.00 actuations	6
Valve, propellant, shutoff	106.00 actuations	6
Valves and nozzles	.70 cycles	4
Varicap	.30 hour	1(2)
Wormshaft	4.00 hours	5

Notes: (1) Failure rate assumed 10 times that of cadium sulfide cells.

(2) Failure rate assumed equal to that of transistors.

have been used in the designing of Mariner C, and the use of the older rate would have placed an unduly pessimistic emphasis on the failure potential of the circuits employing them. The updating of film resistor failure data would have consumed more time than was available; hence, a check was made of JPL on the ratio of the rates used for the two resistor types. It was ascertained that the same rate was often used for both types. PRC did not adopt the JPL rate; however, the rate for film resistors was adjusted to be equal to the rate used for carbon composition resistor in the Mariner R study. The principal effect of this change is to invalidate, to some extent, the comparison between reliabilities of the CC and S subsystems in the two spacecraft. Most of the film resistors in the Mariner R parts complement were contained in the CC and S subsystem.