ANALYSIS OF SPACE TELESCOPE DATA COLLECTION SYSTEM

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INTERIM FINAL REPORT

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DATA COLLECTION SYSTEM

INTERIM FINAL REPORT
Covering the Period
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LIST OF SYMBOLS

BER	Bit Error Rate
BCU	Bus Coupler Unit
BPSK	Bi-phase Shift Keying
BSR	Bit Slip Rate
CCIR	International Radio Consultative Committee
CDI	Command Detector Interface
C.E.	Convolutional Encoder
CU/SDF	Control Unit/Science Data Formatter
DIU	Data Interface Unit
DMS	Data Management Subsystem
DMU	Data Management Unit
DOMSAT	Domestic Satellite System
E	Number of Correctable Symbol Errors per R/S Block
EIRP	Effective Isotropic Radiated Power
ESTR	Engineering/Science Tape Recorders
FGS	Fine Guidance Sensor
GSFC	Goddard Space Flight Center
HGA	High Gain Antenna
Hz	Hertz
I	In-phase
IC	Integrated Circuits
I&C	Instrumentation and Communications Subsystem
J	Number of Bits Per R/A Symbol

LIST OF SYMBOLS (Continued)

Kbps	Kilobits Per Second
LGA	Low Gain Antenna
MA	Multiple Access
MDPS	Megabits Per Second
MDB	Multiplexed Data Bus
MHz	Megahertz
MSB	Most Significant Bit
N_{max}	Maximum Number of Output Symbols of the Convolutional Encoder w/o a Transition
NASCOM	NASA Communications Network
NRZ-L	Non-Return-to-Zero-Level
NSSC-I	NASA Standard Spacecraft Computer, Model I
OTA	Optical Telescope Assembly
$P_1(E)$	The R/S Input Symbol Error Probability
$P_2(e)$	The Output Probability of the R/S Decoder/Deinterleaver
$P_b(e)$	Probability of a Bit Error Occurring on the Inner Channel
$P_{R/S}(E)$	Symbol Error Probability Out of the R/S Decoder/ Deinterleaver
$P_T(e)$	Overall Bit Error Probability
$P_{VD}(E)$	Bit Error Rate Out of the Viterbi Decoder
$P_{WS}(E)$	Average Bit Error Rate of the TDRSS Link
PCI	Periodic Convolutional Interleaver
PCU	Power Control Unit
PIT	Processor Interface Table

LIST OF SYMBOLS (Continued)

PN	Pseudo Noise
PSK	Phase Shift Key
Q	Quadrature-phase
RF	Radio Frequency
RFI	Radio Frequency Interference
RM	Remote Module, Resource Monitor
R/S	Reed-Solomon
SDF	Science Data Formatter
SI	Scientific Instrument
SI C&DH	SI Control and Data Handling (Subsystem)
SNR	Signal to Noise Ratio
SSA	S-band Single Access
SSM	Support Systems Module
ST	Space Telescope Orbiting Observatory
STINT	Standard Interface for Computer
STOCC	Space Telescope Operations Control Center (at GSFC)
ST Sci	Space Telescope Science Institute Contractor
T	Interval of Heavy RFI
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
VCO	Voltage Control Oscillator

ANALYSIS OF SPACE TELESCOPE DATA COLLECTION SYSTEM

SUMMARY OVERVIEW

This report covers the modification No. 4 work statement additions to the original contract NAS8-33570. These work statement tasks are (the work statement tasks added by modification No. 4 are indicated by an asterisk):

E. TASKS:

1. Analysis of the effects of frame synchronization loss.
2. System Parameter analysis pursuant to encoding/decoding, interleaving/de-interleaving, and spectrum spreading to meet flux density requirements.

*3. Analysis of requirements for a very low bit error rate (BER) for engineering data.

4. Analysis and recommendations for various coding and communications techniques as follows:
   - a). Coding and communication of scientific data at the instrument.
   - b). Coding and interleaving data in the central management system.
5. Evaluate the overall impact of frame synchronization loss effect on total data loss pursuant to recovery from an error in decoding as applied to the PN sequence and de-interleaving.

*6. Investigate methods to improve science and engineering data error control encoding to improve the error characteristics through techniques for implementing the length of code to be used, and practicality of the various types of decoding.

A report was written in August 31, 1980 and submitted as an interim final report covering all items of the work statement EXHIBIT "A" for the contract NAS8-33570. The next phase of the contract as indicated above is detailed in work statement EXHIBIT "B", modification number 4 for the contract NAS8-33570. The asterick items above are the additional work statement tasks of the modification Number 4. The tasks 1, 2, 4, and 5 have been fully addressed in the interim final report of August 1980 (MSSU-EIRS-EE-81-5). In an annual summary report covering the period September 1, 1980 - July 1, 1981, the impact of these tasks (1,2,4, and 5) on the engineering data link for the space telescope system was reviewed. This annual summary report is attached to this interim final report as Appendix A.

The various task items of work statement E, modification Number 4 are addressed in the indicated reports:

TASK	REFERENCE
1. Science Data:	Interim Final Report 1980 (MSSU-EIRS-80-3) pages 36-40 and Section 3.B.C
1. Engineering Data:	Section IIB and Appendix A of this report.
2. Science Data:	Interim Final Report 1980 (MSSU-EIRS-80-3) Pages 20-21, Section 2.A.2.b and pages 72-74 Section 3.C.
2. Engineering Data:	The analysis of Limb Angle and Position have shown no problem exists for flux density limitations for Engineering Data. (Reference Lockheed Report COMM-0009A, LMSC/D669864A, page 27, Contained in SE-03, Section N of DMS C-WEAR Item No. 10, January 1982, and Appendix A of this report.
3. Science Data:	Interim Final Report 1980 (MSSU-EIRS-80-3).
3. Engineering Data:	Interim Final Report 1980 (MSSU-EIRS-80-3) page 11 and Section II A, and Appendix A of this report.
4. Science Data:	Interim Final Report 1980 (MSSU-EIRS-80-3), Chapter 4.
4. Engineering Data:	Section II A of this report.

TASK	REFERENCE
5. Science Data:	Interim Final Report 1980 (MSSU-EIRS-80-3) pages 36-40 and page 59 and this report sections 3 and 4.
5. Engineering Data:	Section II B and Appendix A of this report.
6. Science Data:	Interim Final Report 1980 (MSSU-EIRS-80-3).
6. Engineering Data:	Section II.A.2 and Appendix A of this report.

SECTION I

INTRODUCTION

This is the second volume of a two volume report entitled "Analysis of The Space Telescope Data Collection System". The first volume was submitted as an interim final report dated October 1980. The interim report provides a general discussion of the complete communication system, both the forward and return links, of the Space Telescope (ST). It also contains a detailed analysis of the S-band Single-Access (SSA) System.

The analysis of the SSA system consists of the evaluation of synchronization loss on system performance, the need for additional error control encoding of the scientific data at the Science Data Formatter (Reed-Solomon outer coding scheme), and means to minimize all data losses due to known possible sources such as systematic and/or random communication errors. A summary of the SSA analysis is provided in Section IV.

The main objective of this volume is to provide an analysis of the expected performance for the Multiple Access (MA) system. The analysis is presented in Section II and covers the expected bit error rate performance, the effects of synchronization loss, the problem of self-interference, and the problem of phase ambiguity.

Section III deals with the problem of false acceptance of a command word due to data inversion. A mathematical determination of the probability of accepting an erroneous command word due to a data inversion is presented. The problem is examined for three cases; 1) a data inversion only, 2) a data inversion and a random error within the same command word, and a block (up to 256 48 bit words) containing both a data inversion and a random error.

SECTION II

MULTIPLE ACCESS SYSTEM ANALYSIS

The Multiple Access (MA) system is utilized to transmit real-time engineering data at 0.5, 4.0, or 32.0 Kbps and 4.0 Kbps science data simultaneously. Except for the 0.5 Kbps data rate, the data are transmitted to the Tracking and Data Relay Satellite System (TDRSS) utilizing the transmitter portion of the transponder via the high gain antenna (HGA) system. The 0.5 Kbps data rate is transmitted in the same way except via either the HGA or the Low Gain Antenna (LGA) system.

The MA return link utilizes two simultaneous, independent channels employing spread spectrum techniques. Each channel is 1/2 convolutionally encoded and modulo two added to a Pseudo-Noise (PN) code prior to modulating quadrature phases of a 2287.5 MHz, 5.36 watt ± 1 dB RF carrier. Either the I or Q channel may be used to transmit the engineering data at one of the above rates or both channels at the same rate. However, only the I channel may be used to transmit the 4.0 Kbps science data.

The formatting of the data for the MA Link is accomplished in the Support System Module (SSM) where it is collected, recorded and/or transmitted to the Space Telescope Operations Control Center (STOCC). Engineering data from the Scientific Instruments (SI) and the Scientific Instruments Control and Data Handling Subsystem (SI C&DH) are collected by the Control Unit/Science Data Formatter (CU/SDF) and routed to the Data Interface Unit (DIU) as a composite data stream. The engineering data stream is then routed to the Data Management Unit (DMU) via the DIU. The SSM and the Optical Telescope Assembly (OTA) Engineering data are combined with the SI and the SI C&DH engineering data to form the composite ST engineering data rates of 0.5, 4.0, or 32 Kbps.

The DMU arranges the data into major frames which consists of 20 or 120 minor frames. Each minor frame contains either 125 or 250 eight bit words and a 24 bit frame synchronization word. The DMU is capable of collecting and formatting the data in one of five formats; three of which are fixed by hardware control. The data are transferred to the MA system for real-time transmittal to the STOCC or to the Engineering tape recorder for later transmission.

The Engineering Tape Recorder (ETR) is identical to the science tape recorder. The ETR records all engineering data at a 32 Kbps rate. The 4.0 Kbps rate is up converted by an 8-bit sequence to the 32 Kbps rate. The 0.5 Kbps data is utilized for real-time transmission only. All recorded data are played back in reverse at 1.024 Mbps rate and transmitted via the S-band Single Access (SSA) system The reader is referred to Reference 2 for a more detailed discussion of the tape recorder and SSA system. The complete ST Data Transmission Flow is illustrated in Figure 1.

The analysis of the Engineering Data System covers four main aspects. They are: (1) the Bit Error Rate (BER), (2) the effects of synchronization loss, (3) the problem of self-interference on the MA Link, and (4) the problem of phase ambiguity due to NRZ-L waveform. Each of these are discussed in the following paragraphs.

II.A. Expected Bit Error Rate Performance

To achieve an understanding of the error rates possible on the engineering data transmissions each piece of the system should be inspected. The system is to be considered in two sections; the expected error rate at the output of the convolutional encoder and the expected BER over the TDRSS link.

II.A.1. The Output Bit Error of the Convolutional Encoders

A worst case analysis of the composite engineering data stream has been determined by Lockheed, see Reference 3. The bit error rate from the sensor output to the output of the convolutional encoder for the engineering data has been estimated to be no greater than 1×10^{-7} for real-time data and 2×10^{-6} for recorded data. The highest BER of any sensor is assumed to be 2×10^{-6}, this value is based on the WER of the OTA sensor which is specified to be 3×10^{-5} for a 16 bit word. Thus, the estimated BER at the output of the convolutional encoder should be no greater than 2.1×10^{-6} for real-time data and 4.0×10^{-4} for recorded data.

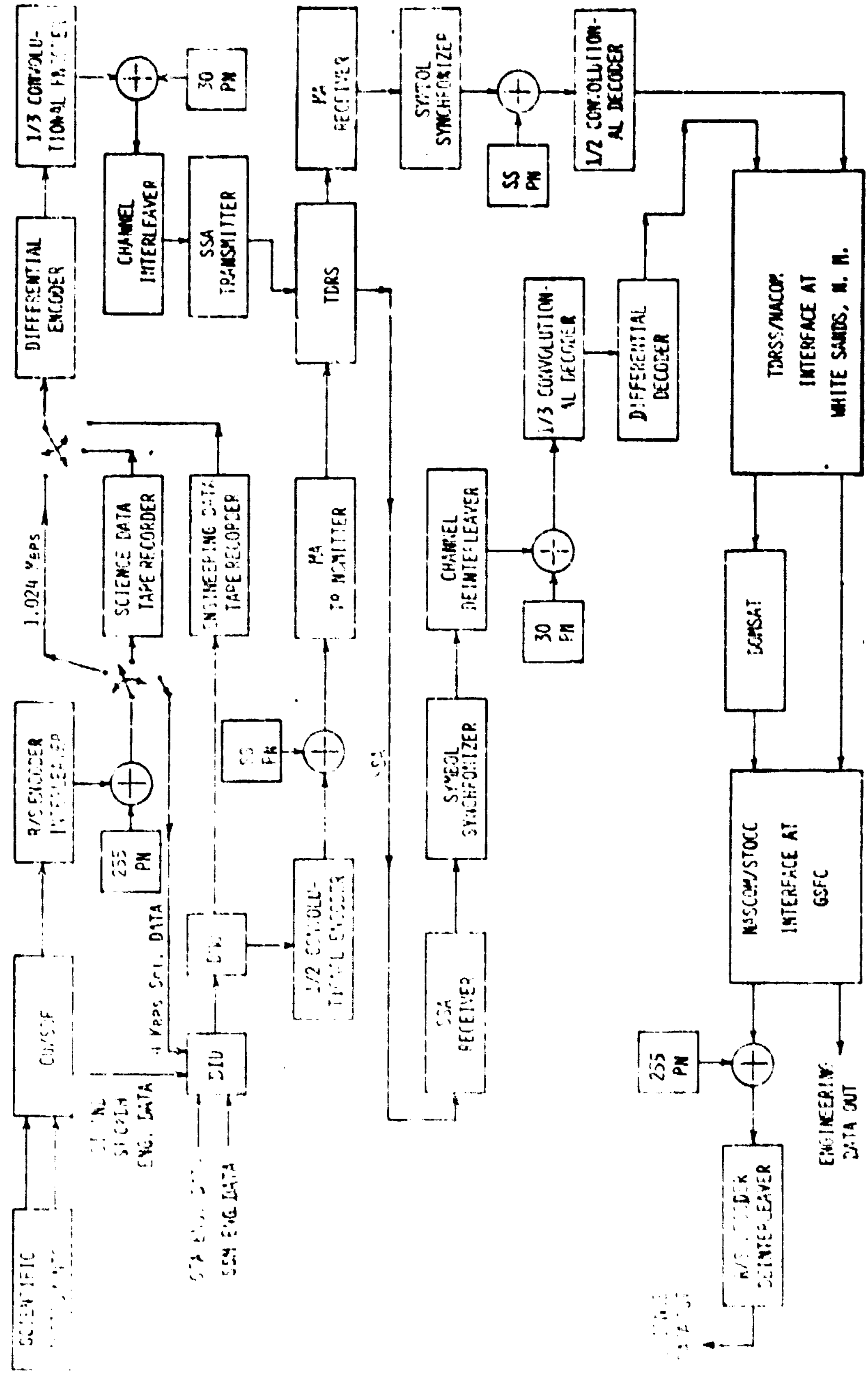

Figure 1. ST Data Transmission Flow

Lockheed recommended verification of the path BER by test rather than analysis. The reason for this is the difficulty of analytically predicting with any degree of confidence the actual degradation of the path due to system noise and equipment failure.

There has been considerable concern expressed regarding the feasibility of testing the equipment for error performance when the specification calls for error rates in the neighborhood of 10^{-7}. This concern is for the extreme length of time required to achieve meaningful statistics. As pointed out in the MSU February 1982 monthly report, one procedure of testing such equipment is to run the equipment for a day under worst case test conditions. If one error occurs, then it may be attributed to chance, but if two errors occur it is highly probable that a system problem exists and further testing is certainly indicated.

Another area of concern is the performance of the tape recorder. Since the BER performance of the tape recorder has a major impact on the expected BER for recorded data, a more detailed discussion of the tape recorder BER is in order. The error rate for the tape recorder has been specified to be 10^{-6} or less (Reference 4). But, as pointed out in the February 1982 Monthly Report, this is the long term error rate. No specifications are mentioned for the short term error rate or for a maximum number of errors.

Not having a short term error rate specification could lead to a three or four minute period of error rate above the 10^{-6} specified. This in turn would increase the BER of the recorded engineering data. This may not be a problem; since initial tests with the tape recorder indicated the performance to be nearly error free. Therefore, the tape recorder will most likely have a BER of less than 10^{-6}; so the average BER for played back engineering data at the input to the TDRSS link should be 4.0×10^{-6}.

II.A.2. Bit Error Rate of the TDRSS Link

The TDRSS will provide a maximum BER of 10^{-5} if the user, the ST in this case, meets certain minimum requirements as specified in Reference 1. One of the main requirements is that the user provides a minimum effective isotropic radiated power (EIRP) in dBw for specific data rates. The values specified in TDRSS User's Guide Table 3-6, page 3-21, assumes there is no system degradation due to antenna point loss, polarization loss (mismatch between the polarization of the received signal and the receiving antenna) or failure to comply with the signal constraints listed in Paragraph 3.9, page 3-61 of Reference 1. If system degradation does exist, then the required EIRP must be increased to compensate for the losses. Thus, one method of estimating the BER performance is to examine the difference between the required EIRP, including all losses, and the actual EIRP provided by the ST. This difference is often referred to as the link margin.

Since the required EIRP must include compensation for system degradation, it would be more desirable to consider received power (P_{Rec}) at the TDRS normalized to a 0-dBi antenna, where P_{Rec} is defined as

$$P_{Rec} = EIRP + L_S + L_\theta + L_P$$

with

L_S = space loss in dB

L_θ = the effective degradation in dB due to inability to point the user antenna directly at the TDRS

L_P = polarization loss in dB.

Thus, the required P_{Rec} must include increases to offset external RFI losses and noncompliance of signal quality. In addition to the aforementioned losses, the P_{Rec} may also be expressed in terms of the data rate, since to achieve a specific data rate, the user must provide a certain EIRP. Thus, using the information from Reference 1, the required received power may be expressed as

$$P_{Rec} = 10\log_{10} R_b - K - 192.2 \text{ dB}$$

where R_b is the data rate before convolutional encoding in bps, and K is a constant whose value is the constant given in Table 3-6 for the appropriate ADR relationship minus the required compensation to offset the external RFI and the total system losses.

An estimate of the degradation due to external RFI can be obtained from Reference 1, Appendix K and the degradation due to system losses can be found in Reference 6. The values of the constant K and the required P_{Rec} for the real-time and recorded data are listed in Table I.

To determine the effective P_{Rec} provided by the ST, the mathematical model described in the Appendix of Reference 7 is used. The values for transmission circuit loss, antenna gain, pointing loss, polarization loss, space loss, etc., are taken from Reference 6 The calculation values for the effective P_{Rec} are listed in Table II for real-time and recorded data. The link margins for real-time data and recorded data are given in Table III.

Based on the link margins of Table III, the TDRSS will provide the desired BER of 10^{-5}. However, concern must be expressed for the low link margin of 1.3 dB provided by the 32 Kbps real-time data rate. A link margin this low could yield a higher BER than the required 4.1×10^{-5} for (Reference 3) brief periods. Therefore, it is recommended that all 32 Kbps real-time engineering data be inspected for data BER requirements. If any of these data are considered important data and must have a BER of no more than 4.1×10^{-5}, then the data should be routed to the engineering tape recorder, thus receiving the benefits of the more reliable SSA system.

One might ask why it is recommended to utilize the tape recorder instead of employing some coding technique. First of all, only the 32 Kbps data rate has a possible problem providing the desired BER of 10^{-5} and then only for short periods. Secondly, the impact to the overall system if coding is employed would be great with regards to implementation costs and to reduction in information rates. There has been some interest expressed in using a 1/3 rate instead of the 1/2 rate convolutional encoder on the MA link, since a 1/3 rate convollutional encoder would provide an additional gain of 0.5 dB (per

Table I. The Required Received Power at TDRS For Various Data Rates.

Data Rate Kbps	System Losses (dB)			External RFI[3] (dB)	Constant (Table 3-6 Ref. 1) (dB)	K (dB)	Required P_{Rec} (dB)
	L_P[1]	L_θ[2]	Non-Compliance				
0.50[4]	0.3	0.3	0.5	0.5	24.6	23.0	- 188.2
4.0[4]	0.3	0.3	0.5	0.5	24.6	23.0	- 179.2
32.0[4]	0.3	0.3	0.5	0.5	24.6	23.0	- 170.2
10.24[5]	0.3	0.3	0.7	1.8	34.7	31.6	- 163.7
0.5[6]	0.3	0	0.5	0.7	34.7	33.2	- 198.4

Require $P_{Rec} = 10 \operatorname{Log}_{10} R_b - K - 192.2$ where R_b is data rate in bps

NOTE:
1. Values from Reference 6
2. The 0.3 dB pointing loss is a standard value used by the CLASS program
3. The RFI values are the "Best Estimate" Reference 1, not the upper bound.
4. MA Return Link with 1/2 Convolutional Coding (Real-time Data via HGA)
5. SSA Return Link with 1/3 Convolutional Coding (Recorded data)
6. MA Link with SSA support.

TABLE II

EFFECTIVE RECEIVED POWER AT TDRS

MA Link (Real-time data)

	HGA	LGA
Transmitter Power in dB	6.3	6.3
Circuit Loss in dB	- 6.2	- 4.6
Antenna Gain in dBi	26.4	- 1.0
Pointing Loss in dB	-0-	-0-
Space Loss in dB	-192.4	-192.4
Data Power/Total Power in dB	- 3.0	- 3.0
Power Received in dB	-168.9	-194.7

SSA Link (Recorded data)

Transmitter Power in dB	11.3
Circuit Loss in dB	- 6.3
Antenna Gain in dB	26.4
Pointing Loss in dB	-0-
Space Loss in dB	-191.9
Power Received in dB	-160.5

Table III. The Link Margins for Real-time and Recorded Data Via MA System.

	Real-Time				Recorded
DATA RATE (Kbps)	.5		4	32	1024
	LGA	HGA	HGA	HGA	HGA
Effective Received Power in dB	- 194.7	- 168.9	- 168.9	- 168.9	- 160.5
Required Received Power in dB	- 198.4	- 188.2	- 179.2	- 170.2	- 163.7
Link Margin in dB	3.7	19.3	10.3	1.3	3.2

Reference 5) above the gain provided by the 1/2 rate convolutional encoder. The problem with utilizing the 1/3 rate convolutional encoder is that the MA link can only use a 1/3 convolutional code on the Q channel of Data Group 1, mode 3 (Reference 1). This in conjunction with only a 0.5 dB gain and a reduced information rate makes the use of a 1/3 convolutional code impractical. The cost of a concatenated coding scheme such as the Reed-Solomon coded used on the SSA link would prove to be prohibitive unless justification could be provided on the basis of the need for the much lower BER provided by this type of system.

II.A.3. The End-to-End Bit Error Rate

The End-to-End BER of the MA link is the sum of the BER at the output of the convolutional encoder and the BER of the TDRSS link, since the two systems are in series. Therefore, the overall BER should be no greater than 1.21×10^{-5} for real-time data and 1.4×10^{-5} for recorded data.

It should be noted that the above BER do not include the effect of synchronization loss on the system. This is discussed in the following subsection.

II.B. The Effect of Synchronization Loss

In the event of frame synchronization loss, it is expected that two frames will be lost at a minimum. The frame construction consists of 20 to 120 minor frames per major frame with each minor frame containing 125 to 250 eight bit words and a 24 bit frame synchronization word. Thus, if synchronization is reacquired within two minor frames 1008 to 2008 bits would be lost. At a data rate of 32 Kbps for a 20 hour period, this would yield an average bit error rate of 17×10^{-6} or 1.7×10^{-5} for the 250 word minor frame. Thus, one frame synchronization loss in 20 hours of transmission will create an effective BER of 1.7×10^{-5} for the longer minor frames.

Data losses from any other sources will compound this figure and due to the poor link margins for the 32 Kbps transmission rate, it is likely that higher error rates than 10^{-5} BER will be experienced.

It would be appropriate at this point to re-emphasize the concern expressed in the MSU February 1982 monthly report pertaining to the relaxing or redefining the bit jitter test specification raised in Reference 4. Bit jitter is critical in determining the bit slip rate. A bit slip is defined as the insertion or deletion of a bit into the data stream at the ground station. Such an occurrence can be disastrous to the frame synchronization, as well as the error control decoder.

The current specification for the TDRSS return link is based upon frequency jitter and jitter rate for sinusoidal and random components. There are certain problems associated with this specification:

1. The bit error rate (BER) depends on the untracked phase jitter component. There is no direct relationship between frequency jitter and BER.
2. The bit slippage rate (BSR) is sensitive to the spectral location of the jitter components and is not directly related to the specification parameters of the TDRSS. (For additional information, the reader is referred to Reference 9.)

For the above reasons, great caution should be used regarding any changes in testing procedures or redefinition of bit jitter.

II.C. Self-Interference on the MA Link

A question posed by Mr. Harvey Golden through Mr. Joe Thomas and involves a legitimate concern which actually arose due to a similar problem which exists in a different vehicle and program.

As a result of possible self-interference a proposed utilization of the MA system by NOSS and XTE projects has been rejected.

The self-interference problem has always existed on the MA system due to the fact that all MA users operate at the same frequency and polarization. These simultaneous transmissions are discriminated by unique PN codes and antenna beam pointing. The current TDRSS design provides a 1-db margin against MA system self-interference.

The primary reason for the rejection of both the NOSS and XTE proposed design was their proposed utilization of more than one MA return link from the same platform. To overcome the self-generated interference between multi-transmitters on the same platform requires increased power resulting in increased self-interference to other MA users above the 1-db design margin. Therefore, to provide the best service to the majority of users, the Networks Directorate must control the total amount of user power in the MA return band. Thus, the Network Directorate has restricted the use of the MA return service to a single link from each platform. This does not, however, prohibit the use of quadriphase types of modulation.

Since the ST MA return system will employ only a single return link (transmitter), the ST system does not have a problem with the self-interference characteristics of the MA return link system similar to that which resulted in the rejection of the NOSS and XTE proposed designs. This information was given to J. Thomas, MSFC, by phone on November 6, 1980. During the November 10, 1980 trip to MSFC, the same information was discussed with H. Golden and he agreed with the conclusion that ST does not have a problem in this respect. These results were also confirmed by D. Herr, G.S.F.C., by phone in November 1980.

II.D. Phase Ambiguity Problem of the MA Link

Phase Ambiguity Problem refers to the inability to distinguish between ones and zeros in a binary bit system. This problem occurs whenever NRZ waveforms are used. One method of correcting this problem is to utilize differential encoding, which is used on the SSA Link for the ST. However, the MA Link does not employ differential encoding and hence data transmitted over the MA Link will face a phase ambiguity problem.

The phase Ambiguity problem of the MA Link will be resolved by utilizing the Telemetry Acquisition Control (TAC) frame synchronizer unit at the ground station. The TAC has the ability to automatically detect an inverted frame synch word. Thus, if the data stream on the MA Link is output from the bit synchronizer in an inverted mode, the

the frame synchronizer will detect this fact. The unit does have the capability of automatically inverting the data stream or of simply indicating the inverted condition by an indicator light on the front panel.

The actual operational mode (automatic inversion or simple indication) will be determined by ground station personnel.

SECTION III

PROBABILITY OF FALSE ACCEPTANCE OF A COMMAND WORD DUE TO DATA INVERSION

This question has several aspects, and to answer the question fully one should actually answer three questions:

1. What is the probability that a data inversion in the detected bit stream will cause a specific 48 bit word to be accepted erroneously?
2. What is the probability that a data inversion in the detected bit stream coupled with a random error in the bit stream will cause a specific 48 bit word to be accepted erroneously?
3. What is the probability that a data inversion in the detected bit stream coupled with a random error in the bit stream will cause a block (up to 256 48 bit words) to be accepted erroneously?

The following characteristics of the command data forward link are noted.

The command data link has a format consisting of up to 256 48 bit words. Each 48 bit word contains a 7 bit station address code which is unique to that station. Furthermore, each station checks this address for errors, thus errors incurred in the station address will cause the complete data block to be rejected.

The 48 bit word consists of 41 bits plus a 7 bit check set formed by cyclic encoding with the generator polynomial $g(x) = 1+X^2+X^6+X^7$ $= (1 + X)(1+X+X^6) = 10100011$. After passing the station address check, the receiver then checks the complete 48 bit coded word for errors that may lie outside the station address field. The code generated by the $g(x) = 1+X^2+X^6+X^7$ is capable of correcting any 2 random errors in the 48 bit field or detecting any 3 errors in the 48 bit field. The code is used only for detection of errors. [Note the minimum hamming distance of a linear code is determined by the weight of the generator polynomial; in this case $g(x)$ has 4 terms; thus, weight 4.]

III.A. Probability of Erroneously Accepting a 48 Bit Word Due To a Data Inversion

Addressing this situation, first note that data inversions in the detected bit stream result in words with an error pattern of all 1's from the point of the data inversion to the end of the word or until a second data inversion might occur within the word. (A point of interest for linear codes is that the error pattern occurring in a code word adds linearly to any code word and hence analysis of the code properties may be conducted for any specific code word, such as the all zeros code word, with no loss of generality.)

Note that any data inversion occurring within the first 7 bits constituting the station address field will be detected by the station address verification logic. Furthermore, it is obvious that a data inversion in the last 7 bits of a message word will create an error pattern of $X^6+X^5+X^4+X^3+X^2+X+1$ which is not divisible by $g(x)$, since the degree of $g(x)$ is 7, one more than the error pattern.

Thus, it is of interest to determine whether $g(x)$ may divide any error pattern structured as

$$X^n + X^{n-1} + X^{n-2} + \dots + X^2 + X + 1 \qquad 7 \le n < 41$$

where each term between X^n and 1 is present.

For n an odd number (such as 11, 7, etc.) there are an even number of terms in the error pattern; hence, 1 is a root of these error patterns and $X + 1$ will evenly divide all error patterns with n equal to an odd number

$$\begin{array}{r l}
 & X^{n-1} + X^{n-3} + \dots + X^2 + 1 \\
X+1 \,\big) & X^n + X^{n-1} + X^{n-2} + X^{n-3} + \dots + X^2 + X + 1 \\
 & \underline{X^n + X^{n-1}} \\
 & \qquad\qquad \underline{X^{n-2} + X^{n-3}} \\
 & \qquad\qquad\qquad\qquad \underline{X^3 + X^2} \\
 & \qquad\qquad\qquad\qquad\qquad\qquad X + 1
\end{array}$$

The polynomial resulting consists of even powers, descending by orders of 2 in magnitude. It remains to be seen whether $1 + X + X^6$ will divide any such polynomial evenly.

Noticing that the polynomial has all even powers and if it also

$$X^{n-1} + X^{n-3} + X^{n-5} + \ldots + X^2 + 1$$

has an even number of terms (such as for n = 11, 15, 19, et.), then the the polynomial has 1 as a root and since $1 + X + X^6$ does not have 1 as a root, $1 + X + X^6$ will not divide it evenly. An example is shown below.

For a data inversion such that the error polynomial has terms from n = 19 to n = 0 we have

$$(X+1)(1+X+X^6)\,\big)\,\overline{X^{19}+X^{18}+X^{17}+X^{16}+\ldots+X^3+X^2+X+1}$$

First Note

$$\begin{array}{r l}
 & \underline{X^{18}+X^{16}+X^{14}+X^{12}+\ldots+X^2+1} \\
X+1\,\big) & X^{19}+X^{18}+X^{17}+X^{16}+\ldots+X^3+X^2+X+1 \\
 & \underline{X^{19}+X^{18}} \\
 & \qquad\quad \underline{X^{17}+X^{16}} \\
 & \qquad\qquad\qquad\qquad \underline{X^3+X^2} \\
 & \qquad\qquad\qquad\qquad\qquad\quad \underline{X+1}
\end{array}$$

and now will

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OF POOR QUALITY

$$
\begin{array}{r|l}
 & X^{12} + X^{10} + X^{8} + X^{7} + X^{5} + X^{3} + X^{2} + X \\
\hline
1+X+X^{6} & X^{18} + X^{16} + X^{14} + X^{12} + X^{10} + X^{8} + X^{6} + X^{4} + X^{2} + 1 \\
 & \underline{X^{18} + X^{13} + X^{12}} \\
 & \underline{X^{16} + X^{11} + X^{10}} \\
 & X^{14} + X^{13} + X^{11} + X^{8} + X^{6} + X^{4} + X^{2} + 1 \\
 & \underline{X^{14} + X^{9} + X^{8}} \\
 & \underline{X^{17} + X^{8} + X^{7}} \\
 & X^{11} + X^{9} + X^{8} + X^{7} + X^{6} + X^{4} + X^{2} + 1 \\
 & \underline{X^{11} + X^{9} + X^{6} + X^{5} + X^{4} + X^{3}} \\
 & X^{8} + X^{7} + X^{5} + X^{3} + X^{2} + 1 \\
 & \underline{X^{8} + X^{3} + X^{2}} \\
 & X^{7} + \quad + X^{5} + 1 \\
 & \underline{X^{7} + X^{2} + X} \\
 & X^{5} + X^{2} + X + 1 = \text{remainder.}
\end{array}
$$

The answer is no.

If the polynomial

$$X^{n-1} + X^{n-3} + X^{n-5} + \ldots + X^{4} + X^{2} + 1$$

has an odd number of terms (n = 9, 13, 17, ... etc.) then will $1+X+X^{6}$ divide it evenly?

This can be answered by determining whether there is a combination of terms which when multiplied by $1 + X + X^{5}$ will produce a set of terms $X^{4} + X^{2} + 1$ to cancel those in the polynomial sequence. Trying those candidates:

$$
\begin{aligned}
1(1+X+X^{6}) &= 1+X+X^{6} \\
X(1+X+X^{6}) &= X+X^{2}+X^{7} \\
X^{2}(1+X+X^{6}) &= X^{2}+X^{3}+X^{8} \\
X^{3}(1+X+X^{6}) &= X^{3}+X^{4}+X^{9} \\
X^{4}(1+X+X^{6}) &= X^{5}+X^{5}+X^{10}
\end{aligned}
$$

To produce terms $1+X^{2}+X^{4}$ with X and X^{3} absent is not possible.

For instance:

$$(1+X)(1+X+X^6) = 1+X^2+X^6+X^7$$

To produce the X^4 term requires additional multiplication by either X^3 or X^4. However, multiplication by X^3 produces X^3 which requires multiplication by X^2 to cancel the X^3 term. This produces an X^2 term which cancels the desired X^2 term and the result is unsatisfactory.

A similar disaster befalls us with respect to the X^4 possibility or using other combinations.

Thus, it is seen that g(x) will <u>not</u> divide any data inversion which results in an error pattern containing an even number of ones (n = odd).

Now consider the case where n is an even number and the data inversion error polynomial contains an odd number of terms:

$$X^n + X^{n-1} + X^{n-2} + X^{n-3} + \ldots + X^2 + X + 1$$

with n even, (and hence the polynomial has n + 1 terms which is an odd number).

For this case, 1 + X will never divide the error polynomial since 1 is not a root of any polynomial with binary coefficients and an odd number of terms.

If 1 + X won't divide the error polynomial, then g(x) will not divide the error polynomial; since 1 + X is a factor of g(x). An example is shown below:

$$\begin{array}{rl}
 & \qquad\quad X^{n-1} + X^{n-3} + \ldots + X \\ \cline{2-2}
X+1 & X^n + X^{n-1} + X^{n-2} + X^{n-3} + \ldots + X^2 + X + 1 \\
 & \underline{X^n + X^{n-1}\qquad\qquad\qquad} \\
 & \qquad\qquad X^{n-2} + X^{n-3} \underline{\qquad\quad} \quad \underline{X^2 + X\quad} \\
 & \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad 1 = \text{remainder,}
\end{array}$$

since n is an even number X + 1 divides by reducing the polynomial by two terms at a time which always leaves 1 as a remainder.

Naturally $1+X+X^6$ cannot divide the polynomial 1. Thus, g(x) will <u>not</u> divide any data inversion error polynomial with an odd number of ones (n = even). Hence g(x) will <u>never</u> <u>divide</u> <u>any</u> <u>command</u> <u>word</u> in which there is a single data inversion occurrence regardless of the point within the word where the data inversion occurs.

> *<u>Thus, a single data inversion alone will never cause false acceptance of a command word</u>.*

III.B. Probability of Erroneously Accepting a 48 Bit Word With a Data Inversion and a Random Error

The second case to be addressed concerns the probability that a data inversion coupled with a random error might occur in the same command word and possibly create a false acceptance of a command word.

The probability of a bit error occurring in the transponder detector has been experimentally measured using a breadboard prototype that has been stated as performing 'very nearly the same' as the actual production units. Assuming, for lack of other data, that this performance is typical, we note from the curve Figure 1 from NASA STD transponder design review Number 2, JPL Contract Number 954308, March 15, 1977 (as supplied by Warner Miller in his memo of September 11, 1981) that for 34.5 db input at 125 bps and a 100 Hz/Sec doppler the probability of a bit error is 6×10^{-6}. (This assumes a 35.5 db SNR at the diplexer input port and a loss of 1 db due to the diplexer.)

By verbal conversation between Mr. Dave Harris of NASA, MSFC and the Motorola transponder testing personnel, the combined error rates due to random decision bit errors and carrier cycle slips at the threshold SNR operating point is less than or at most equal to 10^{-5}. Thus, one may state

$$P(BER) + P\ (\text{cycle slip}) \cong 1 \times 10^{-5}\ .$$

It is prudent to consider several situations such as:

A. $P(BER) \simeq P(\text{cycle slip}) \simeq .5 \times 10^{-5}$

B. $P(BER) \approx .1 \times 10^{-5}$ and $P(\text{cycle slip}) \approx .9 \times 10^{-5}$
C. $P(BER) \approx .9 \times 10^{-5}$ and $P(\text{cycle slip}) \approx .1 \times 10^{-5}$

The probability of a random decision error and a data inversion occurring within the same command word may be calculated as follows:

$$\text{Let } P(BER) = B \quad \text{and } P(\text{cycle slip}) = P(CS).$$

The probability of a data inversion occurring in a command word in the 41 bits after the station address is:

$$P(\text{Data Inversion}) = \frac{41}{125} \times P(CS) .$$

The probability of a single random error occurring within the 41 bits of a command word after the station address is

$$P(BER) = 41B(1 - B)^{40} .$$

Thus, the probability of a false command word acceptance, P(FCWA), due to a random error and a data inversion occuring in the same word is

$$P(FCWA) = 13.448B(1 - B)^{41}P(CS) .$$

B	$P(CS)$	$P(FCWA)$
$.1 \times 10^{-5}$	$.9 \times 10^{-5}$	$\approx 1.21 \times 10^{-10}$
$.5 \times 10^{-5}$	$.5 \times 10^{-5}$	$\approx 3.36 \times 10^{-10}$
$.9 \times 10^{-5}$	$.1 \times 10^{-5}$	$\approx 1.21 \times 10^{-10}$

Thus, for each of the situations considered the probability of a false command word being accepted erroneously is greater than 10^{-9} and is within specification. It is noteworthy to realize that a single data inversion will always cause <u>rejection of a block</u> of data even in the face of random errors since the station addresses are all wrong after the occurrence of the inversion.

III.C. Probability of Erroneously Accepting a Block Containing a Data Inversion and a Random Error

Actually the only way in which a complete block of data can be erroneously accepted due to a data inversion and a random error occurrence is if the data inversion happens to occur twice within a single command word; thus, possibly creating an undetectable error pattern.

Since all error patterns due to data inversions located in the last 7 bits or first 7 bits of the 48 bit word are detectable, there is a 34/48 = .79167 chance a data inversion (when it does occur) would occur within these bounds.

The probability that a double inversion would occur within these bounds is

$$[(.79167)(P(\text{Data Inversion}))]^2$$

$$= [.79167\ (\frac{48}{125})\ (P(CS))]^2\ .$$

The worse case would occur for $P(CS) = 10^{-5}$ and the probability that a single command word would be accepted erroneously is

$$[(.79167)(\frac{48}{125})(10^{-5})]^2 = 9.2417 \times 10^{-12}$$

In a block containing N words, the probability of this occurrence is

$$N(9.2417 \times 10^{-12})\ .$$

Hence, for 256 command words in one block, the probability of a block containing an erroneous word being accepted due to data inversions is

$$2.366 \times 10^{-9}\ .$$

Although this figure is somewhat higher than 10^{-9}, it is for a complete block of data rather than for a single word, as the performance specification addresses.

SECTION IV

SUMMARY OF THE S-BAND SINGLE ACCESS SYSTEM ANALYSIS

This section is a summary of the analysis to determine the overall anticipated BER of the scientific data transmitted via the SSA system. The ST utilizes a concatenated coding scheme. The inner coding scheme is a 1/3 rate convolutional code with a Viterbi decoder and a Periodic Convolutional Interleaver (PCI) system with the 30 PN cover sequence. The Reed-Solomon (R/S) code with interleaving constitutes the outer coding scheme, thus allowing the SSA return link to be separated into an inner and outer channel (see Figure 2). To determine the overall probability of an error, first the probability of an error on the inner channel, $P_1(\varepsilon)$, was calculated, since this is the input error rate to the outer decoder. Once the input error probability had been established then the output error probability of the R/S decoder/deinterleaver, $P_2(\varepsilon)$, was determined. Having established both $P_1(\varepsilon)$ and $P_2(\varepsilon)$, the overall concatenated coding bit error rate, $P_T(\varepsilon)$ was bounded. The overall BER should be less than 1×10^{-7}.

The probability of error on the inner channel is dependent on several variables, two of which are the bit transition density and tape recorder. The maximum number of bits without a transition was determined to be 12 via the procedure outlined in Reference 10. In reference 2 it was determined that due to the input sequence required to produce the 12 bit sequence without a transition the average bit transition would be 2 transitions per 16 output symbols or 1 transition every 8 output symbols. Therefore, the SSA link will meet or exceed the transition density requirements of the TDRSS. The potential problem due to the tape recorder was discussed in Section II.A.1. The inner channel error rate was considered to be 1×10^{-4} to compensate for losses due to tape recorder reversal and multiple frame formats. Based on this value, the overall BER was found to be no more than 1×10^{-9}.

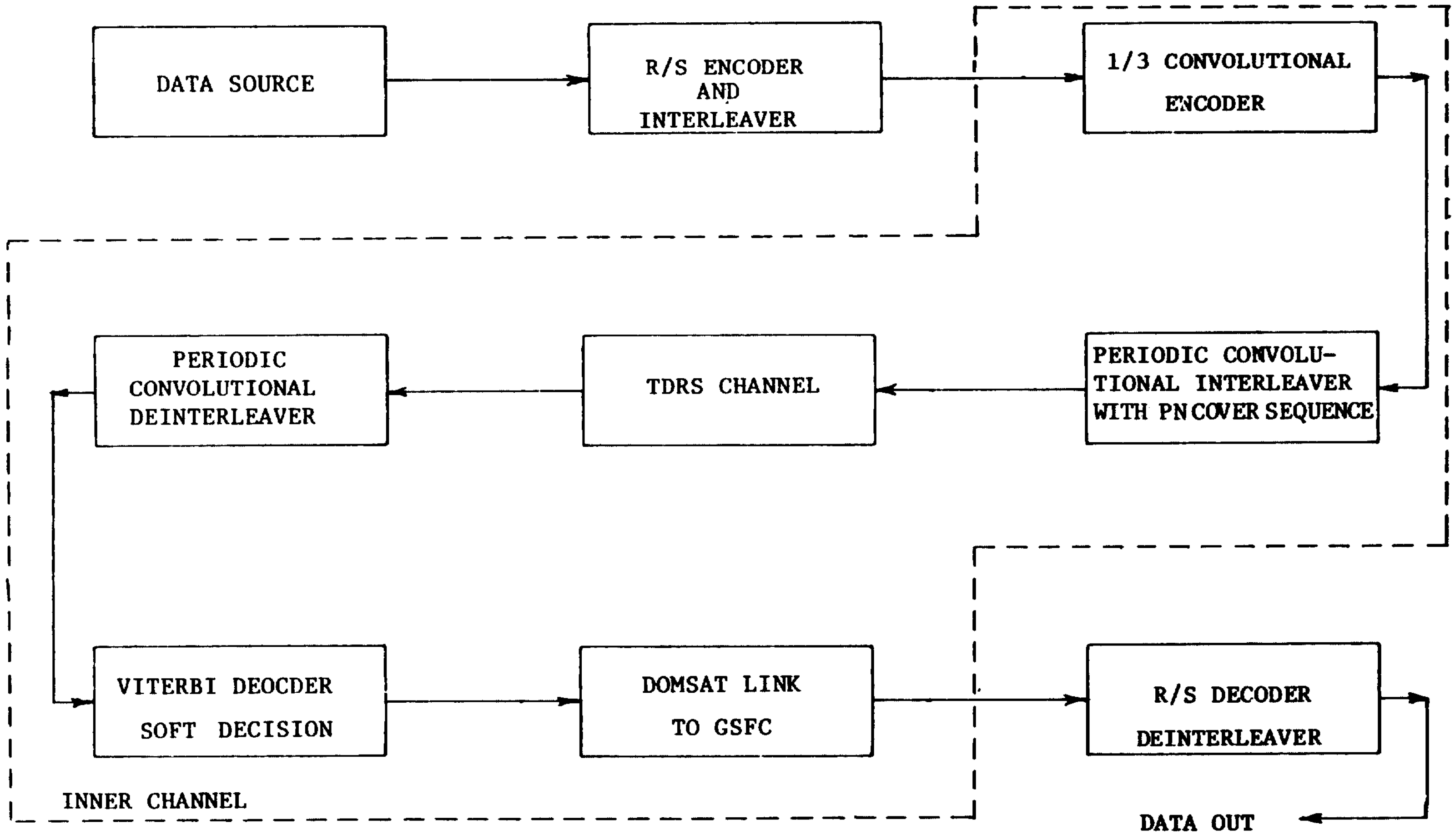

Figure 2. General ST/TDRSS Concatenated Coding Concept

But this estimate is misleading since the system susceptibility to synchronization loss is not accurately represented. A more realistic value was estimated to be no more than 1×10^{-7}, since then, the BER for the SSA link was determined to be less than or equal to 1×10^{-8} by Lockheed in Reference 10 supporting the estimated BER in Reference 2. In Reference 3, it was noted that if the data request WER is included as part of the SSA return link the upperbound on the BER must be increased to 2.5×10^{-8}. The data request WER was not considered in the SSA analysis presented in the interim report.

A potential problem concerning the synchronization strategy of the SSA 1.024 Mbps return link was recognized by Mr. Warner Miller of GSFC in the Spring of 1981. Since this potential problem was not addressed in the interim report, but was discussed in the June 1981 Monthly Report; it is presented below.

This problem concerns the possible loss of 3481 symbols if data inversion takes place, but actual synchronization loss does not take place. In this event, the remaining data in the deinterleaver frame of 3481 symbols will not look like a valid code word to the viterbi decoder and the error metric counters will accumulate large counts rapidly. The present synchronization strategy uses the error metrics from the Viterbi to adjudge the loss of deinterleaver synch and initiating the synch search. However, the present synch strategy will necessarily search 30 states for this particular code, resulting in approximately 120,000 symbols of data loss. This is detailed in a memorandum from Mr. W. Miller dated May 8, 1981.

If the data inversion occurs due to a PSK carrier demodulator cycle slip, the present synch strategy will recover in one or two states with 4000 to 8000 symbols lost, and no particular problem is exhibited. The probability of PSK carrier demodulator cycle slip is extremely low (see monthly report May 1, 1980 to May 31, 1980), being around 10^{-200} for moderate RFI; so this is seen as no problem in the system as it stands.

For heavy RFI periods, the cycle slip problem might be significant, but it is understood that the transmission of data is not to be allowed for the TDRSS users during periods of heavy RFI; thus, alleviating the problem altogether.

If data inversion occurs due to RFI which creates a bit synchronizer bit slip due to low transition density in the transmitted bit stream (see monthly report May 1, 1980 to May 31, 1980) then if no actual carrier cycle slip has occurred the resulting synch search will encompass 30 states and result in 120,000 symbols lost. For this case the average bit error rate would be $1.3563768.10^{-7}$ based on $1.024.10^{6}$ bits per second for 24 hours. However, the probability of RFI creating a bit synch loss is low, approximately 10^{-17}. Thus, one would expect no significant problem due to bit synch loss due to RFI.

In summary, the possibility of data loss due to data inversion which creates a loss of synch indication in the Viterbi decoder/deinterleaver loop does not seem to be significant.

There is another possibility of data loss which may occur. This is due to the situation where the Costas Loop in the ground station receiver is working with the IF output signal-to-noise ratio for either the I or Q channel.

In this situation there is a transmitted signal from the ST vehicle through TDRSS to the White Sands receiving station. Ignoring the RFI (which was discussed above) this configuration is addressed. The signal when received at the TDRSS is up converted from S Band to KU Band and transmitted to the ground station. At the ground station the KU Band signal is down converted to an Intermediate signal frequency (IF) at which time the signal-to-noise ratio is now that which was transmitted minus system losses and space loss (due to distance plus antenna gains of course).

The I and Q channels are now demodulated from IF to baseband by a Costa's Loop demodulator. This point in the system can create a data inversion without actual deinterleaver synch dropout. This occurs if the signal-to-noise ratio at the input to the Costas Loop is not strong enough. At this point, there is not on hand a set of specifications that allow an estimation of the expected SNR at the input to the Costa demodulator; thus, it is not feasible to predict whether or not the received SNR is going to be marginal.

Mr. Warner Miller has stated that experience with previous systems of this type data inversions due to this problem is more likely than due to other factors. If this is the case, then data loss due to data inversion could be a problem if the signal-to-noise ratio is not maintained at a sufficient level.

After considering the above points, the problem does not seem significantly probable to consider modifying the synch strategy for the Viterbi/deinterleaver configuration.

This feeling comes about from three points:

1. The interleaver in the flight equipment and the deinterleaver in the ground equipment have by-pass mode capability. In fact, it is only planned to use the interleaver during RFI or problem periods. (Mr. Warner Miller had initially pushed for this by-pass capability).
2. Calculations have shown that the probability of data inversion without synch dropout (due to RFI) is very very remote.
3. Unless calculations or experimental measurements show a marginal transmitted SNR from the ST vehicle resulting in marginal SNR input to the Costas Loop demodulator, it is very remote that a data inversion will occur out of the Costas Loop due only to normal channel perturbations with no RFI at all.

Point 1 is in itself enough to alleviate concern about the problem potential--the interleaver will not be in use, but a very small percentage of time. Data inversions without interleaving present no problem to the system.

The normal phase error of a Costas Loop is approximately zero mean gaussian in nature with variance approximately:

$$\sigma_o^2 = \frac{1}{Q} \left(\frac{1}{z} + \frac{1}{2z^2} \right)$$

z = SNR per bit

$Q = \frac{B_s}{B_L}$ (Ziemer & Tranter, "Principals of Communication," Page 341, or see "Telecommunication System Eng.," by Lindsey & Simmon)

B_s = Bandwidth of symbol data train $\approx 2.10^6$ Hertz.

B_L = Bandwidth of Costa's Loop Filter = 100 Hertz.

Thus,

$$\sigma_o^2 \approx \frac{1}{2.10^4} \left(\frac{1}{z} + \frac{1}{2z^2} \right)$$

If power SNR per bit at receiver is only 2 db, then $z \approx 1.58$ and

$$\sigma_o^2 \approx .5 \times 10^{-4} \left(\frac{1}{1.58} + \frac{1}{2(1.58)^2} \right) \approx 6 \times 10^{-5}$$

This is very low phase jitter variance, and very unlikely to cause a phase inversion to take place out of the Costas Loop. Thus, Point 3 seems to be remote in possibility.

SECTION V

RESULTS AND RECOMMENDATIONS

The analysis in Section II indicates the MA return link will provide an average BER of no more than 1.21×10^{-5} for real-time data and 1.4×10^{-5} for recorded data. However, the low link margin for the 32 Kbps real-time data may yield a higher BER for brief periods. Therefore, it is recommended that all 32 Kbps data be inspected for data BER requirements. Any data considered important and which must have a BER of no more than 4.1×10^{-5} should be routed to the engineering tape recorder, thereby receiving the benefits of the more reliable SSA system.

The effect of synchronization loss will cause a slight reduction in the expected BER. But the system should still provide a BER of less than the required 4.1 x 10 . Due to the effect of the bit slip rate on the overall BER, extreme caution should be used regarding any changes in testing procedures or redefinition of bit jitter.

The ST MA link should comply with the restriction placed on the system to avoid excessive self-interference. Since the ST employs a single return link (transmitter), the ST system is not effected by the ruling which prohibited the use of the TDRSS MA channel by both NOSS and XTE projects. However, it must be noted that concern has been expressed in Reference 11 with regards to the interference to other MA users caused by the EIRP of the ST when the HGA system is used to transmit 4 Kbps data rate. The amount of degradation is being analyzed, but the results are unknown by this investigator at this time.

A phase ambiguity problem does exist for the ST MA link. The phase ambiguity will be resolved by utilizing the TAC frame synchronizer unit. Hopefully, the automatic inversion mode of operation will be used. If not, it is strongly recommended that the automatic inversion mode be used to avoid unnecessary data loss during the time required to manually detect and correct a phase inversion.

The probability that a data inversion in the detected bit system will cause a phase acceptance of a command word is less than 1×10^{-9} and therefore is within specification.

The SSA return link will provide a BER of no more than 1×10^{-7}. In the interim report dated October 1980, it was recommended that the ST transmit a fixed data pattern to determine the actual system performance during heavy RFI periods. The purpose of such transmissions is to study the noise statistics on the channel and to ascertain the benefits and operational capabilities of the error correcting encoding. In a letter dated July, 1981, to Mr. Joe Thomas, EF22, MSFC, it was recommended that a simple frame synchronization pattern with appropriate frame ID count with all data bits to be alternate 1's and 0's be used for such a test, thus hielding the best conditions for holding bit synchronization during a noisy condition even with bursty errors. The frame synchronization ID will give a time tag to the transmission and the pattern of alternate 1's and 0's will be easy to detect and to analyze.

The objective of such a test is to achieve the following:

1. Study frequency and pattern of induced frame sync errors.
2. Determine frame synch dropout rate.
3. Determine the channel noise characteristics by analyzing the data stream's induced errors for frequency of errors, number of bursts, and burst lengths.
4. Determine the error growth rate and the error decay rate as the transition to and from the heavy RFI period is made.

This experiment could be performed by preloading the on board tape recorders with the desired patterns, as per Mr. Joe Thomas' suggestion. The data reduction could be handled by Marshall Space Flight Center (MSFC) and the analysis would be conducted by MSFC research personnel in conjunction with Mississippi State University research personnel.

Although a similar test is to be conducted under NASA NEEDS program, it is a ground to TDRSS to ground test and there are several disadvantages to this test as far as the ST needs are concerned:

1. The error correcting coding design of the ST would not be tested.
2. The actual RF channel from space vehicle to space vehicle would not be tested and this channel is very different from ground to space vehicle channel.
3. The power levels will be different.
4. The antenna control system will be very different and hence beam alignments much different. This effects possible system loss differences by 0.5 to 1.0 dB.

It is recommended that transmission from ST to TDRSS to the appropriate ground station be conducted through a period of heavy RFI. Transmission should be initiated during moderate conditions if not during light conditions.

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APPENDIX A

MONTHLY REPORT JUNE 1, 1981 - JUNE 3, 1981
(CONTAINS ANNUAL SUMMARY REPORT SEPTEMBER 30, 1980 - JULY 1, 1981)

ANALYSIS OF SPACE TELESCOPE DATA COLLECTION SYSTEM

Monthly Report
Covering the Period
June 1, 1981 - June 30, 1981
Containing An
Annual Summary Covering the Period
September 1, 1980 - July 1, 1981

Submitted to:

Contract Monitor: Mr. Joe Thomas, EF22
George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center, Alabama
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Submitted by:

Mississippi State University
Engineering and Industrial Research Station
Department of Electrical Engineering
Mississippi State, Mississippi
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Principal Investigator: Frank Ingels
Associate Investigator: W. O. Schoggen
Contract No. NAS8-33570

LIST OF SYMBOLS

BER	Bit Error Rate
BCU	Bus Coupler Unit
BPSK	Bi-phase Shift Keying
BSR	Bit Slip Rate
CCIR	International Radio Consultative Committee
CDI	Command Detector Interface
C.E.	Convolutional Encoder
CU/SDF	Control Unit/Science Data Formatter
DIU	Data Interface Unit
DMS	Data Management Subsystem
DMU	Data Management Unit
DOMSAT	Domestic Satellite System
E	Number of Correctable Symbol Errors per R/S Block
EIRP	Effective Isotropic Radiated Power
ESTR	Engineering/Science Tape Recorders
FGS	Fine Guidance Sensor
GSFC	Goddard Space Flight Center
HGA	High Gain Antenna
Hz	Hertz
I	In-phase
IC	Integrated Circuits
I&C	Instrumentation and Communications Subsystem
J	Number of Bits Per R/S Symbol

LIST OF SYMBOLS (Continued)

Kbps	Kilobits Per Second
LGA	Low Gain Antenna
MA	Multiple Access
MDPS	Megabits Per Second
MDB	Multiplexed Data Bus
MHz	Megahertz
MSB	Most Significant Bit
N_{max}	Maximum Number of Output Symbols of the Convolutional Encoder w/o a Transition
NASCOM	NASA Communications Network
NRZ-L	Non-Return-to-Zero-Level
NSSC-I	NASA Standard Spacecraft Computer, Model I
OTA	Optical Telescope Assembly
$P_1(E)$	The R/S Input Symbol Error Probability
$P_2(e)$	The Output Probability of the R/S Decoder/Deinterleaver
$P_b(e)$	Probability of a Bit Error Occurring on the Inner Channel
$P_{R/S}(E)$	Symbol Error Probability Out of the R/S Decoder/ Deinterleaver
$P_T(e)$	Overall Bit Error Probability
$P_{VD}(E)$	Bit Error Rate Out of the Viterbi Decoder
$P_{WS}(E)$	Average Bit Error Rate of the TDRSS Link
PCI	Periodic Convolutional Interleaver
PCU	Power Control Unit
PIT	Processor Interface Table

LIST OF SYMBOLS (Continued)

PN	Pseudo Noise
PSK	Phase Shift Key
Q	Quadrature-phase
RF	Radio Frequency
RFI	Radio Frequency Interface
RM	Remote Module, Resource Monitor
R/S	Reed-Solomon
SDF	Science Data Formatter
SI	Scientific Instrument
SI C&DH	SI Control and Data Handling (Subsystem)
SNR	Signal to Noise Ratio
SSA	S-band Single Access
SSM	Support Systems Module
ST	Space Telescope Orbiting Observatory
STINT	Standard Interface for Computer
STOCC	Space Telescope Operations Control Center (at GSFC)
ST Sci	Space Telescope Science Institute Contractor
T	Interval of Heavy RFI
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
VCO	Voltage Control Oscillator

ANALYSIS OF SPACE TELESCOPE DATA COLLECTION SYSTEM

Summary

Last August 1980 an interim final report was submitted to the contracting agency. That report covered all items of the work statement EXHIBIT "A" for NAS8-33570. The monthly report August 31, 1980 yields a short summary of this interim final report. Interested readers may wish to read the interim final report itself. The next phase of the contract NAS8-33570 was detailed in the work statement EXHIBIT "B", modification number 4 for NAS8-33570, effective starting date February 1, 1981 and terminating January 31, 1982. The scope of work is detailed below with additions from the EXHIBIT "A" work statement identified by an asterisk (*).

TASKS:

1. Analysis of the effects of frame synchronization loss.
2. System parameter analysis pursuant to encoding/decoding, interleaving/de-interleaving, and spectrum spreading to meet flux density requirements.

*3. Analysis of requirements for a very low bit error rate (BER) for engineering data.

4. Analysis and recommendations for various coding and communication techniques as follows:
    (a) Coding and communication of scientific data at the instrument.
    (b) Coding and interleaving data in the central management system.

5. Evaluate the overall impact of frame synchronization loss effect on total data loss pursuant to recovery from an error in decoding as applied to the PN sequence and de-interleaving.

*6. Investigate methods to improve science and engineering data error control encoding to improve the error characteristics through techniques for implementing the length of code to be used, and practicality of the various types of decodings.

The tasks 1,2,4, and 5 have been addressed in the previous interim final report of August 1980. The impact of these tasks (1,2,4 and 5) on the engineering data link for the space telescope system will be addressed in the duration of this contract, a review of work to date is presented below. An analysis of the MA link that is used for transmission of the engineering data has shown that less than a ldb link margin is possible for some circumstances. (See the April 1981 and May 1981 monthly reports and attachment 1 this report). This analysis is supported by a computer simulation program, CLASS, operated by GSFC which also points out possibilities of less than ldb margins for special circumstances.

Margins this low raise concern that less than 10^{-5} BER will be achieved for some engineering data transmissions. Thus one is motivated to seek a higher reliability path. Inspection of Figure 1 will show the possible transmission paths for the engineering data, all of which is sent via the MA link with the exception of tape recorded data which is sent via the SSA link.

The MA system is utilized to transmit real-time engineering data at 0.5, 4.0, 8.0 or 32.0 KBps and science data simultaneously at 4.0

Kbps. Tape recorded data is played back at the 1.024 Mbps data rate only and sent via SSA link.

Except for the 0.5 Kbps data rate, the data are transmitted to the TDRSS utilizing the transmitted portion of the transponder via the high gain antenna (HGA) system. The 0.5 Kbps data rate is transmitted in the same way except via either the HGA or the low gain antenna (LGA) system.

The MA return link utilizes two simultaneous, independent channels employing spread system techniques. Each channel is 1/2 convolutionally encoded and modulo two added to a PN code prior to modulating quadrature phases of a 2287.5 MHz 5 watt RF carrier.

Either the I or Q channel may be used to transmit the engineering data at one of the above rates or both channels at the same rate. However only the I channel may be used to transmit the 4.0 Kbps science data.

The formatting of the data for the MA link is accomplished in the support system module (SSM) where it is collected, recorded and/or transmitted to the STDCC.* Data originating in the ST are grouped into two categories, engineering data and science data. Engineering data contains information on the performance and functorial operation of the ST elements.

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*Refer to the List of Symbols.

Engineering data from the Scientific Instruments (SI) and the SI C&DH are collected by the CU/SDR and routed to the DIU as a composite data stream.

Engineering data is routed to the Data Management Unit (DMU) via DIU. The SSM and the Optical Telescope Assembly (OTA) engineering data are combined with the SI and the SI C&DH engineering data to form the composite ST engineering data rates of 0.5, 4.0, 8.0 or 32 Kbps.

The DMU arranges the data into major frames which consist of 120 or 20 minor frames. Each minor frame contains either 250 or 125 eight bit words and a 24 bit frame synchronization word. The DMU is capable of collecting and formatting the data in one of the five formats; three of which are programmable by software control and two of which are fixed by hardware control. The data are transferred to the Multiple Access (MA) system for real-time transmittal to the STOCC or to the engineering tape recorder for later transmission. The 0.5 Kbps data rate is utilized for real-time transmission only.

The following discussion addresses various tasks.

TASK 2:

To achieve an understanding of the error rates possible on engineering data transmissions each piece of the system should be inspected. The system is to be considered as three main modes:

1. Tape Recorded Data (played back over SSA Link)
2. Data Transmitted Over the MA Link at 0.5, 4.0 and 8.0 Kbps
3. Data Transmitted Over the MA Link at 32 Kbps.

MODE 1:

The data recorded on the engineering tape recroder is never played back over the MA Transmitter Link. This data is always played back over the SSA Link with differential encoding and rate 1/3 convolutional encoding with a PN cover sequence and channel interleaving.

The SSA link will most likely provide a 10^{-7} BER if R/S encoding is also used, but as we see for engineering data the R/S coding is not used. Thus we expect perhaps 10^{-6} BER from the SSA Link under the most severe circumstances, with the exception of the Heavy RFI environment in which data will not be transmitted.

The error rates for the tape recorders has been established as less than 10^{-6} BER, perhaps 10^{-7}; so we estimate the average BER for engineering data that is tape recorded and played back over the SSA Link to be about 10^{-6}.

MODE 2:

Engineering and science data which under go real time transmission at 0.5, 4.0 and 8.0 Kbps will be sent over the MA link which does not have differential encoding and which has only rate 1/2 convolutional encoding and no interleaving rather than the 1/3 convolutional encoding of the SSA link.

The average BER of the MA Link is thus expected to be substantially less than the SSA link. In fact the MA Link is designed to 10^{-5} BER with some link margin (typically 5 db).

The expected BER for these data rates is 10^{-5} BER.

MODE 3:

Engineering and science data which under go real time transmission at 32.0 Kbps will suffer more degradation than the lower frequencies. Analysis has shown periods of RFI and worst case system parameters that will likely result in less than 1 db Link margin for the 32.- Kbps rate. This leads to concern for engineering and science data that might suffer too high a data loss if the BER slips to 10^{-4} or so for brief periods.

We also might voice concern for the frame synchronization and bit synchronization of the system for this case.

TASK 3 and 5:

In the event of frame synchronization loss it is expected that two frames will be lost at a minimum. The frame construction consists of 20 to 120 minor frames per major frame with each minor frame containing 125 to 250 eight bit words and a 24 bit frame synchronization word. Thus if we were to reacquire frame synchronization within two minor frames we would lose 1008 bits minimum and 2008 bits maximum. At a data rate of 32 Kbps for a 20 hour period this would yield an average bit error rate of $BER=17x10^{-6}$ or $1.7x10^{-5}$ for the 250 word minor frame. This one frame synchronization loss in 20 hours of transmission will create an effective BER of $1.7.10^{-5}$ for the longer minor frames.

Data losses from any other sources will compound this figure and due to the poor link margins for the 32 Kbps transmission rate it is likely that higher error rates than 10^{-5} BER will be experienced.

TASK 3 and 5:

It is recommended that any data to be transmitted via the MA link be inspected for data BER requirements. If any of the data will be considered important data and must have a lower BER than 10^{-5} then this data should be routed to the engineering tape recorder. Thus this data would receive the benefits of rate 1/3 convolutional encoding (equivalent to several db gain) and interleaving as opposed to simply rate 1/2 convolutional encoding.

In particular the OTA focus and optical parameters might merit the tape recording considerations.

ITEMS REVIEWED OTHER THAN THE ABOVE TASKS:

Several other items have been looked at by request of MSFC. These items are:

1. "What problems does Space Telescope face concerning Self-Interference on the MA return link service of the TDRSS?"

This question arose from Mr. Harvey Golden through Mr. Joe Thomas and involves a legitimate concern which actually arose due to a similar problem which exists in a different vehicle and program.

As a result of possible self-interference a proposed utilization of the MA system by NOSS and XTE projects has been rejected.

The self-interference problem has always existed on the MA system due to the fact that all MA users operate at the same frequency and polarization. These simultaneous transmissions are discriminated by unique PN codes and antenna beam pointing. The current TDRSS design provides a 1-db margin against MA system self-interference.

The primary reason for the rejection of both the NOSS and XTE proposed design was their proposed utilization of more than one MA return link from the same platform. To overcome the self-generated interference between multi-transmitters on the same platform requires increased power resulting in increased self-interference to other MA users above the 1-db design margin. Therefore to provide the best service to the majority of users the Networks Directorate must control the total amount of user power in the MA return band. Thus the network directorate has restricted the use of the MA return service to a single link from each platform. This does not however prohibit the user of quadriphase types of modulation.

Since the ST MA return system will employ only a single return link (transmitter), the ST system does not have a problem with the self-interference characteristics of the MA return link system similar to that which resulted in the rejection of the NOSS and XTE proposed designs. This information was given to J. Thomas, MSFC, by phone on November 6, 1980. During the last trip to MSFC, November 10, 1980, the same information was discussed with H. Golden and he agreed with the conclusion that ST does not have a problem in this respect. These results were also confirmed by D. Herr, G.S.F.C., by phone in November.

2. The following question was posed during the December 1980 time period:

> "Does the 4KHz Science and Engineering SSA Data Link for the Space Telescope System Face a Phase Ambiguity Problem for Decoding at White Sands or Elsewhere?"

The answer to this questions is NO.

The reason lies in the use of a Differential Encoder through which the Science Data and the 4KHz, 8 KHz and 32 KHz Engineering Data stream must pass to be transmitted on the SSA Return Link.

Reference is made to the monthly report for January 1, 1980 to January 31, 1980 which diagrams the SSA Link, Figure 4 of that report and Figure 5 of that report.

However it is pertinent to point out that the MA Return Link, Figure 3 of the above referenced report, does not contain a Differential Encoder and hence data transmitted over the MA Link will face a phase abmiguity problem. Note is made of the statement in the TDRSS users guide, revision 4 page 3-35, paragraph 3.3.3.1.e. Each MA data channel signal format for the the TDRSS ground interface will be NRZ-L. <u>TDRSS will resolve data phase ambiguity for users with differentially encoded data formats</u>. The Space Telescope does not have differentially encoded data format for engineering data over the MA Link. Thus the MA link will most likely exhibit phase ambiguity at one time or another.

3. Several telephone conversations were held with Mr. Joe Thomas of NASA/MSFC in February 1981 regarding two questions concerning the space telescope communications links. These questions are paraphrased below:

A. The MA communications link has a potential phase ambiguity of received data due to the fact that NRZ-L data is transmitted via a PSK modulated link.

What is the nature of the ground stations reaction to an incoming data stream? That is does it recognize an inverted data stream and if so what action does it take?

B. The tape recorded data is up converted if the data to be recorded is the 4 or 8 Kbps data rate.

How is the ground station configured to deal with the incoming data stream which may be up converted 4 or 8 Kbps data played back in reverse at a 1.024 Mbps rate?

Mr. Steve Tompkins (301+344-8845) of NASA/GSFC was contacted with regards these questions.

Addressing question number 1:

The ground station contains a standard Telemetry Acquisition Control (TAC) frame synchronizer unit which has the ability to automatically detect an inverted frame synch word. Thus, if the data stream on the MA link is output from the bit synchronizer in an inverted mode the frame synchronizer will detect this fact. The unit does have the capability of automatically inverting the data stream or of simply indicating the inverted condition by an indicator light on the front panel.

The actual operational mode (automatic inversion of the inverted data stream or simply indication of the condition on the front panel) will be determined by ground station personnel.

Addressing question number 2:

The up converted data which is received at the ground station in reverse order and at a 1.024 Mbps rate will be down converted (the eight bit pattern for a "1" and the eight bit pattern for a "0" will be searched for by a pattern recognizer and the incoming data stream will be reduced by a factor of 8 to the original data stream length) at the ground station. This can be accomplished without frame synch acquisition.

After down conversion the reverse synch pattern which is part of the original data will be searched for and locked on at the ground station.

A fair question is how the ground stations will recognize whether the incoming data stream at 1.024 Mbps needs down converting or not? (Remember that the 1.024 Mbps engineering data stream is recorded directly with no up conversion).

The answer is rather nebulous.

In theory, the ground station operator knows the order in which data was tape recorded and thus knows which data rate was originally used, thus, knowing when to down convert what data.

Remembering the tape recorder has gaps in the output and mandatory synch patterns before and after the data (See monthly report for November 1979 for a review of data recording procedure) whenever the data rate is changed, the operator should have time to change the ground station logic configured in when these gaps occur.

It is possible however to incur data loss due to an error in the recording log as to what rates are recorded when.

It is recommended that the MA system frame synch be operated in the mode which allows automatic detection and inversion of inverted data stream output from the bit synch.

It is also recommended that the exact procedure for handling tape recorded data including change over of data rates be detailed in a memo from the GSFC personnel or contractor personnel who know these procedures.

Mr. Steve Tompkins of NASA Goddard (301/344-8845) was contacted by telephone once again (March 25, 1981) to determine if any change in the TAC frame synchronizer had occurred.

He assures us that the TAC frame synchronizer (being built by Ford Aerospace) does contain the capability of detecting normal and inverted frame synchronization patterns.

It, the frame synchronizer, has 4 basic modes three of which are:

1. No recognition of inverted synchronization pattern
2. Recognition of inverted synchronization pattern and immediate inversions of data stream so as to output normal (noninverted) data

3. Recognition of inverted synchronization pattern and standby for command to inverted data. This mode also will wait for 2 successive inverted frame synchronization patterns before acting.

These states are transmitted to the TAC computer units via a 2-bit status word from the frame synchronizer to the TAC computer.

Ford Aerospace built this same unit for a previous program and no plans for alteration have been made.

Of course, the main question is whether the NASA/GODDARD personnel plan to utilize the capability inherent in the TAC systems. To date I have not found anyone who can answer this question.

A telephone conversation with Mr. Earl Maynard (NASA/Huntsville) was held on March 25, 1981 during which time the above information was relayed to Mr. Maynard.

A request was made for Mr. Maynard to relay the above information to Mr. Joe Thomas who was unavailable at that time.

It was suggested that perhaps Mr. Maynard should call Mr. Tompkins to see who we might contact at NASA/Goddard concerning use of the TAC information. Additionally Mr. Tompkins was requested to send letters to Ingels and Thomas confirming the above information.

A copy of this letter has been received on April 8, 1981 by Frank Ingels. This letter confirms the above remarks.

Mr. Steve Tompkins of NASA Goddard (301/344-8845) was contacted by telephone once again (March 25, 1981) to determine if any change in the TAC frame synchronizer had occurred.

Mr. Tompkins stated that the Hardware Design Committee had met this month and that the capability for 4 modes of operation within the frame synchronizer has definitely been chosen.

These four modes are detailed in a letter to Mr. Joe Thomas of NASA/MSFC and Dr. Frank Ingels of MSU from Mr. Steve Tompkins. The letter is dated April 4, 1981.

Although the technical capability of operating in mode C is to be provided it is not absolutely certain the the Operational Committee will choose to use this mode all the time. However, it si certainly the most likely mode to be chosen and it is Mr. Tompkins opinion that mode C will be used all of the time.

Further conversation was held concerning the link margin for the MA link using engineering data.

MSU has estimated a worse case link margin of 0.1 db while the worst case link margin indicated by the computer simulation system called Class is predicted to be 1.2 db. Both worst case figures occur while using a 32 Kbps data rate.

Mr. Tompkins is sending a set of computer printouts to Dr. Ingels for review.

4. A telephone conversation with Mr. Warner Miller of GSFC on June 8, 1981, discussed a potential problem for the Space Telescope 1.024 Mbps data channel that was recognized by Mr. Miller. This problem concerns the possible loss of 3481 symbols if data inversion

takes place, but actual synchronization loss does not take place. In this event, the remaining data in the deinterleaver frame of 3481 symbols will not look like a valid code word to the Viterbi decoder and the error metric counters will accumulate large counts rapidly. The present synchronization strategy uses the error metrics from the Viterbi to adjudge the loss of deinterleaver synch and initiating the synch search. However the present synch strategy will necessarily search 30 states for this particular code, resulting in approximately 120,000 symbols of data loss. This is detailed in a memorandum from Mr. W. Miller dated May 8, 1981.

If the data inversion occurs due to a PSK carrier demodulator cycle slip, the present synch strategy will recover in one or two states with 4000 to 8000 symbols lost, and no particular problem is exhibited. The probability of PSK carrier demodulator cycle slip is extremely low (see monthly report May 1, 1980 to May 31, 1980), being around 10^{-200} for moderate RFI; so this is seen as no problem in the system as it stands.

For heavy RFI periods, the cycle slip problem might be significant, but it is my understanding that the transmission of data is not to be allowed for the TDRSS users during periods of heavy RFI; thus, alleviating the problem altogether.

If data inversion occurs due to RFI which creates a bit synchronizer bit slip due to low transition density in the transmitted bit stream (see monthly report May 1, 1980 to May 31, 1980) then if no actual carrier cycle slip has occurred the resulting synch search will encompass 30 states and result in 120,000 symbols lost.

For this case the average bit error rate would be $1.3563768.10^{-7}$ based on $1.024.10^{6}$ bits per second for 24 hours. However, the probability of RFI creating a bit synch loss is low, approximately 10^{-17}. Thus, we would expect no significant problem due to bit synch loss due to RFI.

In summary, the possibility of data loss due to data inversion which creates a loss of synch indication in the Viterbi decoder/deinterleaver loop does not seem to be significant.

There is another possibility of data loss which may occur. This is due to the situation where the Costa's Loop in the ground station receiver is working with the IF output signal-to-noise ratio for either the 1 or Q channel.

In this situation we have a transmitted signal-to-noise ratio from the ST vehicle through TDRSS to the White Sands receiving station. Ignoring the RFI (which we have discussed above) lets look at this configuration. The signal when received at the TDRSS is up converted to an Intermediate signal frequency (IF) at which time the signal-to-noise ratio is now that which was transmitted minus system losses and space loss (due to distance plus antenna gains of course).

The I and Q channels are now demodulated from IF to baseband by a Costa's Loop demodulator. This point in the system can create a data inversion without actual deinterleaver synch dropout. This occurs if the signal-to-noise ratio at the input to the Costa's Loop is not strong enough. At this point, I do not have a set of specifications that allow an estimation of the expected SNR at the input to the Costa's demodulator; thus, I am unable to predict whether the received SNR is going to be marginal.

Mr. Warner Miller has stated that experience with previous systems of this type data inversions due to this problem is more likely than due to other factors. If this is the case, then data loss due to data inversion could be a problem if the signal-to-noise is not maintained at a sufficient level.

After considering the above points, the problem does not seem significantly probable to consider modifying the synch strategy for the Viterbi/deinterleaver configuration.

This feeling comes about from three points:

1. The interleaver in the flight equipment and the deinterleaver in the gound equipment have by-pass mode capability. In fact, it is only planned to use the interleaver during RFI or problem periods. (Mr. Warner Miller had initially pushed for this by-pass capability, I think).
2. Calculations have shown that the probability of data inversion without synch dropout (due to RFI) is very remote.
3. Unless calculations or experimental measurements show a marginal transmitted SNR from the ST vehicle resulting in marginal SNR input to the Costa's Loop demodulator, I would feel it very remote that a data inversion will occur out of the Costa's Loop due only to normal channel perturbations with no RFI at all.

Point 1 is in itself enough to alleviate concern about the problem potential--the interleaver will not be in use, but a very small percentage of time. Data inversions without interleaving present no problem to the system.

The normal phase error of a Costa's Loop is approximately zero mean gaussian in nature with variance approximately:

$$\sigma_o^2 = \frac{1}{Q} \left(\frac{1}{z} + \frac{1}{2z^2} \right)$$

$z \doteq$ SNR per bit

$Q = \frac{B_s}{B_L}$ (Ziemer & Tranter, "Principals of Communication," Page 341, or see "Telecommunication System Eng." by Lindsey & Simmon)

B_s = Bandwidth of symbol data train $\doteq$ 2.10^6 Hertz

B_L = Bandwidth of Costa's Loop Filter = 100 Hertz.

Thus,

$$\sigma_o^2 \doteq \frac{1}{2.10^4} \left(\frac{1}{z} + \frac{1}{2z^2} \right)$$

If power SNR per bit at receiver is only 2 db, then $z \doteq 1.58$ and

$$\sigma_o^2 \doteq .5 \; 10^{-4} \left(\frac{1}{1.58} + \frac{1}{2(1.58)^2} \right) \doteq 6.10^{-5}$$

This is very low phase jitter variance, and very unlikely to cause a phase inversion to take place out of the Costa's Loop. Thus, Point 3 seems to be remote in possibility.

During the recent discussions with Mr. Warner Miller, the NEEDS program was brought up. This program(NASA End-to-End Data System) will transmit a data sequence from the ground in Europe (Munich or Spain) through the TDRSS to the ground station in the USA. The purpose of this equipment is to study the RFI problem and the coding designs which have been implemented to counter the RFI.

5. In the year 1980, Interim Final Report, October 1980, page 78, I recommended to MSFC personnel that they consider an experiment that transmits a known data sequence from the ST vehicle to White Sands via TDRSS during heavy RFI periods so that we may study the effects of RFI on the encoded data and to ascertain how the coding is performing.

The NEEDS project is very similar except that the transmission to TDRSS is from a ground station rather than from ST. NASA/MSFC should consider a ST data Format sequence transmission using the NEEDS project as a preliminary test and study. The RTOPS number is 5066156.

6. A table, Table 1, summarizing the TDRSS EIRP requirements for the MA return link as we can best determine is attached. It would be appreciated if any updating of this table would be made known to these investigators.

TABLE

TDRSS EIRP REQUIREMENTS FOR
THE MA RETURN LINK

Assumed information (uncoded data rate = $5x10^4$ bps

Coded (1/2 rate) data RF channel rate = 10^5 bps

Data Group 1, Modes 1 & 2.

	January 1980
Uncoded required	27.59 dBw
Rate 1/2 coded required EIRP	22.39 dBw
Achievable data rate without coding. dB (relative to 1b/sec)	19.4 + EIRP
Achievable data rate with rate 1/2 coding (db relative to 1b/sec)	24.6 + EIRP

NOTE: Coding rate 1/2 assumed (5.2) dB gain hence requiring less EIRP

EXAMPLE: If rate = $5x10^4$ bps 10 log $5x10^4$ = 46.99 + EIRP

thus. EIRP required = 46.99 - 19.4 = 27.59 dbw

TDRSS users guide revision 4. January 1980. page 3-21.

ATTACHMENT 1

MA LINK MARGIN ANALYSIS

In an attempt to describe the probable operating characteristics of the Space Telescope Engineering Communication System (in particular the MA Link) a discussion of the Space Telescope/TDRSS/White Sands (ST, TDRSS, WS) link is presented for both the most likely case of non-RFI conditions and for bursty conditions.

The TDRSS channel is designed originally to provide an Average BER = 10^{-5} with E_b/N_o (bit energy-to-noise ratio).

$$E_b/N_o = \frac{P_{rec}}{N_o} - 10 \log R+Y .$$

where

$$\frac{P_{rec}}{N_o} = EIRP + L_S + L_p + L_0 + (G/T) - 10 \log(K)$$

$$EIRP = EIRP + L_S + L_p + L_0 + (G/T) - 10 \log(K)$$

L_p = polarization loss. (in dB)

L_s = space loss in (dB)

$L\theta$ = degradation in pointing (pointing losses)dB

G/T = User receiving system to thermal noise temperature.

EIRP = 27.59-.5 = 27.09 dB

L_s = 192.2 dB

L_p = .5

L_θ = 0 dB

TDRSS TO ST MA FORWARD LINK

The MA forward link command information from the TDRSS is a suppressed -Carrier, spread spectrum, quadriphase signal with the command data at 125 bits per second modulo 2 added asynchronously to a short pseudonoise (PN) spreading code on the "in phase I' signal.

ST TO TDRSS MA RETURN LINK

The MA system utilizes two simultaneous independent chanels employing spread spectrum techniques for transmission of various combinations of real time Science and Engineering data.

Each channel is 1/2 rate convolutionally encoded and asynchronously modulo 2 added to the unique PN gold code, assigned to ST, prior to modulating quadrature phases of a 2287.7 MHz, 5 watt RF carrier. This signal using staggered quadraphase-phase shift keyed (SQPSK) modulation is transmitted via either the high gain or low gain antenna. Engineering data may be transmitted on either the in phase (I) or quadrature phase (Q) channel at one of the data rates or on both channels simultaneously at the same rate.

The MA channel codes uses a rate 1/2 constraint length convolutional code.

ENGINEERING DATA FORMATS

There are five engineering telemetry formats being provided to obtain ST information, these are summarized as follows.

(1) Basic programmable format (4 or 8 Kbps rate)

(2) 500 bps fixed format

(3) 4 Kbps fixed format

(4) 500 and 1000 bps programmable format

(5) 32 Kbps programmable diagnostic format

On the ground the telemetry frame sync pattern (the first 24 bits of the composite telemetry frame) will be used to decommutate the composite data. The maximum VER for the downlink at the ground demultiplexer input shall be 10^{-5} in order to obtain the required telemetry channel performance.

In the case of Engineering data the RF return link performance (including all contributions of the TDRSS) is a maximum bit error rate of 10^{-5} for the ST telemetry data through TDRSS.

The transmitter power for the MA transponder is specified as 5.36 watts ± dB (direct output) over the flight temp range, or (7.3 dBw).

The TDRSS channel has been designed originally to provide an average $BER = 10^{-5}$ with $(E_b/N_0)_I = 3.00$ dB $(E_b/N_0)_I$ as the SNR of the input to the Viterbi Decoder.

The MA High Gain Antenna (HGA) has a net gain of 15.239 dBw. (including possible pointing losses which result in a EIRP equivalent to 22.53 dBw ($10 \log_{10} 5.36$ watts + 15.239 dbw)

In an 80 minute orbit, approximately 20 minutes will be allotted for ST to transmit to TDRSS during 68 minutes look time of availability.

RFI LOSS ESTIMATES

RFI Situation	Eq. Loss.
(a) 100% of the transmission time	.7 dB
(b) 2 - 3 minutes of allotted transmission time	2-5 dB
(c) 1 minute of allotted transmission time	≥ 5 dB

A transmission during situation C is not allowed. This leaves situation A (a predominately random error channel due to AWGN on a space to space link) and situation B (a mixed bag of random errors and some bursts due to RFI).

With an EIRP of 22.53 dbw and rate 1/2 convolutional encoding the system margin will be .14 dbw. This arises from the fact that TDRSS requires 22.39 dbw to guarantee a 10^{-5} BER using rate 1/2 convolutional encoding.

Thus the Link Margin is

$$22.53 \text{ dbw} - 22.39 \text{ dbw} = .14 \text{ dbw}.$$

Reference is also made to the CLASS simulation program of GSFC.