PROCEEDINGS
OF
THE EIGHTEENTH INTERNATIONAL SYMPOSIUM
ON
SPACE TECHNOLOGY
AND
SCIENCE

KAGOSHIMA

1992

The Experiment of CCSDS Packet Telemetry Using A Highly Elliptical Orbit Satellite "HITEN"

Tadashi TAKANO*, Takahiro YAMADA*, Koshiro SHUTO*,
Toshiyuki TANAKA and Katherine I. MOYD*****

Abstract

This paper describes the outline of the telemetry scheme proposed by the Consultative Committee of Space Data Systems (CCSDS), and the on-orbit experiment which was carried out to show the applicability of the CCSDS packet telemetry scheme using the Japan's satellite Hiten in a highly elliptical orbit.

The telemetry data which are generated by the instruments are packetized in Hiten, and reformed to the original data in earth stations successfully. The experimental results showed that the standardized scheme is helpful in allowing for tracking cross support between organizations, and the concatenated code is quite effective to transmit data in a low C/N condition.

1. Introduction

Telemetry schemes are different for each space organization or even for individual satellites of the same organization at present. The Consultative Committee of Space Data Systems (CCSDS) proposes the unified packet telemetry scheme to offer a universal tool for global cross-support or for cost reduction to multiple mission support(1) (2). The feature of the telemetry scheme are: (a)flexibility to deal with multiple data sources, (b) tolerance to low C/N environment.

The CCSDC packet telemetry adopts two levels in format : the first level, a source packet is a fundamental user unit, and the second, a transfer frame is the transmission process independent of the source data. The transfer frame is strengthened by channel coding and interleaving. The most powerful code is the concatenated code of a convolutional code and a Reed-Solomon code (RS code). This type of coding gathers much attention for applications to deep space communications(3) or VSAT satellite communications due to low bit-error-rate in low C/N environment(4).

For the purpose to verify the error characteristics of codes, the S/N value of the radio link can be coarsely selected according to the distance between the earth and the satellite in a highly elliptical orbit and the modes of communication subsystem. Moreover, two methods for precisely changing the S/N were contrived to cope with the abrupt change of bit errors of coded signals.

This paper describes the CCSDS packet telemetry scheme, and then presents the on-orbit experiment using the Japan's satellite Hiten to show the applicability of the CCSDS telemetry scheme.

2. CCSDS packet telemetry

The CCSDS packet telemetry is defined by two levels, as shown in Fig.1. A source packet is composed of telemetry data to be transmitted from a source to its associated user and a primary header which includes a packet identifier and sequence control bits. A secondary header and error correcting bits are optional. If some

---

* Institute of Space and Astronautical Science:
3-1-1 Yoshino-dai, Sagamihara, 229 Japan
** Hitachi Ltd.:
216 Totsuka-machi, Totsuka-ku, Yokohama, 244 Japan
*** Jet Propulsion Laboratory:
4800 Oak Grove Drive, Pasadena, California 91109, USA

data sources generate very long source packets, they may be divided into parts and conveyed by multiple segments.

The variable length packets and segments are multiplexed into the data field of a fixed length unit called a "transfer frame". A frame header contains identification information along with the information needed to extract the packets and segments on the ground. If a particular group of sources needs to be separated, a dedicated sequence of transfer frames can be assigned as a virtual channel. Transfer frames are separated by standard 32-bit synchronization markers.

If desired, the entire telemetry stream may be encoded for channel error correction with a standard convolutional code, using Viterbi maximum-likelihood decoding(inner code). However, for marginal S/N ratios, the Viterbi decoder may produce burst errors. These may then be corrected using a standard interleaved Reed-Solomon code over the transfer frame (outer code). Use of the Reed-Solomon code without the convolutional code has recently been approved by the CCSDS.

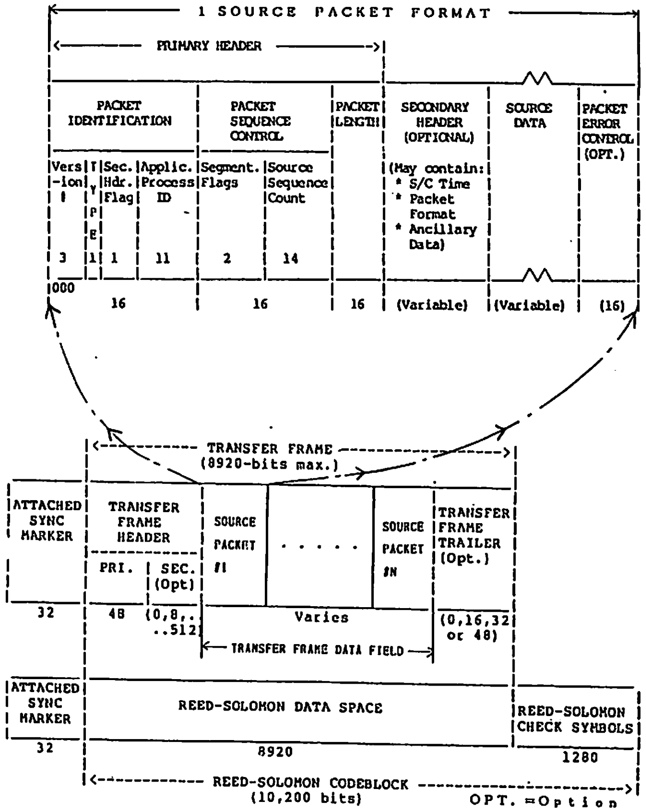


Fig.1 CCSDS packet telemetry format.

Table 1 Code parameters

INNER CODE : CONVOLUTIONAL CODE	
CODE RATE	R=1/2 Bit/SYMBOL
CONSTRAINT LENGTH	K=7 BITS
MINIMUM DISTANCE	10 BITS
DECODING	SOFT DECISION, VITERBI
OUTER CODE : REED-SOLOMON (RS) CODE	
RS SYMBOL	8 BITS
BLOCK LENGTH	255 RS SYMBOLS
INFORMATION LENGTH	223 RS SYMBOLS
MINIMUM DISTANCE	17 RS SYMBOLS
INTERLEAVE	5 RS SYMBOLS
SYNCHRONIZATION PATTERN	1ACFFC1D (HEXADECIMAL)

Table 1 shows parameters of a recommended inner code and a outer code. One RS transmission frame of 10240 bits includes the raw data field of 8872 bits without any option. The overhead ratio, therefore, is 0.852 if three source packets are included.

3. Satellite Hiten and its telemetry system

Hiten undergoes several times acceleration by the moon's gravity in order to pursue a swing-by experiment(5). Its orbit is highly elliptical around the earth, as illustrated in Fig.2.

Signal paths for packet telemetry are shown in Fig.3 together with conventional telemetry paths. OBC (On-Board Computer) is a mission instrument for packet telemetry, on-board computing and fault tolerance experiments. OBC gathers raw data from on-board instruments via DPU to edit them into the CCSDS format and encode by a RS code with or without a convolutional code. The output of OBC is fed to TMX (Transmitter in X-band) via DPU (Data Processing Unit) to modulate in PM with a Bi-phase-L code. TMX can transmit X-band power of 800mW (Power HI) or 160mW (Power LO), which is radiated from MGA-X (Medium Gain Antenna in X-band). DPU has the capability to handle the bit rate of uncoded 8192bps(Bit Rate HI) or convolutionally coded 2048bps(Bit Rate MED). The convolutional code used in Hiten adopts the older

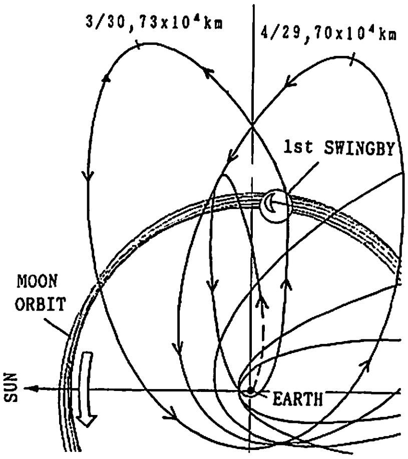


Fig.2 Orbit of Hiten. (1990.1.24-4.30)

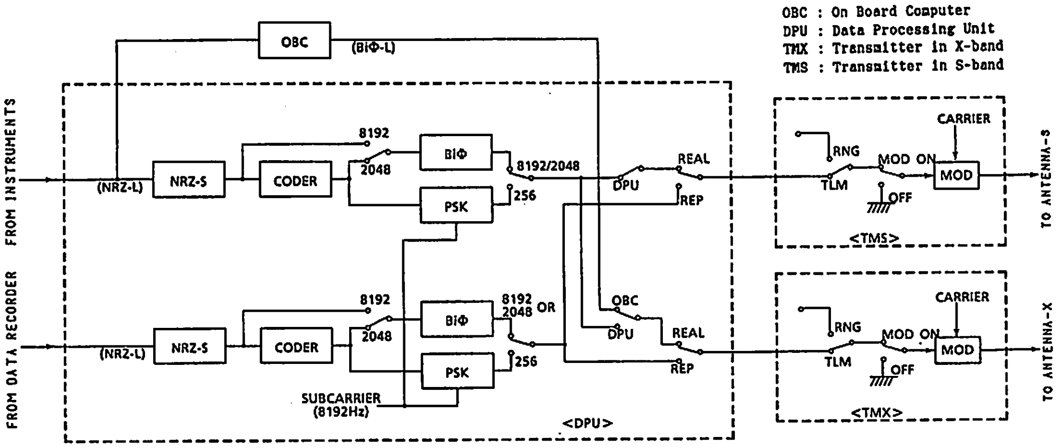


Fig.3 Communications subsystem of Hiten

JPL version whose connection vector is different from the newer CCSDS version. But the BER characteristics should not be influenced by the difference.

For the error measurement of the RS code, we have to know the original data so that the raw data from on-board instruments can not be used. In this experiments, a fixed telemetry data pattern is used instead of a PN code in order to measure errors at far end.

Therefore, the S/N value of the radio link can be coarsely changed according to the distance between the satellite and the earth, the output modes of the transmitter, and the bit rate with a particular coding scheme.

The radio wave was received on the earth by the 64 meter diameter antenna at the Usuda Deep Space Center (UDSC) of ISAS. The receiver system configuration at UDSC is shown in Fig.4. Demodulation scheme is synchronous detection. The RS decoding, de-interleaving and depacketizing is pursued by way of a dedicated equipment and its software in realtime. An example of the telemetry link budget is shown in Table 2 at the distance of the moon.

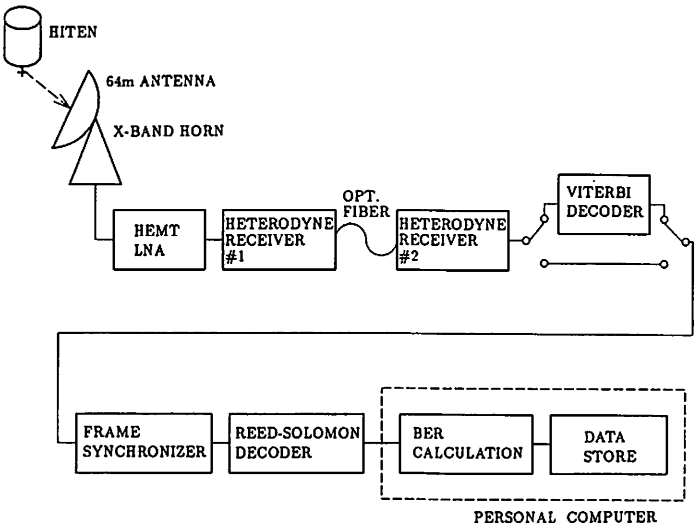


Fig.4 Receiving system on the earth.

Table 2 An example of a link budget.

ITEM	VALUE	NOTE
TRANSMITTER POWER	+29.0 DBM	X-BAND, HIGH POWER MODE
TRANSMITT. ANT. GAIN	+4.0 DB	MGA, MAX.VALUE
FEEDER LOSS	-2.3 DB	
POLARIZATION LOSS	-3.0 DB	LP/CP
FREE SPACE LOSS	-222.7 DB	3.8x10E5 km(MOON DIST.)
RECEIV. ANT. GAIN	70.6 DBI	64 m DIAMTER
POINTIG LOSS	-0.3 DB	HOMOLOGY ERROR, INVERSED FROM ACTUAL AGC LEVEL
TOTAL POWER	-124.7 DBM	
SIG. MODULATION LOSS	-0.3 DB	M.I.=1.30 RAD. INCLDING OTHER LOSS
PULSE RATE	39.1 DB·HZ	8192 BPS
SYS. NOISE POWER DENSITY	-179.3 DBM/HZ	ANTENNA: 30.0 K LNA: 55K
Eb/NO	15.2 DB	
REQUIRED Eb/NO	9.6 DB	BPSK, SYNCH.DET, 10E-5
CAR. MODULATION LOSS	-11.5 DB	M.I.=1.30 RAD.
CARRIER LEVEL	-136.2 DBM	AGC LEVEL

The telemetry data from Hiten in the CCSDS scheme was also received by the 26 meter antenna of the Deep Space Network (DSN) of the Jet Propulsion Laboratory, USA. The received and demodulated bit stream was processed off-line to decode the RS code and extract the packets.

Conventional telemetry works at S- and X-bands. Raw telemetry data from on-board instruments are fed into DPU to be processed for editing and encoding. Commanding to the satellite is carried out from UDSC in S-band.

4. Coding performance verification

In order to measure the abrupt change of error of a coded signal, it is needed to precisely change the E_b/N_o of the signal around its own threshold value. But it is difficult to secure the experiment time with the suitable distance between the satellite and the earth, because of the operation interference with other missions.

We, therefore, devised and tried two methods for that purpose at UDSC as follows: (a) insert a variable attenuator between the X-band low noise amplifier and the subsequent down-converter, (b) add noise from a strong and adjustable noise source through a directional coupler before the low noise amplifier. The configurations are illustrated in Fig.5. A precise attenuator is used to obtain high resolution. The method (a) changes signal level and noise level simultaneously, and the method (b) changes only noise level, whereas the actual telemetry link has only the signal level changed.

In the method (a), the S/N ratio of the output is given by

$$\frac{S_o}{N_o} = \frac{K(T_{ANT}+T_{LNA})B}{S_i}\left(1+\frac{L-1}{G}\,\frac{T_{ATT}}{T_{ANT}+T_{LNA}}+\frac{L}{G}\,\frac{T_{MIX}}{T_{ANT}+T_{LNA}}\right), \qquad (1)$$

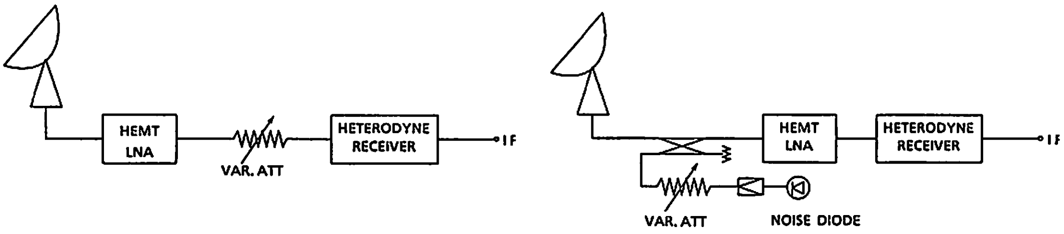
where suffix o and i indicate output and input, respectively, T_{ANT}, T_{LNA}, T_{ATT} and T_{MIX}: noise temperature of the antenna, the LNA, the attenuator and the first mixer, respectively, k:Boltzmann's constant, G:LNA gain, L:inserted attenuation.

An AGC amplifier in the heterodyne receiver loses the function to stabilize the output level, when the attenuation is increased and the LNA input level becomes below -165dBm. As this fact requires the calibration at every input level, the method (a) was confirmed to be inadequate.

In the method (b), S/N is given by Eq.(2) using added noise temperature ΔT,

$$\frac{S_o}{N_o} = \frac{k(T_{ANT}+T_{LNA}+\Delta T)}{S_i} \qquad (2)$$

As an optical transmission system in UDSC needs high input level to overcome quantum noise, the dynamic range of the amplifier prior to the fibre is limited so that the nonlinearity can not be neglected. Therefore, the receiver characteristics was carefully calibrated by measuring the BER of a PN code injected at the LNA input while changing ΔT. The S/N value is assumed to be unchanged by the nonlinearity.



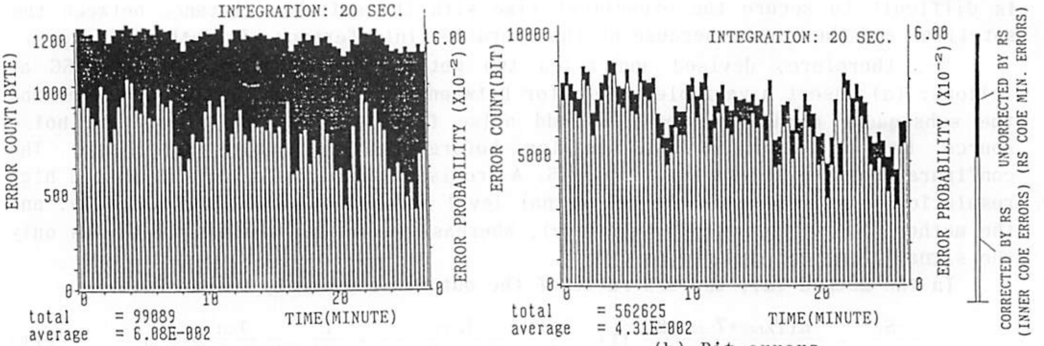
(a) Variable attenuator insertion after LNA. (b) Variable noise addition before LNA.

Fig.5 Methods for precisely changing the S/N of a link.

5. Experimental results

5.1 Telemetry data reception with various satellite distance

From March to April, 1990, actual telemetry data were packetized and transmitted from the satellite to the earth. The data were retrieved successfully with the outer code of the RS code and the inner code of the convolutional code or none. The error rate of the link was measured at appropriate distance between the satellite and the earth. Due to the lack of the knowledge of the original data, we could not measure the errors which were not corrected by the outer code or the RS code.



(a) Byte errors. (b) Bit errors.

1990.4.7, Power HI, Bit Rate HI Inner Code: Uncoded, Outer Code: RS Code

Fig.6 Measured transmission errors.

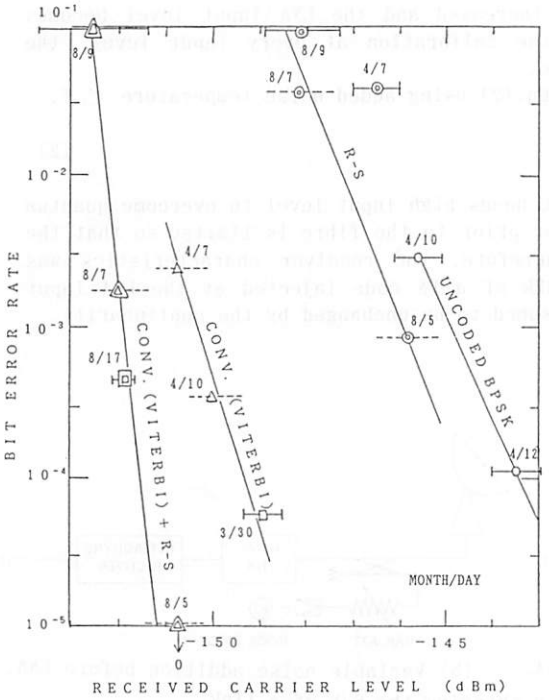
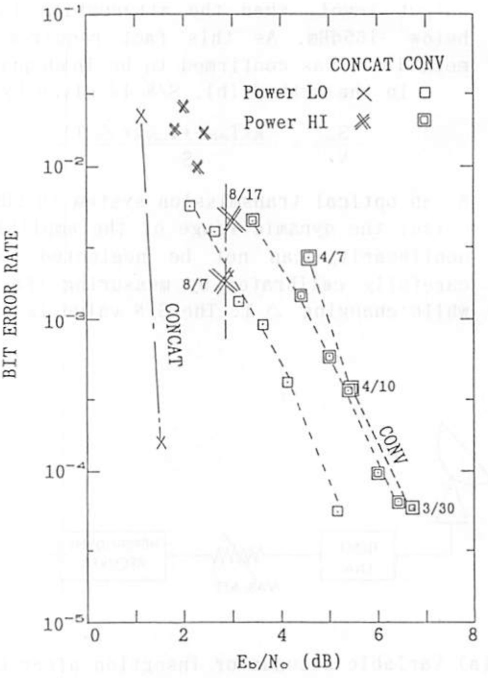


Fig.7 Bit error rate in relation with satellite condition.



Marks with MONTH/DAY: Converted from Fig.7.,
Marks without MONTH/DAY: noise addition method

Fig.8 Bit error rate versus E$_b$/N$_o$

Figure 6 shows the change of bit and byte errors in a part of a single operation path. The byte error is essential for the RS code because of the processing in byte. The bit error is calculated by simply multiplying the byte error with 8 bits. The corrected errors by the outer code is equal to the errors of the inner code. The uncorrected data mean the product of the occurrence number of the RS code error and the byte number 17 above which the RS code loses the correction capability. Therefore, the true value is larger than this calculated value.

After July, 1990, the fixed data pattern was used. The change of source data made no difficulty in data transmission and handling.

The error rate is plotted in Fig.7 versus the received carrier level which is read from the AGC monitor. The carrier level depends on the satellite distance and transmitter output modes. The data are not abundant.

One can convert the carrier level to E_b/N_0 using the bit rate, modulation index and the system noise temperature, in the manner of Table 2. As the modulation loss in Table 2 is quite sensitive to the modulation index which is actually unknown in orbit, the index was measured through the comparison between the beacon mode and telemetry mode powers. As the carrier level indication on the AGC monitor is smeared by the noise even when the noise input level to the heterodyne receiver is lowered in proportion to the carrier level, the reading was calibrated relative to the true value on a pen-recorder. The result is shown in Fig.8.

5.2 Error rate change with noise addition to the receiver

The error rate was measured in the receiver configuration of Fig.5 (b) changing noise addition level in addition to the DPU bit rate modes and the TMX power modes. The results are plotted again in Fig.8.

The experimental results showed fairly good coincidence of measured bit error rate with theoretical values, and that concatenated coding is quite effective to transmit data in a low C/N condition. The method to precisely change the link condition is also verified to be applicable and convenient.

5.3 Reception demonstration in USA

The packet telemetry was successfully received by DSN in Bit Rate HI mode. Four nonconformities were discovered between the Hiten version and the CCSDS standard as follows:

(1) The Virtual Channel Frame Counter in the Transfer Frame Primary Header is fixed at Zero, though the CCSDS recommends monotonic increase,

(2) There is spare octet of zero bits before each synchronization field,

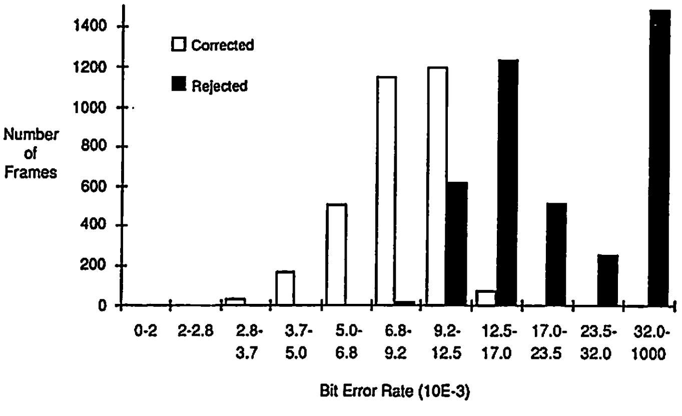


Fig.9 RS code performance versus the link condition (BER before decoding).

(3) The Hiten RS code uses conventional representation while CCSDS recommends dual basis,

(4) The Packet Length Field in the Primary Header is larger by one than the CCSDS version.

The correction rate of the RS code is plotted in Fig.9 as a function of the actual link bit error rate from the known fixed pattern. The threshold is about 4dB which is slightly lower than the theoretical value of 6 dB.

6. Conclusions

The first field test of the CCSDS Packet telemetry was carried out successfully. The standardized telemetry scheme were shown to be flexible to carry different kinds of data and helpful for tracking cross supports between organizations. The RS code or the concatenated code are quite useful in a low C/N condition, though the measured data variation is larger than 1dB due to the nonlinearity of the ground receiver, and the uncertainly of carrier level and modulation index. The satellite Hiten in a highly elliptical orbit offered a convenient circumstance for the communications experiment. It was revealed that there are several differences between the Hiten version and the CCSDS standard.

The obtained results could be used to make a practical CCSDS compatible system in the near future.

Acknowledgement

We would like to thank Mr.D.Tejima of Hitachi for his eager collaboration in the experiment, and Prof.T.Hayashi of Chiba Institute of Technology and Prof.k.Uesugi of ISAS for their help to achieve the OBC mission aboard Hiten.

References

(1)CCSDS,"Telemetry channel coding",CCSDS 101.0-B-2,Blue Book, Jan.,1987.

(2)CCSDS,"Packet telemetry",CCSDS 102.0-B-2,Blue Book, Jan.,1987.

(3)J.H.Yuen(edit.),"Deep space telecommunications systems engineering",Plenum Press,New York,1983.

(4)A.Fujimura et al.,"Development of a variable coding gain concatenated coding scheme and its fields test via Ka band satellite",Proc.1992 IEICE Spring Conf.,B-205,March,1992.

(5)K.Uesugi,H.Matsuo,J.Kawaguchi and T.Hayashi,"Japanese first double lunar swingby mission HITEN",Proc.41st IAF Congress,Oct., 1990.