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TITLE- Performance of the RF Channel for the Apollo Spacecraft Up-Data System

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ABSTRACT

A performance analysis is presented for the up-data system used with the Apollo spacecraft. Measures of performance are the probability of message rejection and of undetected error on the MSFN to spacecraft link and the probability of no verification on the spacecraft to MSFN telemetry link. Specifically, these measures are analyzed at each end of an RF channel furnished by the Apollo Unified S-Band System. This analysis includes the performance that is expected if the five for one sub-bit coding were removed on the up-link as well as removal of the code, code complement, and code feature used in updating the spacecraft computers.

The analysis shows that the formats used in the present system provide the required performance as delineated in the Apollo Program Specification.[1] Namely, that no more than one message in one thousand will be rejected and acceptance of a false message shall be less than 10^{-9}. The analysis also shows that complete elimination of the sub-bit coding degrades the error protection capabilities of the system, particularly in its ability to reject noise. The code, code complement, and code feature used in the computer update formats appears a likely candidate for deletion if it is desired to increase the data transmission rate. It should be noted, however, that this feature is the only protection for the serial transfer of data between the up-data link equipment and the spacecraft computer.

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SUBJECT: Performance of the RF Channel for the Apollo Spacecraft Up-Data System
Case 900

DATE: May 28, 1968

FROM: R. L. Selden

TM: 68-2034-6

TECHNICAL MEMORANDUM

INTRODUCTION

The Unified S-Band communications system that serves between Apollo Space Vehicles and the Manned Space Flight Network (MSFN) provides the RF channel that includes the capability to transmit digital data between an earth based station and the space vehicle. This data channel is used to transmit various types of functional data to the vehicle including: Real Time Commands (RTC) which actuate relays onboard the vehicle; computer input data to the guidance computers onboard the vehicle; timing updates to the Command and Service Module's Central Timing Equipment (CTE) and test messages. A more complete description of the System including its operation and an analysis of the ground network performance is contained in References (2), (3), and (4). This report provides an analysis of the performance of the RF Up-Data Channel with probabilities of undetected error and data rejection as the measure of performance. The analysis also includes a determination of the data systems sensitivity to noise. That is, what is the probability that noise will be accepted as a valid message. Possible alternative formats are also evaluated to enable a comparison between our present system and one with less redundancy (e.g. higher data rate). Since all data transmitted to a vehicle must be verified by telemetry from that vehicle, an analysis of the telemetry performance from the vehicle to earth is also presented.

DISCUSSION

The space vehicles in the Apollo program that have an up-data capability are the CSM, LM and the S-IVB/IU. The types of data that are transmitted to each are: RTC's, test messages, computer data (AGC) and CTE updates to the CSM; computer data (LGC) and test messages to the LM, and computer data (LVDC) and test messages to the S-IVB/IU. This memorandum specifically addresses the performance of the up-data systems of the CSM and LM spacecraft. Since the S-IVB/IU does not require up-data transmissions over relatively long ranges, the performance of this vehicle's up-data system is anticipated to be significantly better than that presented here for the LM and CSM.

This has been demonstrated, to a degree, on the AS-501 and 502 missions(5). For this reason, no further discussion is presented on the S-IVB/IU up-data RF system performance.

All of these up-data messages are sub-bit encoded. That is, each data or information bit transmitted is encoded into five sub-bits. An information "one" is a particular five bit pattern while an information "zero" is the complement of the information "one" code. The formats of the various types of up-data messages are given in Table I.

Table I

Apollo Up-Data Formats

Vehicle	Type of Message	No. of Information Bits	No. of Sub-bits
CSM	RTC	12	60
	AGC (computer)	22	110
	CTE	30	150
	TEST	30	150
LM	LGC (computer)	22	110
	TEST	22	110

Correct receipt of these up-data messages is verified on the ground via the spacecraft telemetry channel. In general, RTC's are verified by a command acceptance pattern or pulse (CAP) and the computer words by a bit-by-bit comparison of the down-linked words (telemetry) with those that were transmitted to the vehicle. This verification is accomplished by the remote site command computer located at each MSFN station. Specifically, the RTC's are verified by the correct receipt of a particular four-bit pattern contained within the CSM telemetry format (an eight-bit pattern is used in the LM 1-3 systems). Computer words are compared bit-by-bit (down-linked telemetry with up-linked data) and the verification criteria is that two out of eight comparisons must show complete agreement.

PERFORMANCE ANALYSIS - UP-LINK

Three criteria are used in the evaluation of the link between the earth and an Apollo spacecraft. These are: (1) probability of message rejection; (2) probability of an undetected error, that is, the probability that a message is accepted as valid when it was received in error; and (3) the probability that noise will be accepted as a valid command.

In the analysis that follows a sub-bit error probability of 10^{-6} is used. This error rate is somewhat arbitrary and in fact is a little higher than is predicted for an Apollo spacecraft communicating via an omnidirectional antenna with a station of the MSFN equipped with an 85 foot diameter antenna. This condition is considered the mission configuration that will provide the poorest performance by the up-data channel.

PROBABILITY OF MESSAGE REJECTION

To accept as valid a message transmitted from the MSFN requires that all sub-bits contained within the message format be detected correctly. Assuming the errors in detection occur at random* the probability of correct detection of a sub-bit is given by:

$$P_a = 1 - P_e, \tag{1}$$

where P_a is the probability of correct detection (acceptance) and P_e is the probability of sub-bit error - assumed here to be 10^{-6}.

The probability of accepting n successive sub-bits correctly is then the product of the individual probabilities or

$$P_{a-m} = [1 - P_e]^n, \tag{2}$$

where P_{a-m} is the probability of up-data message acceptance and n is the message length in sub-bits (See Table I).

The probability of message rejection is then simply

$$P_{r-m} = 1 - [1 - P_e]^n \tag{3}$$

It can be readily determined that this calculation cannot be easily accomplished using logarithms (as is usually done) because of the large values of n. It can, however, be easily computed using the series

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* The noise in the channel is assumed Gaussian.

$$[1 + x]^n = 1 - nx + \frac{n(n-1)x^2}{2!} \text{ --- or}$$

$$P_{r-m} = 1 - [1 - n10^{-6} + \frac{n(n-1)10^{-12}}{2} \qquad (4)$$

Using the message lengths in sub-bits, given in Table I, and assuming a 10^{-6} sub-bit error probability, the probability of message rejection can be calculated using equation (4). These have been calculated and are tabulated in Table II.

Table II

Probability of Up-Data Message Rejection

Vehicle	Message Type	Sub-bit Word Length	Probability of Rejection
CSM	RTC	60	$6X10^{-5}$
	AGC (computer)	110	$1.1X10^{-4}$
	CTE	150	$1.5X10^{-4}$
	TEST	150	$1.5X10^{-4}$
LM	LGC (computer)	110	$1.1X10^{-4}$

The Apollo Program Specification requires that no more than one message out of 1,000 correct messages be rejected by the space vehicle. From above it can be seen that all types of messages can be received with a rejection rate that is an order of magnitude better than that required. It should also be obvious that the rejection rate gets even smaller if sub-bit coding is not used (i.e., the value of n in equation (4) used for the above calculations is reduced by 5).

PROBABILITY OF AN UNDETECTED ERROR

The spacecraft decoding equipment can, because a message is received in error, decide that a valid message has been detected when in fact it has not. Two mechanisms exist that can create this undetected error phenomenon. These are: (1) successive sub-bits can be received in error so that the decoder decides an information "one" has been received when a "zero" was transmitted or conversely, and (2) noise from the FM subcarrier discriminator which drives the command decoder can look like a successive string of valid sub-bits. To determine the probability of undetected error the formats of the different types of up-data messages have to be investigated. For example, each message uses the first three information bits (15 sub-bits) as a vehicle address and the next three information bits as a system address. The system address identifies the type of message (or to what vehicle system the word is addressed). It should be obvious from this, that even if five successive sub-bits are detected in error, the message will still be detected in error if the five errors occur in the vehicle or systems address portion of the word.* The information bits following the vehicle and system address contain the instruction information. For RTC's and CTE updates (CSM) the 6 and 24 bits define a specific instruction. For computer inputs, the instruction or input data is further coded so that a keycode (5 information bits), its complement and the digital keycode are contained within the instruction field. From this it follows that five successive sub-bit detection errors in the information or instruction field of a RTC or CTE (CSM) will cause an error that will go undetected. However, in a computer update, since a $K\bar{K}K$ (K is a keycode or 5 information bits) pattern is used, 15 successive sub-bit errors must occur and they may represent any one of $32(2^5)$ possible patterns. To compute the probability of an undetected error (or the probability of acceptance when the message has been received in error), a determination is required of the detected message with the minimum number of errors that will cause the message to appear valid. It remains then to multiply the probabilities of sub-bit error, acceptance and the number of possible patterns, to obtain the probability of an undetected error. A summary of the criteria used in determining this parameter follows

RTC - (CSM) - Five successive sub-bits must be detected in error in one of the six message bits.

CTE - (CSM) - Five successive sub-bits must be detected in error in one of the 24 message bits.

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*An error in the systems address cannot route an erroneous message to another system because each system uses a different word length (e.g., CSM: RTC's - 12 bits; AGC - 22 bits; CTE - 30 bits; LM: LGC - 22 bits; and S-IVB/IU - all commands go to the Launch Vehicle Digital Computer).

Computer Input - (AGC for the CSM and LGC for the LM) - 15 successive sub-bits must be in error, five each in the K, $\bar{K}$ and K portions of the message or information field. Any one of the five bits in K and the corresponding position in the following $\bar{K}$ and K portions of the message can be in error.

The probability of an undetected error can be expressed as:

$$P_a = C(P_e)^k(1 - P_e)^{n-k} , \qquad (5)$$

where P_a is the probability of acceptance of a message that was detected with error.

C is the number of possible message bits in which an error can be made and still have the total message appear valid.

P_e is the probability of sub-bit error (taken her as 10^{-6}).

K is the minimum number of successive sub-bits that can be detected in error and still have the total message appear valid, and

n is the number of sub-bits in the message being received.

Table III presents a tabulation of P_a for the different types of messages.

Table III

Probability of Undetected Error

Vehicle	Type of Message	n	C	K	P_a
CSM	RTC	60	6	5	$\sim 6\text{X}10^{-30}$
	CTE	150	24	5	$\sim 24\text{X}10^{-30}$
	AGC	110	5	15	$\sim 5\text{X}10^{-90}$
LM	LGC	110	5	15	$\sim 5\text{X}10^{-90}$

The Apollo Program Specification requires that no more than one message in 10^9 be accepted as valid when in fact the message was received in error. Table III indicates that the present system easily meets this criterion when the space vehicle is receiving data from the ground. Equation (5) shows that this security is provided primarily by the sub-bit encoding. Elimination of the sub-bit encoding reduces the values for n and K by a factor of five. This essentially reduces the exponents of the P_a values by a similar factor. Clearly then, the criterion of accepting no more than one incorrect message out of 10^9 is not satisfied if the present sub-bit coding were to be removed. (A lesser degree of sub-bit coding would however provide the necessary protection; for example, three sub-bits per information bit would suffice).

In the same category of accepting a message as valid that was detected in error is the system's susceptibility to noise. The noise at the input to the up-data equipment when no signal is present is assumed to be Gaussian and the probability of detecting noise as a sub-bit one is equally likely as detection of a zero. In the discussion that follows it is assumed that no other mechanism in the spacecraft up-data equipment is provided to reject noise (e.g. receiver squelch, timing circuits, etc.) so that the results of the analysis below represent a lower bound on noise rejection performance. The probability of detecting noise as a valid message is given by

$$P_{a-n} = C(1/2)^n \quad , \qquad (6)$$

where C is the number of valid combinations or patterns. All commands or messages require that a specific vehicle and system address be received (i.e. the first 30 sub-bits must conform to a single specific code word). The message field, then, determines the number of possible acceptable message patterns. In the CSM system the number of possible valid up-data messages are: 2^6 for RTC's; 2^{24} for CTE updates; and, 2^5 for AGC updates. This number of valid words are taken here as the total number of combinations possible in the message field of the up-data word; in reality it is something less because not all combinations are used. For example, there is a capability for 64 relay actuations by an RTC, but not all 64 are used. Because of this, the probabilities given in Table IV of accepting noise as a valid command are conservative.

Table IV

Probability of Accepting Noise as a Valid Up-Data Message

Vehicle	Type of Message	Number of Valid Messages	Sub-bit Word Length	$P_{a-n}=C(1/2)^n$
		(C)	(n)	
CSM	RTC	2^6	60	$\sim 5.6\text{X}10^{-17}$
	AGC (complex)	2^5	110	$\sim 2.5\text{X}10^{-32}$
	CTE	2^{24}	150	$\sim 1.2\text{X}10^{-38}$
LM	AGC (complex)	2^5	110	$\sim 2.5\text{X}10^{-32}$

The impact on predicted performance if the five for one sub-bit encoding is removed can be determined by reducing n by five. This increases the P_{a-n} shown in Table IV to the values given in Table V.

Table V

Probability of Accepting Noise as a Valid Message
No Sub-bit Encoding

Vehicle	Type of Message	Number of Valid Messages	Word Length	P_{a-n}
CSM	RTC	2^6	12	$\sim 1.6\text{X}10^{-2}$
	AGC	2^5	22	$\sim 7.6\text{X}10^{-6}$
	CTE	2^{24}	30	$\sim 1.6\text{X}10^{-2}$
LM				$\sim 7.6\text{X}10^{-6}$

The data in Tables IV and V show that the sensitivity of the up-data system to noise increases rapidly when sub-bit coding is reduced (approximately 3.5 orders of magnitude per sub-bit reduction). Complete elimination of sub-bit encoding (data rate increase of five) increases the susceptibility to noise to an intolerable level.

The up-data messages addressed to the spacecraft computer, as noted before, contain a three to one redundancy, which provides additional error portection. A natural question is what is the performance if this redundancy is removed? Before providing an answer to this question it is well to note that this $K\overline{K}K$ arrangement not only provides some protection on the MSFN to spacecraft link but is primarily to protect the serial data transfer between the up-data equipment and the spacecraft computer. If this feature were eliminated, several alternative formats would be available. The most likely is to replace $K\bar{K}K$ with three different and distinct key codes; for example, $K_1K_2K_3$. Another scheme might be to transmit one complete computer word (15 information bits) in each up-data message. Since performance has already been determined for the present system formats with and without sub-bit encoding, it remains to determine the expected performance without the $K\bar{K}K$ coding with and without information bit sub-bit encoding.

PERFORMANCE OF UP-DATA TO COMPUTER WITHOUT $K\bar{K}K$ CODING

For up-data messages to the computer, without the $K\bar{K}K$ feature the probability of message rejection is the same as with the $K\bar{K}K$ coding. This can be explained by noting that a message, for acceptance, still requires the successful detection of 110 successive sub-bits. Also, the elimination of sub-bit encoding reduces the probability of rejection because only 22 successive bits need to be received and detected without error. The probability of an undetected error without the $K\bar{K}K$ coding is significantly increased, but is still a very small quantity. Referring to equation (5), without the $K\bar{K}K$, using instead $K_1K_2K_3$. the value of the k is reduced from 15 to 5 and C is increased from 5 to 15. This increases the probability of undetected error from 5×10^{-90} to approximately 15×10^{-30}. Further eliminating the sub-bit encoding reduces K to 1 and n to 22 so that P_a becomes 15×10^{-6}. Consider now the systems sensitivity to noise if the $K\bar{K}K$ feature is removed; instead of 2^5 possible messages in a valid computer message, there are now 2^{15} (C in equation (6)). This raises the probability of noise acceptance from $\sim 2.5 \times 10^{-32}$ to $\sim 2.5 \times 10^{-28}$. Further, if the sub-bit coding is removed as well as the $K\bar{K}K$ code n in equation (6) is reduced from 110 to 22 and P_{a-n} is further increased to $\sim 8 \times 10^{-3}$. This latter value is probably unacceptable. A composite of Tables I, II, III, IV and V including the anticipated performance without the $K\bar{K}K$ coding is presented in Table VI.

It is instructive at this point to determine how much improvement in information rate can be achieved if some of the redundancy is removed. From the foregoing discussion and the summary data presented in Table VI, it can be shown that the performance criteria can be satisfied, if the sub-bit coding is reduced from five to three and the $K\bar{K}K$ format for computer data is eliminated (changed to $K_1K_2K_3$) and replaced with a simple parity check. The sub-bit change increases the transfer rate from 200 bits per second to 333.3 bits per second; the K$\bar{K}$K change allows input to the spacecraft computer at three times the present rate. This would allow a rate increase into the up-data link equipment of five to one, but because of onboard data processing, would allow only about a four to one improvement in transfer rate. (At present 3 key codes are transmitted to the spacecraft in 480 m. sec.) This is made up of three messages transmissions at 110 m. sec. each and 50 m. sec. of processing time per message. The scheme proposed here would transmit three key codes per message and would use three sub-bits per information bit. One transmission then would be 66 m. sec. for transmission with 50 m. sec. of data processing required for a total of 116 m. sec. From Reference (1) it can be seen that this improvement diminishes the time to send a computer load by less than half because of the verification required, propagation delay, etc. For this reason it would appear that format modifications are not desirable at this time.

COMMAND VERIFICATION - DOWN-LINK TELEMETRY PERFORMANCE

As noted before, correct reception of all data transmitted to the spacecraft is verified by the ground system. The verification is accomplished by determining that a specific four (CSM) or eight (LM) bit MAP pattern has been received for all but computer updates and by a bit-by-bit comparison of the telemetered up-data computer words with those that were transmitted. The criteria for verification of proper receipt by the spacecraft is the reception of one valid MAP or two good comparisons out of eight (for computer data). It is of interest to determine the performance of the down-link telemetry channel to ascertain that if an up-data message is properly received by the spacecraft that it can be properly verified on the ground. The normal operating precedure requires retransmission until a valid verification is obtained. Two spacecraft configurations are evaluated for this down-link channel. These are when the telemetry bit error rate is 10^{-3} which is higher than is expected when the spacecraft at lunar range is transmitting via its omnidirectional antenna and 10^{-6} which is higher than expected when operating via the spacecraft high gain antenna.

It should be noted that the LM in a low bit rate telemetry mode (1.6 kbps) does not transmit MAPs or computer data so that verification of LM commands is possible only in the high bit rate mode. (Since this requires the high gain antenna for adequate performance, an analysis at a telemetry bit error rate of 10^{-6} only is applicable.)

To verify all up-data messages except computer updates requires reception of a specific four or eight bit word (MAP). (Four from the CSM and eight from LM 1 and 3; LM 4 and subsequent vehicles have no RTC capability.) The probability of receiving x bits in a row correctly is:

$$P_a = [1 - 10^{-3}]^x \text{ or } [1 - 10^{-6}]^x$$, where x is

either 4 or 8. The probability of no verification, P_{n-v}, is then $\sim 8\text{X}10^{-3}$ for an eight bit LM MAP (LM 1-3) at a BER of 10^{-3} and $\sim 8\text{X}10^{-6}$ at a telemetry bit error rate of 10^{-6}. For the CSM, using a four bit MAP, the probability of non-verification is $\sim 4\text{X}10^{-3}$ (telemetry bit error rate 10^{-3}) and $4\text{X}10^{-6}$ (telemetry bit error rate 10^{-6}). For any up-data transmission there are at least two MAPs transmitted back to the MSFN. Since only correct receipt of one is required for verification the probabilities of non-verification after two MAP transmissions is given by

$$P_{n-v} = 1 - [(P_a)^2 + 2(P_a)(1 - P_a)] , \qquad (7)$$

where P_a is the probability of acceptance of a MAP in one sample. Using the values for P_a, calculated above the probabilities of no verification (which requires a retransmission of the message) after two transmissions from the spacecraft become

CSM	Bit Error Rate	10^{-3}	$P_{n-v} = 1.6\text{X}10^{-5}$
		10^{-6}	$P_{n-v} = 1.6\text{X}10^{-11}$
LM 1-3	Bit Error Rate	10^{-3}	$P_{n-v} = 6.4\text{X}10^{-5}$
		10^{-6}	$P_{n-v} = 6.4\text{X}10^{-11}$

The verification of computer updates, requires a good comparison be obtained in two out of eight tries between the down-linked computer words and those that were transmitted to the spacecraft. To simplify the calculation of the probability of non-verification, it is assumed here that a good comparison is one in which all telemetered computer words compare favorably with those that were transmitted. In fact, the comparison is made on an individual word basis. That is each computer word telemetered to earth is compared independent of all other words. The data presented here then is somewhat pessimistic. Arbitrarily, the analysis for the probability of non-verification assumes a block of 14 spacecraft computer words or 210 bits of data. The probability of receiving all 210 correctly in one transmission is then simply, $P_a = [1 - P_e]^{210}$, and the probability of rejection because of an error $P_r = 1 - [1 - P_e]^{210}$. P_e, here is the telemetry bit error rate and is assumed to be 10^{-3}[*] or 10^{-6}, as before. The probability that in two or more blocks of data a valid comparison is not achieved, out ot eight blocks can be shown to be:

$$P_{n-v} = [(P_r)^8 + 8(P_r)^7(1 - P_r)] \quad , \qquad (8)$$

where P_{n-v} is the probability that two or more valid comparisons will not occur in eight frames and P_r is the probability of an invalid comparison in one frame. Also of interest is the probability of achieving a valid comparison in the first two frames. This is given by:

$$P_e = [1 - P_r]^2 \qquad (9)$$

The values for P_r are readily obtained from the equation above and are $P_r = 1 - [1 - 10^{-3}]^{210}$ or 0.18 for a bit error rate of 10^{-3} and $P_r = 1 - [1 - 10^{-6}]^{210} = 2.1X10^{-4}$ for a telemetry bit error rate of 10^{-6}. Using these values and equation (8) the probability of not obtaining a comparison at least twice in eight tries becomes $P_{nv} = 4.1X10^{-5}$ for a telemetry bit error rate of 10^{-3} and $P_{nv} = 1.4X10^{-25}$ for a bit error rate of 10^{-6}. The probability of non-verification in the first two tries (equation (9)) is $P_{nv} = 1 - P_c$ or .328 for a telemetry bit error rate of 10^{-3} and $4.2X10^{-4}$ for a 10^{-6} bit error rate. The normal mode of up-data operation is to operate in a high bit rate telemetry mode with a bit error rate of less than 10^{-6}. Table VII summarizes the expected telemetry performance for the up-data verification process.

SUMMARY AND CONCLUSIONS

Tables VI and VII present a summary of the expected performance of the Apollo up-data system. All of the data presented in these tables represent worst case performance.

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[*] A bit error rate of 10^{-3} will not normally be encountered in the verification process. This corresponds to a low bit rate telemetry mode from lunar distance and is not a normal command mode.

From Table VI it is apparent that the present up-data system more than satisfies the requirements imposed by the Apollo Program Specification. It would appear also that complete elimination of the sub-bit coding on the up-link, to increase the information data rate, is not desirable because of the increased susceptibility of the system to noise. It does appear, however, that the sub-bit encoding could be reduced (e.g., 3 sub-bits per information bit) resulting in an increased data rate as well as potential major spacecraft modifications. Because of the hardware impact, this is not recommended. Additionally, it appears that the K$\overline{K}$K coding on the computer updates could be eliminated without serious degradation of up-data system performance. This coding, however, is the only protection afforded the transfer of data between the up-data system and the computer. Because of this, and the potential hardware and software modifications required, this change is not recommended. The above recommendations assume that the time required for operation of the up-data system, including verification via down-link telemetry, is adequate to meet mission operations requirements. Even if the above suggested changes were implemented the total time required for operation (e.g., loading the spacecraft computer) is not significantly reduced.

The verification accomplished on the ground, using data telemetered from the spacecraft also appears adequate. Very little additional time will be added to the total operation time of the up-data system because of lack of verification due to poor telemetry performance.

2034-RLS-dlb R. L. Selden

Attachments
(Tables I through VII)

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Table VI

Summary cf Up-Link Up-Data Performance

Performance Parameter	Message Type	Present System		Alternative Systems to Increase Data Rate	
			Present System w/o Sub-bit Coding	Present System w/o $K\bar{K}K$ Coding	No Sub-bits No $K\bar{K}K$
Message Rejection	RTC	$6X10^{-5}$	$1.2X10^{-5}$	N/A	N/A
	CTE (CSM only)	$1.5X10^{-4}$	$3.0X10^{-5}$	N/A	N/A
	Computer	$1.1X10^{-4}$	$2.2X10^{-5}$	$1.1X10^{-4}$	$2.2X10^{-5}$
Undetected Error Signal Input	RTC	$6X10^{-30}$	$6.0X10^{-6}$	N/A	N/A
	CTE	$2.4X10^{-29}$	$2.4X10^{-5}$	N/A	N/A
	Computer	$5.0X10^{-90}$	$5.0X10^{-18}$	$1.5X10^{-29}$	$1.5X10^{-5}$
Undetected Error Noise Input	RTC	$5.6X10^{-17}$	$1.6X10^{-2}$	N/A	N/A
	CTE	$1.2X10^{-38}$	$1.6X10^{-2}$	N/A	N/A
	Computer	$2.5X10^{-32}$	$7.6X10^{-6}$	$2.5X10^{-28}$	$8.0X10^{-3}$

Sub-bit Error Rate 10^{-6}

Table VII

Summary of Down-Link Telemetry Performance
(Up-Data Verification)

		Probability of No Verification-P_{n-v}		
		MAPS		
Vehicle	Telemetry Bit Rate	Bit Error Rate[2]	Number of Verification Attempts	P_{n-v}
CSM	1.6 kbps	10^{-3}	1	$4X10^{-3}$
			2	$1.6X10^{-5}$
	51.2 kbps	10^{-6}	1	$4X10^{-6}$
			2	$1.6X10^{-11}$
LM	51.2 [1] (LM 1-3)	10^{-6}	1	$8X10^{-6}$
			2	$6.4X10^{-11}$
		Computer Word Comparisons		
CSM	51.2 [3]	10^{-6}	2 out of 2	$2.1X10^{-4}$
			2 out of 8	$1.4X10^{-25}$
LM	51.2	10^{-6}	2 out of 2	$2.1X10^{-4}$
			2 out of 8	$1.4X10^{-25}$

1. No MAPS are transmitted in the LM Low Bit Rate Telemetry.

2. 10^{-3} Bit Error Rate Corresponds to Lunar Range-Spacecraft Omnidirectional Antenna.

   10^{-6} Bit Error Rate Corresponds to Lunar Range-Spacecraft High Gain Antenna.

3. Normal Computer Update Mode Requires the Spacecraft to be in a High Bit Rate Telemetry Mode.