Double Star – Polar (TC-2)

Neutral Atom Imager

N U A D U

Operational Manual

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List of acronyms

ADP	Acceptance Data Package
ADC	Analog to Digital Converter
A/E	Absorptivity / Emissivity
AIV	Assembly Integration Verification
AWG	Acceptance Working Group
BC	Bus Controller
CALT	Chinese Academy of Launch Vehicle Technology
CAST	Chinese Academy of Space Technology
CNSA	Chinese National Space Administration
CSA	Charge Sensitive Amplifier
CSSAR	Center for Space Science and Applied Research
DITS	Double Star Integration Testing System
ECR	Engineering Change Request
EPOS	European Payload Operational Service
ESOC	European Space Operational Service
FEP	Fluorinated Ethylene Propylene (teflon)
HK	HouseKeeping
HRM	High Rate Multiplexer
IST	Integration and system level test
ITO	Indium Tin Oxide (transparent conductive layer)
LFT	Limited Functional Test
MEP	Main Equipment Platform
MLC	Memory Load Command
NAI	Neutral Atom Imager (=NUADU @ DSP-2)
NCR	Non-Conformance Report
NUADU	Neutral Atom Detection Unit (=Neutral Atom Imager for DSP-2)
OBDH	Onboard Data Handling System
OSR	Optical Solar Reflector
PDMS	Payload Data Management System
PLRT	PayLoad Remote Terminal
PSR	PreShipment Review
RFW	Request For Waiver
RT	Remote Terminal
SART	SAtellite Remote Terminal
SSC	Spin Segment Clock
SSM	Second Surface Mirror
SSR	Solid State Recorder
SRP	Sun Reference Pulse
STG	SelfTest Generator

General

From the user's point of view, the neutral atom imager NUADU should be considered as an ENA-sensitive camera that covers full 4-π solid angle with angular resolution of 16 x 128 = 2048 pixels, energetic resolution of four energetic discrimination levels and time resolution (sampling rate of full images) 1 to 32 satellite spin periods.

Angular resolution

The differential angular distribution of ENA flux in azimuthal range Fi = 0° to 360° is recorded with making use of satellite spin. The azimuthal angle is divided to 128 sectors by spatial synchronisation of NUADU electronics operation. The synchronisation signals SRP (Sun Reference Pulse) and SSC (Spin Segment Clock) are provided by satellite service system through interface connector. The respective sector index is related to SRP (located at Fi = 0°).

The differential angular resolution of ENA flux in elevation range Theta = 0° (North ecliptical pole) to Theta = 180° (South ecliptical pole) is provided with making use of 16 fixed detectors, regularly spaced over the elevation range. The elevation angle of any single detector is defined by formula:

$$\text{Theta (Nd)} = 11.25 \times (\text{Nd}-1) + 5.625 \quad [°]$$

where Nd is index of the detector (1,2,3,…,16)

The angular response characteristic of each single detector is defined by detector active area (14.2mm x 10mm) and input aperture dimension (46,5mm x 10mm) that is located in the distance of 227mm from the detector active area. The detailed angular characteristic is described in IDS.

Energetic resolution and threshold control

The signal from detectors is discriminated to four energetic thresholds. The particular threshold levels are the same for all 16 detectors. For practical use, the thresholds are indexed as L (lower), M (medium), U (upper) and T (top). The L threshold can be set in limited range by a telecommand ZENTHRSET, while other three thresholds are permanently fixed (wired) during the flight. The L-threshold is set by the recent telecommand until a new threshold is set by another ZENTHRSET telecommand, regardless that the instrument was unpowered meantime. The electrical threshold were defined after the calibration at Manne Siegbahn Laboratory in Stockholm. It was decided to define them in milivolts. The L discrimination level is remotely commandable and defined by formula:

$$Th\_L (Nth) = 33.9 + Nth / 1.604 \qquad [mV]$$

where Nth is an argument of ZENTHRSET telecommand (0,1,2,…,255). The presettable L threshold allows an optimization with regard to electronic noise of the detectors during the flight.

The electrical threshold of other three discriminators is set as follows:

Th_M = 92 mV,
Th_U = 246 mV
Th_T = 626 mV

The physical energetic thresholds for ENA and ions are significantly infuenced by dead-layer losses of the detector (energy struggle) for each specific particle composition (see Calibration report DSP-NUA-CAL-1).

Time resolution and Integration mode

The time resolution (full-image sampling rate, or frequency at which ENA images are generated) depends on instrument integration mode. The integration mode defines how many spacecraft spins will be integrated to one image (one scientific data frame). In the integration mode SUM1, the full image (data frame) will be issued after completing of each one spacecraft spin, while in the integration mode SUM32, the frame will be issued only after completion of 32 spins. The integration mode is set by a telecommand ZENSUM and is fixed until a new integration mode is set by another ZENSUM telecommand, regardless that the instrument was unpowered meantime. The period of frame issue in nominal mode is:

$$\mathrm{Tfn\ (Sm)} = \mathrm{Ts} \times \mathrm{Sm} \quad [\mathrm{sec}]$$

Where Tfn is period of frame issue in nominal mode, Ts is s/c spin period and Sm is index of integration mode SUM (1,2,…,32)

High Voltage regulation (HV preset)

The HV system provides bipolar symmetric voltage that is regulated with 8-bit resolution in the range 0… ±5000V. The respective preset telecommand is ZENHVSET. The HV preset value is fixed until a new value of HV is preset by another ZENHVSET telecommand, regardless the instrument was unpowered meantime.

The value of preset HV is defined by formula:

$$\mathrm{HV\ (Shv)} = 19.6 \times \mathrm{Shv} \quad [\mathrm{V}]$$

Where Shv is argument of ZENHVSET telecommand.

The HV preset value has lowest priority to real physical value of the high voltage on the deflector plates. The real physical voltage on deflector plates can be disabled with higher priority by ZENHVOFF telecommand and by inserted HV safety plug.

High Voltage ON-OFF control

The HV ON-OFF control provides complete ON-OFF switching of the HV to the deflector plates. The control is provided by HV optocouplers at the output of HV powering unit. The respective telecommands are ZENHVON and ZENHVOFF. The HV status is fixed until it will be changed by new telecommand, regardless that the instrument was unpowered meantime.

In the Toggle Mode the real HV is switched ON-OFF automatically, but only when HV sytem is in ON state. The OFF status disables the HV also for Toggle mode. The HV ON-OFF control has lower priority than HV safety plug. The real high voltage on the deflector plates can be physically disabled by inserted HV safety plug.

The HV ON-OFF status is indicated by BIT7 of Status byte (HK02)

High Voltage Safety Plug

Te HV Safety Plug physically disables the powering of HV supply unit, so that the real voltage on the deflector plates is zero, regardless the HV preset value or HV-ON state. The safety plug must be inserted for instrument operation at the air pressure higher than 10^{-4} Pa (= 10^{-5} mbar). There is no direct indication in the instrument output data that the plug is inserted. The HV safety plug must be unconditionaly removed before the flight !!!

Toggle mode

The operation in the toggle mode is similar to nominal operation, but respective integration mode (SUM#) is combined with alternate ON-OFF switching (toggle) of the high voltage on the deflector plates. The toggle mode is activated by ZENTOGON telecommand and remains active until it is cancelled by ZENTOGOFF telecommand, regardless that the instrument was unpowered meantime. In the toggle mode, the nominal data frame (with nominal HV on deflector plates) is alternated with the same kind of frame, but with HV switched-OFF. The purpose of this operational mode is to compare ENA flux with charged particles flux. As HV transient is relatively slow, one s/c spin is dedicated to the transient process and data are not acquired during this spin. This decreases average data rate as the period of frame issue in toggle mode is:

$$\mathrm{Tft}\ (\mathrm{Sm}) = \mathrm{Ts} \times (\mathrm{Sm}+1) \qquad [\mathrm{s}]$$

Where Tft is period of frame issue in toggle mode, Ts is s/c spin period and Sm is index of integration mode (1,2,…,32).

The Toggle Mode is indicated by BIT6 of status byte (HK02) in housekeeping data. The same indicator is located in the scientific data frame, where it will be used for data processing.

The necessary condition for activating the Toggle Mode is that the HV must be enabled (ON) by ZENHVON telecommand. The ZENHVOFF telecommand physically disables the HV also in Toggle Mode. So that during the data procesing the attention must be paid for both bit indicators BIT7 (HV ON-OFF) and BIT6 (Toggle ON-OFF) of the status byte.

Selftest Generator

The Selftest Generator (STG), when activated, provides a spin-synchronized sequence of testing pulses (charge injection) to the inputs of charge sensitive amplifiers (CSA). This provides relatively simple testing of the processing electronics from CSA input to the event counters. The amplitude of the testing pulses is modulated the way, that in the first quarter of the spin the L threshold is activated, in the second quarter of spin the M threshold is activated, in the third quarter the U threshold is activated and in the last quarter of the spin the T threshold is activated. This provides typical step pattern in the output data frame. The Selftest Generator is activated by ZENSTGON telecommand and remains active until ZENSTGOFF telecommand is received, regardless the instrument was unpowered meantime.

Housekeeping (HK) information

The housekeeping information provides basic health and technical information about the instrument. The HK information consists of 17 bytes and is transferred to the spacecraft HK acquisition system with period Thk = 1 second. The same information is recorded in parallel to each instrument output data frame, where it occupies first 17 positions (bytes).

HK01 = ENFM (Frame Mode indicator)

The HK01 provides basic indication about type of the frame:

A7 = Frame containing nominal scientific data
76 = Frame containing dump of RAM memory
C5 = Frame containing dump of EEPROM memory
FC = Frame containing Test pattern

HK02 = ENSTAT (Status byte)

The ENSTAT byte is bit-oriented status indicator, providing indication of HV ON/OFF status (BIT7), the Toggle Mode status (BIT6), Selftest generator status (BIT5) and Integration Mode status (BITs0-4) as follows:

```
BIT7                                  BIT0 (LSB)

X    X    X    X    X    X    X    X

|    |    |    |____|____|____|____|____ SUM (1 – 32)

|    |    |_______________________________ STG (1=ON, 0=OFF)

|    |____________________________________ TOGGLE (1=ON, 0=OFF)

|_________________________________________ HV (1=ON, 0=OFF)
```

The integration mode index (1-32) is evaluated from ENSTAT byte as follows:

Sm = (0x1F & ENSTAT) + 1

Where Sm is Integration mode index, 0x1F is a mask and "&" is logic operator AND

HK03, HK04, HK05, HK06 – Onboard time indicator

The instrument onboard time is running with resolution of 1 second that is derived from SSC signal. The onboard time is periodically updated by OBT synchronization broadcast command that is distributed by PDMS system via MIL-STD-1553B bus. The OBT is reset in

NUADU unpowered status. After the instrument power-On, the OBT starts its counting from zero until it is preset to correct value by next PDMS time synchronization broadcast.

HK03 = ENOBT1; Onboard Time 1 (Most Significant Byte)

HK04 = ENOBT2; Onboard Time 2

HK05 = ENOBT3; Onboard Time 3

HK06 = ENOBT4; Onboard Time 4 (Less Significant Byte)

The onboard time has the same format as that broadcasted by PDMS.

HK07 – HK14

The HK07-HK14 bytes are analog values that are sensed by dedicated analog electronics and converted to digital values by 8-channel ADC with 8-bit resolution. The conversion to real physical values shall be provided by following calibration formulas:

HK07 = EN5V;	Internal +5V voltage = EN5V / 34.0 [V]
HK08 = ENVREF;	Reference voltage [V] = ENVREF / 51.2
HK09 = ENHVCUR;	HV primary current [mA] = ENHVCUR / 8.3
HK10 = ENTEMPE;	Temperature of electronics [C°] = ENTEMPE × 0.625 - 60
HK11 = ENTEMPD;	Temperature of detectors [C°] = ENTEMPE × 0.625 - 60
HK12 = ENHVMON;	HighVoltage monitor [V] = ENHVMON × 19.6
HK13 = ENBIAS;	Detector Bias Voltage [V] = ENBIAS / 3.0
HK14 = EN24V;	Internal +24V voltage [V] = EN24V / 8.5

HK15 = ENHVSET;

The ENHVSET byte provides feedback information - what HV value was preset by last ZENHVSET telecommand. The physical value of this preset value shall be evaluated by formula:

$$\text{HV set voltage [V]} = \text{ENHVSET} \times 19.6$$

At normal condition, the HV monitor should be equal to HV preset value, i.e.:

$$\text{ENHVMON} = \text{ENHVSET}$$

HK16 = ENTHRSET

The ENTHRSET byte provides feedback information - what L-threshold value was preset by last ZENTHRSET telecommand. The physical value of this preset shall be evaluated by formula:

$$\text{L-threshold command-set [mV]} = \text{ENTHRSET} / 1.604 + 33.9$$

HK17 = ENTECH Technical byte

The ENTECH is bit-oriented and provides a technical information (sync. signals detection and SW boot information) as follows:

```
BIT7                               BIT0 (LSB)

X  X  X  X     X       X       X      X(LSB)
|  |  |  |     |       |       |______|_______RAM bank (0,1,2,3) used for runtime SW
|  |  |  |     |_______|_____________________EPROM  bank (0,1,2) used for boot
|  |  |  |___________________________________SWCHECKSUM (1=OK, 0=BAD)
|  |  |______________________________________SWLOAD (1=PROM, 0=EPROM)
|  |_____ ___________________________________SSC (1=Detected, 0=MISSING)
|____________________________________________SRP (1=Detected, 0=MISSING)
```

BIT0 – BIT1 indicate which RAM bank was used for runtime operational SW

BIT2 – BIT3 indicate which EPROM bank was used for booting of SW

BIT4 – provides information about checksum control of operational software

BIT5 – informs whether current operational SW was loaded from PROM or EPROM

BIT6 – informs whether SSC was detected during instrument initialization

BIT7 – informs whether SRP was detected during instrument initialization

If the synchronization signals SSC and/or SRP will be permanently unrecognized, then instrument will issue only one frame RAM, where synchronization bits will be set to zero. There will be no other instrument operation unless SRP and SSC will be received.

If the synchronization signals SSC and/or SRP will be supplied to instrument only after the timeout > 5s after the power-ON, then instrument will start to operate normally, but will permanently indicate missing synchronization signals in the technical byte.

TELECOMMANDS

There are 14 telecommands defined for NUADU system that are transferred to the instrument via MIL-STD-1553B bus. The digital control codes of the telecommands are fixed and the instrument will not recognize any other control codes.

Cmd. Name	Cont.code	Action taken
ZENHVON	(00D4)	- provides activation (ON) of HV supply
ZENHVOFF	(00E5)	- provides inactivation (OFF) of HV supply
ZENTOGON	(0087)	- provides activation (ON) of Toggle mode
ZENTOGOFF	(0098)	- provides inactivation (OFF) of Toggle mode
ZENSTGON	(00A1)	- provides activation (ON) of Selftest generator
ZENSTGOFF	(00B2)	- provides inactivation (OFF) of Selftest generator
ZENSUM	(xx5D)	- by argument 'xx' provides activation of respective integration mode. The formula to set required integration mode is as follows: $xx_{dec} = SUM(n) - 1$ (i.e., $xx_{dec} = 0$ for SUM1, ... , $xx_{dec} = 31_{dec}$ for SUM32)
ZENHVSET	(xx3F)	- by argument 'xx' provides presetting of HV in the range 0 to 5000V. The formula to set required HV is as follows: $xx_{dec} = HV[V] / 19.6$
ZENTHRSET	(xx4A)	- by argument 'xx' presets the L-threshold in the range 33.9 mV to 193 mV. The formula to set required threshold is as follows: $xx_{dec} = Lth\ [mV] \times 1.604 - 54.38$
ZENRDRAM	(001C)	- provides dump of RAM memory to output data frame.
ZENRDEPR	(0038)	- provides dump of PROM memory to output data frame
ZENRUNEPR	(0095)	- provides load and run of operation software from EEPROM
ZENTEST	(00FC)	- provides an issue of the test pattern frame

ZENWREPR (00C5) - provides remote in-flight EEPROM preprogramming. It is a multiword telecommand with following structure:

Word	Code	Interpretation
01	00C5	Control code (fixed)
02	xxxx	EEPROM start address (allowed range 0000h – 1FDDh)
03	xxxx	data to write
04	xxxx	data to write
....		
17	xxxx	data to write
18	xxxx	data to write (last word)

The ZENWREPR telecommand should be used only carefully as it edits the EEPROM version of operational software. The EEPROM software can by loaded to operational RAM memory and executed by ZENRUNEPR telecommand. On each instrument restart (power – OFF and ON) the operational software is loaded and executed from PROM memory. If run of (edited) EEPROM version is needed – it must be activated by ZENRUNEPR telecommand after each power OFF status. The identification of the currently active SW version (PROM vs EEPROM) is provided by BIT5 of technical byte (HK17).

TELEMETRY DATA FRAMES

There are 4 different data frames defined in NUADU system. All the frames have the same size of 8210 bytes and very uniform structure, where first 17 bytes is allways occupied by current HK sequence, then 8192 bytes of data is transferred and one byte with frame checksum value is added at the end. Each frame is transferred to PDMS in 17 standardized CCSDS packets, the packet consist of 8 messages (32 words = 64bytes each) defined on MIL-STD-1553B bus. The last packet is not fully occupied with the data frame information, but the rest of its capacity (222bytes) is filled with the (ASCII) text sequence NUADU*NUADU*… NUADU* (37x) for easy instrument identification, when data are not completely coherent, e.g. at bad download condition from the satellite.

1. Scientific data frame (frame nominal, ENFM = A7)

The scientific data represent the channel count for respective detector (D01…D16), respective threshold of this detector (Top, Upper, Medium, Low) and respective spin segment (S0…S128), related to Sun reference pulse, which is considered at azimuthal location Fi = 0°.

Byte index	Content	
0018	D01 T 001	– pixel D01-S001, count for T-threshold
0019	D01 U 001	– pixel D01-S001, count for U-threshold
0020	D01 M 001	– pixel D01-S001, count for M-threshold
0021	D01 L 001	– pixel D01-S001, count for L-threshold
0022	D02 T 001	– pixel D02-S001, count for T-threshold
0023	D02 U 001	– pixel D02-S001, count for U-threshold
…		
8206	D16 T 128	– pixel D16-S128, count for U-threshold
8207	D16 U 128	– pixel D16-S128, count for U-threshold
8208	D16 M 128	– pixel D16-S128, count for M-threshold
8209	D16 L 128	– pixel D16-S128, count for L-threshold

| | |______ Spin segment index (S001–S128)
| |_________ Threshold (T=Top, U=Upper, M=Medium, L=Lower)
|___________ Detector index (D01–D16)

The original count value (that consists of max. 13 significant bits) is compressed by semilogarithmic formula to 8bit value (i.e. to one byte). Four most significant bits of this byte represent the Exponent (E). Four less significant bits of this byte represent the Mantissa (M):

D7 D6 D5 D4 D3 D2 D1 D0 - LSB
| |
EXPONENT MANTISSA

The original count (N) of respective pixel at respective threshold is then decoded as follows:

$N = M,$ if $E = 0$

$N = (M + 16) \times 2^{(E-1)}$, if $E > 0$

RAM dump frame (ENFM = 76)

The RAM frame is issued by the instrument as the first frame after the power-ON and also by the telecommand ZENRDRAM. The data part (0018-8209) of the frame RAM content only an instrument RAM memory dump, so that no processing is required.

EPROM dump frame (ENFM = C5)

The frame EPROM is issued by the instrument only on the telecommand ZENRDEPR. The data part (0018-8209) of the frame EPROM content only an instrument EEPROM memory dump, so that no processing is required.

TEST pattern frame (ENFM = FC)

The frame TEST is issued by the instrument only on the telecommand ZENTEST. The test pattern data serve just for simple technical check of proper data transmission from NUADU to the PDMS. The data part (0018-8209) consist from 16bit incremental counter as follows:

0018 00 (MSB)

0019 00 (LSB)

0020 00 (MSB)

0021 01 (LSB)

0022 00 (MSB)

0023 02 (LSB)

...

8206 1F (MSB)

8207 FE (LSB)

8208 1F (MSB)

8209 FF (LSB)

Checksum byte

The checksum byte is the last byte (position 8210) and is generated as sequentional XOR operation over all frame bytes from position 0001 to 8209.