BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B69 12007

SUBJECT: The Probability of an ALSEP Accepting an Erroneous Command - Case 320

DATE: December 1, 1969

FROM: J. E. Johnson

ABSTRACT

The structure of Real-Time Commands uplinked to an ALSEP on the lunar surface is examined. Assuming random errors and a bit error rate of 10^{-6}, the probability that an ALSEP will accept a command in error is 7×10^{-12}. The probability that an ALSEP will accept a good command is .99998. The probability of one ALSEP accepting a command intended for another ALSEP is on the order of 10^{-18}. A threshold circuit inhibits power to the digital subsection of the ALSEP command decoder in the absence of an uplink signal, so that the possibility of noise being accepted as a command is very remote. Furthermore, the command as received by the ALSEP is telemetered to the ground, permitting almost instantaneous recognition of receipt of an erroneous command.

Some command anomalies were noted with the Early Apollo Scientific Experiments Package (EASEP), both in prelaunch checkout and after emplacement on the lunar surface during the Apollo 11 mission. This led to some command tests being conducted at MSC on a later-mission ALSEP. The results of these tests are summarized in an appendix.

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MEMORANDUM FOR FILE

This memorandum examines ALSEP command system operation to determine the probability of accepting an erroneous command. Assuming the ALSEP data subsystem functions as it is intended to, the probability of accepting an erroneous command is quite low, 7×10^{-12} for a bit error rate on the uplink of 10^{-6}.

DESCRIPTION OF COMMAND SYSTEM OPERATION

All uplinked commands to an ALSEP are Real-Time Commands (RTC's) which are used to perform binary functions (turn power on or off, switch modes, etc.). The RTC format is different from that used for the Apollo spacecraft. The command itself is 7 bits long, and is not sub-bit encoded. The command word structure for an ALSEP RTC is:

20 logical "1's" (used for sync)
 7 bits for the ALSEP decoder address
 7 bits for the complement of the RTC
 7 bits for the true form of the RTC
34 logical "1's" (used for timing)
75 bits total

All of the legal RTC's for all ALSEP's are stored pre-mission at each of the MSFN stations designated for possible ALSEP support (all the USB land stations). Normally, support will be provided by three 30' MSFN stations spaced so as to provide continuous coverage. ALSEP command and telemetry processing at a site is provided by a Remote Site ALSEP Processor (RSAP), one of the two 642B computers at each site used during manned mission support periods for CSM-LM-LV telemetry or command processing. For ALSEP, both command and telemetry processing functions are combined in one program, and only one machine is required.

An ALSEP command is called up via a Computer Execute Request (CER) sent by wide-band and high-speed data circuits from the MCC to the site selected for uplinking. The CER includes the identification number of the RTC to be uplinked and the address of the designated ALSEP decoder. The command word is assembled by the RSAP and uplinked at a 1 kbps rate on a 2119 MHz carrier phase-modulated by 1 and 2 KHz subcarriers.

The ALSEP command decoder incorporates a threshold detector, consisting of a threshold phase detector, an integrator, and a Schmitt trigger circuit. The threshold detector is activated by the string of logical "1's" preceding the information portion of the command and causes power to be applied to the digital section of the decoder. Should the signal level fall below the threshold before the information portion of the command has been completely received, the power will be removed. This feature provides a safeguard against accepting noise as a valid command.

The decoder has two separate digital subsections, each responding to its unique 7-bit address. After power has been applied, an address search mode is entered. If one of the digital subsections detects its address, the programming logic associated with that subsection generates a signal to inhibit further operation of the other subsection. A comparison is then made on each pair of complement-true RTC bits. If the comparison is completely valid, the command will be accepted and gated to the proper destination. In addition, a logical "1" will be read into the left-most stage of the 8-bit shift register used in the decoding and comparison processes. If the comparison is not completely valid, a logical "0" will be entered instead. The other seven stages will retain the 7-bit true form of the RTC as received by the decoder, and the entire 8-bits (known as the command verification message) will be read-out and telemetered to the MSFN. There is one exception: the command verification message is not included in the 10.6 kbps telemetry bit stream associated with the active seismic mode of operation.

The RSAP will normally examine the telemetry bit stream for the presence of the logical "1" in the command verification message. If it is detected, a Command Analysis Pattern Verification (CAP VER) message is assembled and placed on the high-speed data line also used for telemetry data transmission to the MCC. If the logical "1" is not detected, a reject message is sent in lieu of the verification message.

The RSAP may also operate in an override mode, in which the downlinked command verification message will not be examined on-site. In all cases, however, the 8-bit command verification message will be returned to the MCC and can be inspected by ALSEP controllers there.

PROBABILITY ANALYSIS

The threshold detector will act to prevent noise being accepted as a command. Analysis of the probability of operation of the threshold detector by noise is beyond the scope of this memorandum. Since its operation by noise depends on achieving and maintaining proper phase relationships in the input "signal" for at least the 21-bit intervals (21 ms) associated with the address and RTC portions of the command word, the chance of its inadvertent operation is exceedingly remote. The probabilities that will be examined are therefore those associated with the actual uplinking of a command carrier with its associated 1 and 2 KHz subcarriers.

Errors occurring on the uplink path are assumed to be random and equally as likely to convert a "1" to a "0" as a "0" to a "1". For purposes of assigning numerical values, the 10^{-6} bit-error-rate specification on the Apollo data system will be used. The probabilities of errors occurring in ground processing and remote site-MCC data transmission are not considered.

An error in the logical "1's" used before the address for sync and after the RTC for timing is not likely to be of any consequence. It would take several sync bit errors to cause difficulty and would probably result in the decoder not accepting the command. The timing pulses are "after the fact" and are used to insure adequate spacing between commands.

An error in the 7-bit decoder address will cause the decoder to remain in the search mode until the input disappears, unless the correct 7-bit pattern can be obtained by including portions of either the sync or complement-true RTC bits. In either case, the bit structure following the pseudo-address would be exceedingly unlikely to exhibit the correct pattern. The probability, first, that a sequence of 7 bits not in the address position would correspond to a valid decoder address, and second, that the sequence of the following 14 bits would exhibit 7 pairs of complement-true relationships is negligible.

There is the possibility of errors in the address portion of the command word converting one address to a different valid address. A total ot 5 ALSEP's are planned (this includes the EASEP); with two valid addresses each, there will be 10 valid addresses if all are in operation at the same time. (ALSEP's have an operating lifetime of either one or two years, pre-set before launch.) The two valid addresses per decoder differ in only one bit position. An error in this bit position is of no consequence, however, since both decoder sections exercise the same control functions. What is of concern is the possibility of addressing the wrong ALSEP. An examination of the ALSEP address codes (from the ALSEP Command Data Format Control Book)[2] shows the following bit pattern differences:*

ALSEP	#1	addresses differ from	#2	addresses	in	3 bit positions
"	#1	"	#3	"		3 " "
"	#1	"	#4	"		either 3 or 4 bit positions
ALSEP	#2	addresses differ from	#3	addresses	in	4 bit positions
"	#2	"	#4	"		either 4 or 5 bit positions
"	#3	"	#4	"		either 3 or 4 bit positions

(The either-or situations arise from the fact that the two valid addresses for ALSEP #4 differ in the second bit position; all others differ in the first bit position.)

If the probability of a single bit error is p, and the probability of accepting a command intended for ALSEP #n is denoted by Pr(n), then:

Pr(ALSEP 1 accepting wrong command) = Pr(2) + Pr(3) + Pr(4)

$$= p^3 + p^3 + 1/2\ p^3 + 1/2\ p^4$$

$$\simeq 2.5p^3$$

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*The fifth ALSEP has just recently been added to the program, and its address structure has not yet been defined.

Pr(ALSEP 2 accepting wrong command) = Pr(1) + Pr(3) + Pr(4)

$$= p^3 + p^4 + 1/2\ p^4 + 1/2\ p^5$$

$$\simeq p^3$$

Pr(ALSEP 3 accepting wrong command) = Pr(1) + Pr(2) + Pr(4)

$$= p^3 + p^4 + 1/2\ p^3 + 1/2\ p^4$$

$$\simeq 1.5p^3$$

Pr(ALSEP 4 accepting wrong command) = Pr(1) + Pr(2) + Pr(3)

$$= 1/2\ p^3 + 1/2\ p^4 + 1/2\ p^4 + 1/2\ p^5 + 1/2\ p^3 + 1/2\ p^4$$

$$\simeq p^3$$

Thus, the probability associated with each ALSEP is on the order of p^3, or 10^{-18} for $p = 10^{-6}$.

An error in the remaining 14 RTC bits will escape detection only if its corresponding complementary bit is also in error. The probability of both the true and complementary bits being in error is p^2, and since this can happen in any one of 7 different pairs, the total probability is $7p^2$. For $p = 10^{-6}$, this probability is 7×10^{-12}.

The probability of accepting a command is one minus the probability of rejecting it, or:

$$\Pr(\text{accept}) = Q = 1-\Pr(\text{reject})$$

An error in any one of 20 bit positions (excluding the "don't care" bit in the address) will cause rejection, unless there is a complementary bit error as well. Thus:

$$Q \simeq q^{20} = (1- p)^{20}$$

$$\simeq 1-20\ p = 1-20 \times 10^6 \text{ for } p = 10^{-6}$$

Of the 20 commands per million that could be expected to be rejected, 7 could be expected due to an error in the true RTC, and 13 due to an error in either the address or the complement of the RTC.

To summarize (for $p = 10^{-6}$):

Probability of accepting an RTC	$= 1-20 \times 10^{-6}$
Probability of rejecting a good RTC	$= 13 \times 10^{-6}$
Probability of a bad RTC	$= 7 \times 10^{-6}$
Probability of accepting a bad RTC	$= 7 \times 10^{-12}$
Probability of accepting an RTC for another ALSEP	= order of 10^{-18}

If an erroneous command were received and acted upon, the ground would have almost immediate indication of this event via telemetry (except in the high-bit-rate active seismic mode) and could then issue a command to rectify the situation.

CONCLUSIONS

It is concluded that if the ALSEP command decoder functions properly, a very high degree of protection is afforded against inadvertent commanding. It should be noted, however, that if the threshold detector were to fail in such a way as to apply power to the digital section of the decoder, if the command carrier and one and two kHz subcarriers were inadvertently left on, or if two modulated carriers were simultaneously on, the susceptibility of the system would be very much higher (see appendix). Also, it should be recognized that the system is not "secure"; the coding is not classified, and the modulation technique not particularly hard to duplicate. A power level at the input to the ALSEP receiver between -61 and -101 dbm is required, implying a fairly significant amount of transmitted power and antenna gain (for example, 500 watts with a 30' antenna for a -101 dbm received signal level).

J. E. Johnson

2034-JEJ-drc J. E. Johnson

Attachment
Appendix

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REFERENCES

1. ALSEP Mission Configuration System Description, Flight Support Division, MSC, October, 1969.

2. Apollo Lunar Surface Experiment Package (ALSEP) Command Data Format Control Book, Data Acquisition Plan Annex C-1, Rev. 2, Change 2, Flight Support Division, MSC, October 17, 1969.

3. ALSEP Remote Sites Data Processing Program Requirements, Data Acquisition Plan Annex E-1, Change 3, Flight Support Division, MSC, July 18, 1969.

4. Apollo Lunar Surface Experiments Package (ALSEP) Flight System Familiarization Manual, ALSEP MT-03, Bendix Corp. for MSC, August 1, 1967.

5. "Command Decoder Functional Description," ATM-225, Bendix Systems Division, June 29, 1966.

6. "ALSEP Command Anomaly Data Package Review," Lockheed Electronics Company, September 25, 1969.

7. "MSFN-ALSEP Command Link Test Data Package," Lockheed Electronics Company, September 25, 1969.

APPENDIX

ALSEP COMMAND ANOMALY TESTS

Command anomalies were experienced in checkout of the EASEP at the manufacturer's facility, at KSC, and after emplacement of the package on the moon during the Apollo 11 mission. As a result of these anomalies, tests were conducted on another package at the Electronic Systems Telecommunications Laboratory (ESTL) at MSC in August and September of 1969. This appendix summarizes the principal findings of the tests and comments briefly on their significance to the subject of this memorandum. Further test information is contained in References 6 and 7.

The chief difficulties experienced were in accepting commands when two uplink carriers, both modulated, were being received and in erratic command verification, often when no commands had been accepted. Specifically, the ESTL tests showed:

(1) If two uplink carriers modulated with valid commands were transmitted simultaneously, the ALSEP would occasionally execute a random command. The frequency of occurrence was a function of difference in carrier powers and the relative phasing of the two signals. The minimum time between execution of "commands" was about one minute.

(2) If two uplink carriers were modulated with all "1's", a random command would be executed at a minimum interval of about seven minutes.

(3) No commands were executed when there was no modulation on the uplink carriers.

(4) With only one uplink carrier, valid command verifications were often followed by spurious command verification pattern 177 (all "1's").

(5) With no uplink carrier, no commands were executed; however, spurious random command verification patterns were transmitted about every 27 minutes.

Simultaneous uplinking of two modulated carriers is not, of course, a correct operational procedure. Under these

APPENDIX

conditions, the sum of the two signals at the ALSEP receiver could be expected to activate the threshold detector and cause the command decoder to look at the resultant more-or-less random patterns of "0's" and "1's" in search of a "valid" command. If the composite signal were in fact random, a pseudo-valid address could be expected once every 2^6 bit intervals, and a pseudo-valid command whose complement check was correct every 2^7 trials associated with a correct address. Therefore, a correct-appearing address and command could be expected every 2^{13} ms, or slightly less than once a minute, in close agreement with the test results.

The downlink verification of one random, unexecuted command every 27 minutes similarly is about what could be expected on a random basis. The command verification word consists of a single bit set to "1" to indicate acceptance of a command, plus the 7 true bits of the command. Therefore, only one bit need be in error to make it appear a command was accepted. This verification word is sent only once. Given the ALSEP telemetry frame rate of 604 ms, a spurious command verification rate of one per 27 minutes would correspond with a bit error rate of 3.7×10^{-4}, in fair agreement with expected telemetry system performance when working into a 30 ft. USB antenna.

Reference 6 concludes as follows:

> "The execution of random commands can occur under many different conditions involving two simultaneous up-link RF carriers. This could cause physical harm to an extravehicular astronaut, loss of a one-time experiment capability, or the interruption of data from an experiment package. To preclude this possibility it is recommended that the deployment of the ALSEP be carried out and completed with power off and that ALSEP be activated when the crew is preparing to leave the lunar surface. It is further recommended that safeguards be taken to prevent simultaneous transmission on ALSEP frequency (2119 MHz) by more than one ground station."

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