Summary

This document provides details of downlink data for the AMSAT ESEO payload – based upon the FUNcube-1 spec for compatibility with the dashboard and data warehouse

Distribution: Confidential

Keywords:

Document-ID:

Issue: 1.2

Date: 20 Nov 2018

Prepared: Graham Shirville

Revised: Chris Bridges, David Bowman

Checked: Duncan Hills, Dave Johnson, David Bowman, Graham Shirville

Approved: Graham Shirville

Revision Record

issue	date	total pages	Authorisation	affected pages	brief description of change
1.1 DRAFT	22.03.15				Added details of where to look for extended sat-id.
1.1 ESEO wip	11.08.15		Graham		Modified to reflect ESEO tlm. more work needed to finalise bit counts and channels in RT and WOD frames
1.1f	23.08.15		Graham		Updated after discussions VZV/MRF and with FC team. pending further redefinitions on a skype Thursday 27th August
1.1g	24.08.15		Duncan		Bit order defined – see section 2
1.1h	28.08.15		Graham		Revised after telcall. Agreed to concentrate on the RT and WOD coming from the EPS board directly and via the CAN bus from the RX & TX boards for the time being so that thermal testing can be undertaken asap Also followed Duncan's advice to make WOD frames parse better.
1.1j	28.08.15		Graham		Various tweaks and move WOD frames
1.1k	18.06.16		Chris, ALL		ESEO Workshop at Surrey Space Centre: Update RTT & WOD definitions for FSW & Dashboard

1.1L	28.06.2016		Chris, David (Skype)	ALL	Updated RTT, WOD, Schedule
1.1M	19.07.2016		Chris, Pete		Defined 2B as payload_header in 4k8 payload mode. Further edits from Skype call with team.
1.1N	16.11.2018		Chris		Added temperature equations from 20 Nov 2018. Added RF equations from 'ESEO TLM ver 0.1e 04/10/2018.docx' Corrected terminology in places. Added WOD eqns. Issued as 1.21

List of TBD's and TBC's

TBC/TBD	*Location*	*Subject*	*Due date*	*Action by*
TBD		Internally generated CCT debug / status data		PB
TBC		Confirmation of platform EPS data via CAN		CPB, Done
TBD		Detail of data format and limits from science payloads. – e.g. How much memory holds current valid data. / Start - finish address		Internal
TBD		ESEO Platform Telemetry Equations		ESA
TBC		AMS Local Equations		CPB, Done

Table of Content

List of Acronyms

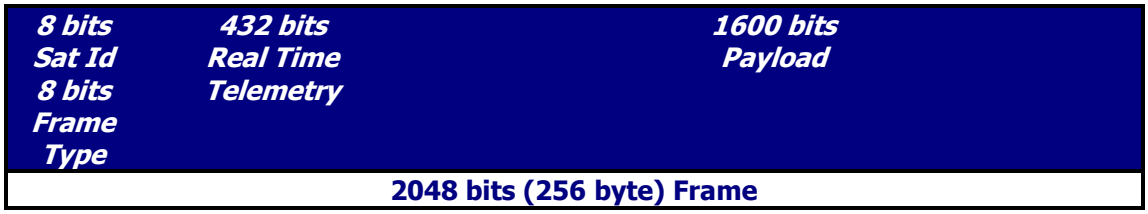
ANT	Antenna (board)
ADC	Analogue to Digital Converter
ACS	Attitude Control Subsystem
BCR	Battery Charge Regulator
BPSK	Binary Phase Shift Keying
CCT	Command Control and Telemetry (board)
EPS	Electrical Power Subsystem
FEC	Forward Error Correction
MSE	Material Science Experiment
PA	Power Amplifier (board)
RF	Radio Frequency (board)
RS	Reed Solomon (error-correction code)
SW	Software
TBC	To Be Confirmed
TBD	To Be Determined
TBW	To Be Written
TCS	Thermal Control Subsystem
TRX	Transponder

1 Overview

This document defines the data downlink format for the telemetry transmitted by the AMSAT payload on ESEO. Both the content of each downlink frame and the transmission order of the different frame types will be addressed.

The FEC encoding method and frame size remains unchanged from the original found here by James Miller: http://www.amsat.org/articles/g3ruh/125.html

"The Telemetry uses 1200bps BPSK with both convolution and block coding based on the proven AMSAT OSCAR-40 FEC telemetry model. The encoding starts with a 256-byte (2048 bit) data frame, this is passed through a pair of RS (160,128) encoders, a scrambler, convolution encoder and the interleaver. This produces 5200 bits to transmit. Thus, ignoring pre- and post-amble, each data frame will take 4.3s to transmit"



Each frame consists of an 8-bit satellite id and an 8-bit frame type indicator then 432 bits of real time data followed by 1600 bits of payload data. This results in the required total frame size of 2048 bits (256 bytes). The FEC encoded data (5200 bits) together with 700ms of idle tones fixes the frame transmission rate to one frame every five seconds.

Additionally, it is possible to configure the spacecraft to downlink debug status information in Fitter message slot 5.

2 Frame Types

All data is transmitted MSB first i.e. in "network byte order" and the first 16 bits of each frame will indicate the Satellite Identification number as well as defining the contents of the final 1600 bits of the frame. i.e. Fitter message number or whole orbit data frame number. Values for Sat ID and frame type can be found in the Transmission Schedule table at the end of the document.

Frame types:

- Whole orbit data.
- Fitter messages.

The RF modes are:

- 0x00: Receive only, with data collection
- 0x01: Low power BPSK telemetry mode
- 0x02: High power BPSK telemetry mode
- 0x03: Low power transponder mode
- 0x04: High power transponder mode
- 0x05: Autonomous Mode

The data mode flag complements the RF mode to accommodate various RF and data combinations to act as a redundant communications link for ESEO. These are:

- 0x00: AMS + ESEO at 1k2 (default)
- 0x01: AMS + ESEO + Payload at 4k8

Depending of which RF and data modes are selected, the transmission sequence may vary.

In the first data mode, the usual FUNcube frame of RTT and WOD will be adhered to within the typical 5 second transmission schedule. But in the second data mode, the data rate is increased allowing 4 FUNcube frames to be transmitted in the 5 seconds – again, still following the transmission schedule. The first frame will still adhere to the RTT + WOD sequencing, but the next 3 frames will be of payload data. If payload data is not available to fill these three 256B data slots, AMS Payload data will be repeated. These will be collected on the ground via the FUNcube Dashboard.

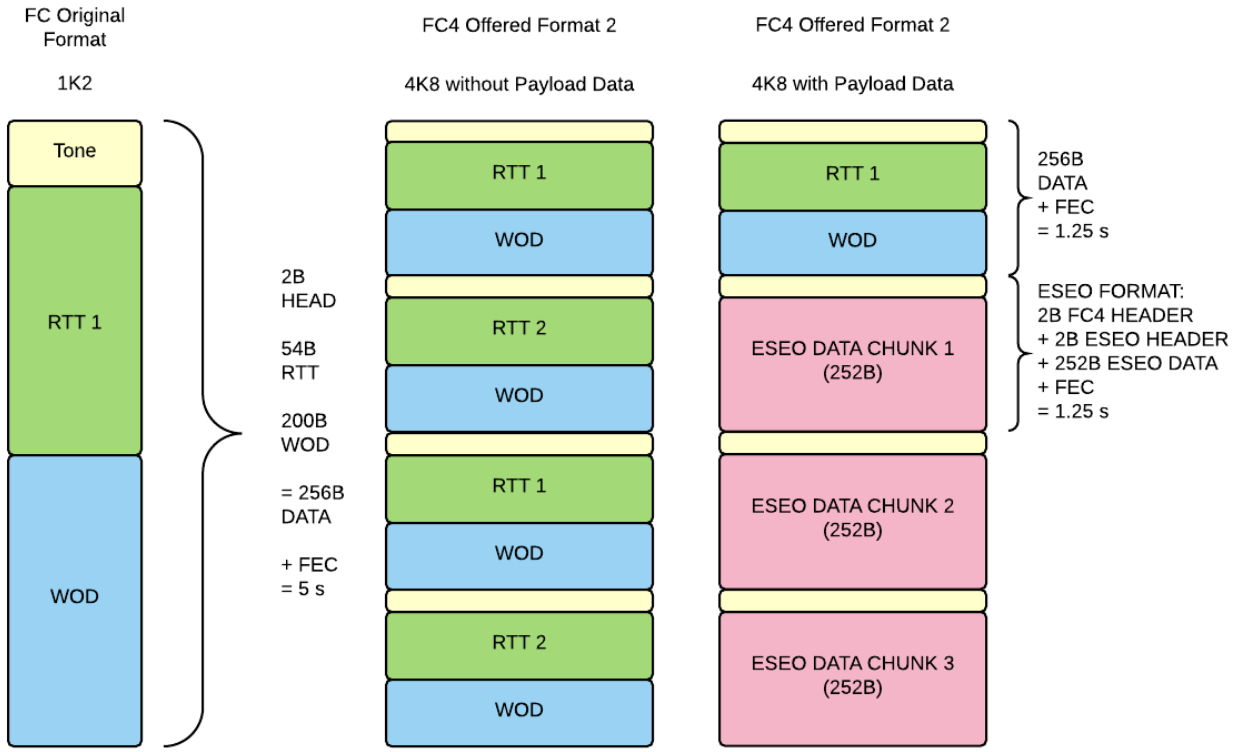


Figure 1. Offered 4k8 Mode: If Payload Data is empty / unused, the AMS will repeat existing telemetry

Real Time Telemetry

Each frame starts with Sat ID and frame type then 432 bits of real time data. This real-time data is updated every from sensors in the AMSAT Payload, from the AMSAT CCT board and from the ESEO platform housekeeping data.

Whole Orbit Data

This is intended to provide all the information required to demonstrate the physical and operational characteristics of the satellite over an entire orbit. The data will be sampled once per minute for 104 minutes and a full set of data is transmitted once every 24 frames or 2 minutes. Whole Orbit Data is received on the ground and presented in graphical form for educational outreach. Included are the battery voltage, system current and solar current collected together temperatures current and voltages from many subsystems.

Fitter Messages

These are the text messages received from ground stations to be periodically retransmitted within the 2 minutes telemetry sequence. Messages will not be broken up and sent over multiple frames, so the maximum length of a message is 200 bytes. The format of messages is transparent to the satellite, each received message will just be copied out verbatim.

Messages can be uploaded to specific AT32 memory slots with the slot id specified at upload time. After an upload attempt status bits in the Real Time Telemetry will be set to indicate the slot id and success or failure. An authentication (not encryption) scheme will be used to verify message validity.

3 Extended Sat Id/Frame Types

To ensure the data format and transmission type can be used with multiple satellites the ID scheme allows the ground station to determine the Sat Identity.

The format of the first two bytes is shown below. Satellite ID and frame type information are contained within these 16 bits.

Byte 0								Byte 1							
Sat ID		Frame Type						Sat ID						Frame Type	
S6	S7	F2	F3	F4	F5	F6	F7	S0	S1	S2	S3	S4	S5	F0	F1
1	1	D	Variable					0	0	0	0	0	1	0	0

The original two bits of Sat ID are the least significant bits of a byte of Sat ID data, and first six bits of Frame Type are now the least significant bits of a byte of Frame Type data. Frame Type 40 is used for debugging.

For ESEO payload transfer, F0 is set to 1 and the following 2B is for ESEO Science payload data which is a packet index (or counter) addressing 64 KB in 252B chunks (256B – 2B header – 2B packet index).

For satellites using this Extended Identification scheme, the overview diagram of a frame is:

2 bits Sat Id 6 bits Frame Type	*6 bits Sat Id 2 bits Frame Type*	*432 bits Real Time Telemetry*	*1600 bits Payload*
2048 bits (256 byte) Frame			

4 Data Sources

AMSAT – The AMSAT payload via internal wiring and I2C
OBD – The main on-board data handling computer via CAN bus
STX – S Band transmitter
ACS – Attitude Control System
SSM – Sun Sensor main
MWM – Momentum Wheel main
GPS – Global positioning system receiver
PMM – Power Management Unit main

5 Data Collection/Transmission

This section details the rate at which data is collected and from which sensors. The table also defines the order and bit format for transmission.

Real Time Telemetry: Total 448 bits / 56 bytes (inc 8 bits sat ID and 8 bits frame type)
Collection Frequency: every 5 seconds (1K2) or 1.25 seconds (4K8)
Storage Count: 0 (real time!)

Bit total	Frame Type + SAT ID	Data Source	Data Type	Data Channel Name
8	1 & 2	Local	UNSIGNED8	SAT ID 2 bits, Frame type 6 bits
16	1 & 2	Local	UNSIGNED8	SAT ID 6 Bits, Frame type 2 bits
24	1 & 2	*AMSAT CCT*	UNSIGNED8	EPS DC/DC Converter output voltage (10b) 0.100*x V
32	1 & 2	*AMSAT CCT*	UNSIGNED8	EPS DC/DC Converter output current (10b) 5.131579*x mA
40	1 & 2	*AMSAT CCT*	UNSIGNED8	EPS DC/DC Converter temperature (10b) y = -0.7796212*x + 98.19402 degC
48	1 & 2	*AMSAT CCT*	UNSIGNED8	EPS Enclosure temperature (10b) y = -0.7385868*x + 97.74249 degC
56	1 & 2	*AMSAT CCT*	UNSIGNED8	CCT Processor temperature (10b) y = -0.7725984*x + 94.95152 degC
64	1 & 2	*AMSAT CCT*	UNSIGNED8	EPS 3.3 V Voltage (10b) 0.031141509*x V
72	1 & 2	*AMSAT CCT*	UNSIGNED8	EPS 3.3 V Current (10b) 3.75*x mA
80	1 & 2	*AMSAT CCT*	UNSIGNED8	EPS Transponder 6/9 V Voltage (10b) 0.0885753425*x V
88	1 & 2	*AMSAT CCT*	UNSIGNED8	EPS Transponder 6/9 V Current (10b) y = (x-2) * 2.5941175 mA
96	1 & 2	*AMSAT CCT*	UNSIGNED8	EPS 9 V Voltage (10b) 0.088171498*x V
104	1 & 2	*AMSAT CCT*	UNSIGNED8	EPS 9 V Current (10b) 2.52778*x mA
112	1 & 2	*AMSAT TX*	UNSIGNED8	VHF transmitter forward power $y = 0.0136x^2 + 0.4995x + 1E\text{-}12$
120	1 & 2	*AMSAT TX*	UNSIGNED8	VHF transmitter reflected power $y = 0.0136x^2 + 0.4995x + 1E\text{-}12$
128	1 & 2	*AMSAT TX*	UNSIGNED8	FM power amplifier temperature (10b) y = -0.789929*x + 97.5934 degC
136	1 & 2	*AMSAT TX*	UNSIGNED8	BPSK power amplifier temperature (10b) y = -0.8104347*x + 91.93637 degC
144	1 & 2	*AMSAT TX*	UNSIGNED8	BPSK power amplifier current (10b) y = 2.18x mA

152	1 & 2	*AMSAT TX*	UNSIGNED8	BPSK 3.3V supply current (Osco + driver amp) y = 0.8x V
160	1 & 2	*AMSAT RX*	UNSIGNED8	L-Band transponder receiver RSSI (10b) (See end of table)
168	1 & 2	*AMSAT RX*	UNSIGNED8	L-Band command receiver RSSI (10b) (See end of table)
176	1 & 2	*AMSAT RX*	UNSIGNED8	L-Band command receiver Doppler (10b) (See end of table)
184	1 & 2	*AMSAT RX*	UNSIGNED8	L-Band CMD receiver oscillator temperature (10b) y = -0.8592393*x + 94.30121 degC
192	1 & 2	*AMSAT CCT*	UNSIGNED24	Sequence number
216	1 & 2	*AMSAT CCT*	UNSIGNED8	Last Command
224	1 & 2	*AMSAT CCT*	UNSIGNED3	RF Mode: 0x00: Receive only, with data collection 0x01: Low power BPSK telem mode 0x02: High power BPSK telem mode 0x03: Low power transponder mode 0x04: High power transponder mode 0x05: Autonomous Mode
227	1 & 2	*AMSAT CCT*	UNSIGNED2	Data Mode: 0x00: AMS + ESEO data mode at 1k2 (default) 0x01: AMS + ESEO data + Payload mode at 4k8
229	1 & 2	*AMSAT CCT*	1	Payload Transfer Status: 0x00: Get data from payload 0x01: Downlink data to ground
230	1 & 2	*AMSAT CCT*	 1 1 1	FM Transponder Status: ESEO Eclipse State (0 = no, 1 = yes) Autonomous Mode State (0 = A, 1 = B) CTCSS Detect State (0 = OFF, 1 = ON)
233	1 & 2	*AMSAT CCT*	1	Safe mode state
234	1 & 2	*AMSAT CCT*	1	In Safe mode (over temperature protection - Traco)
235	Only 1	*ESEO OBC*	UNSIGNED16	PMM_VOLTAGE_SP1_STRING_1 Solar panel voltage for eclipse detection
251	Only 1	*ESEO OBC*	UNSIGNED16	PMM_VOLTAGE_SP2_STRING_1
267	Only 1	*ESEO OBC*	UNSIGNED16	PMM_VOLTAGE_SP3_STRING_1
283	Only 1	*ESEO OBC*	UNSIGNED8	ESEO OBD_MODE 0x00: OBDH power up 0x01: AOCS initialization 0x02: AOCS damping 0x04: AOCS normal SUN 0x08: AOCS normal ECLIPSE 0x10: Safe mode S1: minor main bus power down 0x20: Safe mode S2: sever main bus power down 0x40: Safe mode S3: major main bus power down
291	Only 1	*ESEO OBC*	UNSIGNED20	ESEO OBD_EQUIPMENT_STATUS: 0: TMTC main ON/OFF 1: TMTC redundant ON/OFF 2: Power Management Unit main ON/OFF 3: Power Management Unit redundant ON/OFF 4: Sun sensor main ON/OFF 5: Sun sensor redundant ON/OFF 6: Earth sensor ON/OFF 7: Magnetometer main ON/OFF 8: Magnetometer redundant ON/OFF 9: Magnetic Torquer main ON/OFF 10: Magnetic Torquer redundant ON/OFF 11: Momentum Wheel main ON/OFF 12: Momentum Wheel redundant ON/OFF 13: TRITEL ON/OFF

				14: Langmuir Probe ON/OFF 15: uCAM ON/OFF 16: De-orbit mechanism ON/OFF 17: AMSAT-UK ON/OFF (Always on) 18: S-Band ON/OFF 19: GPS receiver ON/OFF
311	Only 1	*ESEO OBC*	UNSIGNED8	OBD_WD_RESET_COUNT
319	Only 1	*ESEO OBC*	REAL32	ACS_OMEGA_P (Roll, deg/s)
351	Only 1	*ESEO OBC*	REAL32	ACS_OMEGA_Q (Pitch, deg/s)
383	Only 1	*ESEO OBC*	REAL32	ACS_OMEGA_R (Yaw, deg/s)
415	Only 1	*ESEO OBC*	UNSIGNED8	STX_TEMP_4 (S-band Amplifier temperature)
423	Only 1	*ESEO OBC*	UNSIGNED8	PMM_VOLTAGE_MB (16b) (Main Bus Voltage)
Total	431 bits	Spare = 1 bits		
235	Only 2	*ESEO OBC*	REAL32	ACS_ORBIT_x (Orbital position)
267	Only 2	*ESEO OBC*	REAL32	ACS_ORBIT_y
299	Only 2	*ESEO OBC*	REAL32	ACS_ORBIT_z
331	Only 2	*ESEO OBC*	UNSIGNED16	PMM_AMSAT_CURRENT (16b) (AMSAT Switch current)
347	Only 2	*ESEO OBC*	UNSIGNED8 (was 16)	MWM_VOLTAGE (Momentum wheel Measured DC-link voltage)
355	Only 2	*ESEO OBC*	UNSIGNED16	MWM_CURRENT (Momentum wheel Measured current)
371	Only 2	*ESEO OBC*	UNSIGNED16	MWM_OMEGAMESURED (Measured rotation speed)
387	Only 2	*ESEO OBC*	SIGNED16	MPS_HPT01 (High Pressure Transducer measures tank pressure)
403	Only 2	*ESEO OBC*	SIGNED12	PMM_TEMP_SP1_SENS_1 (Temp. of the solar panel 1)
415	Only 2	*ESEO OBC*	SIGNED12	PMM_TEMP_BP1_SENS_1 (Temp. of battery pack 1)
Total	427 bits	Spare = 5 bits		

Equations for Transponder RSSI, Command RSSI and Command Doppler:

Transponder RSSI // Transponder RSSI -dBm
double[,] valToAdc = { { -120, double.MinValue }, { -120, 108 }, { -118, 110 }, { -116, 112 }, { -115, 114 }, { -114, 116 }, { -113, 117 }, { -112, 118 }, { -111, 120 }, { -110, 122 }, { -109, 123 }, { -108, 124 }, { -107, 126 }, { -106, 128 }, { -105, 130 }, { -104, 131 }, { -103, 133 }, { -102, 134 }, { -101, 136 }, { -100, 137 }, { -99, 139 }, { -98, 140 }, { -96, 144 }, { -94, 147 }, { -92, 151 }, { -90, 154 }, { -88, 157 }, { -86, 159 }, { -84, 161 }, { -82, 163 }, { -80, 165 }, { -78, 168 }, { -76, 171 }, { -74, 174 }, { -72, 176 }, { -70, 178 }, { -68, 179 }, { -66, 180 }, { -64, 181 }, { -64, double.MaxValue } };

Command RSSI // Command RSSI -dBm
double[,] valToAdc = { { -120, double.MinValue }, { -120, 93 }, { -118, 95 }, { -117, 96 }, { -116, 98 }, { -114, 100 }, { -113, 101 }, { -112, 103 }, { -111, 104 }, { -109, 106 }, { -108, 108 }, { -107, 109 }, { -106, 110 }, { -105, 111 }, { -104, 113 }, { -103, 114 }, { -102, 116 }, { -101, 117 }, { -100, 118 }, { -99, 119 }, { -98, 121 }, { -96, 124 }, { -94, 127 }, { -92, 130 }, { -90, 133 }, { -88, 135 }, { -86, 136 }, { -84, 138 }, { -82, 140 }, { -80, 142 }, { -78, 145 }, { -76, 147 }, { -74, 150 }, { -72, 152 }, { -70, 153 }, { -68, 155 }, { -64, 156 }, { -64, double.MaxValue } };

Command Doppler// Command Doppler +/-kHz
double[,] valToAdc = { { -9.0, double.MinValue }, { -9.0, 140 }, { -8.0, 139 }, { -7.0, 138 }, { -6.0, 136 }, { -5.0, 134 }, { -4.0, 131 }, { -3.0, 128 }, { -2.0, 124 }, { -1.0, 120 }, { 0.0, 115 }, { +1.0, 110 }, { +2.0, 105 }, { +3.0, 100 }, { +4.0, 95 }, { +5.0, 91 }, { +6.0, 87 }, { +7.0, 84 }, { +8.0, 82 }, { +9.0, 80 }, { +10, 78 }, { +11, 77 }, { +12, 76 }, { +12, double.MaxValue } };

Whole Orbit Data:
Collection Frequency: Every 60 seconds
Storage Count: 100 (minutes)

Total Bits	Frame Type	Bits per src	Data Source	Bits Per Channel	Data Channel Name
298 Bits x 100 = 3725 bytes	***Whole Orbit Data 298 bits***	88	AMSAT EPS	UNSIGNED8	A: CCT Processor Temp. (10b) y = -0.7725984*x + 94.95152 degC
				UNSIGNED8	B: Enclosure temp. (10b) y = -0.7385868*x + 97.74249 degC
				UNSIGNED8	C: DCDC Converter temp. (10b) y = -0.7796212*x + 98.19402 degC
				UNSIGNED8	D: DCDC Supply Current (10b) 5.131579*x mA
				UNSIGNED8	E: DCDC Supply Voltage (10b) 0.100*x V
				UNSIGNED8	F: EPS 6/9V Transponder supply voltage (10b) 0.0885753425*x V
				UNSIGNED8	G: EPS 9V Voltage (10b) 0.088171498*x V
				UNSIGNED8	H: EPS 3V3 Voltage (10b) 0.031141509*x V
				UNSIGNED8	I: EPS 6/9V Transponder supply current (10b) y = (x-2) * 2.5941175 mA
				UNSIGNED8	J: EPS 3V3 Current (10b) 3.75*x mA
				UNSIGNED8	K: EPS 9V Current (10b) 2.52778*x mA
		32	AMSAT L-RECEIVER	UNSIGNED8	L-Band transponder RSSI freq. (10b) (See end of table)
				UNSIGNED8	L-Band command Doppler (10b) (See end of table)
				UNSIGNED8	L-Band command RSSI (10b) (See end of table)
				UNSIGNED8	L-Band command oscillator temp. (10b) y = -0.8592393*x + 94.30121 degC
		48	AMSAT VHF TRANSMITTER	UNSIGNED8	A: BPSK PA temp. (10b) y = -0.8104347*x + 91.93637 degC
				UNSIGNED8	B: Forward power (10b) y = 0.0136x^2 + 0.4995x + 1E-12
				UNSIGNED8	C: Reverse power (10b) y = 0.0136x^2 + 0.4995x + 1E-12
				UNSIGNED8	D: BPSK PA Current (10b) y = 2.18x mA
				UNSIGNED8	E: FM PA Current (10b) y = 2.18x mA
				UNSIGNED8	F: FM PA temp. (10b) y = -0.789929*x + 97.5934 degC G: <Unused> H: <Unused>
		50	AMSAT CCT	UNSIGNED8	Command Watchdog time remaining (hours)
				UNSIGNED4	No. of uplink packets received (16b)
				UNSIGNED8	RAM Memory Error Count CAN Bus Communications Status Packet 1:
				UNSIGNED13	ESEO Master, CANopen Transactions (32b)
				UNSIGNED4	AMS Master, Payload Number (4b),
				UNSIGNED13	AMS Master, CANopen Transactions (32b)
		48	ESEO CAN		From AS-12_0005-SYS-PLA-OBDH-AR-03.pdf:

		(EPS)	SIGNED8	PMM_TEMP_SP1_SENS_1 (16b), Solar panel 1 temperature
			SIGNED8	PMM_TEMP_SP2_SENS_1 (16b)
			SIGNED8	PMM_TEMP_SP3_SENS_1 (16b)
			SIGNED8	PMM_CURRENT_BP1 (16b), Battery pack 1 current
			UNSIGNED16	PMM_VOLTAGE_MB (16b), Main Bus Voltage
	32	ESEO CAN (ADCS)	SIGNED32	Absolute angular rotation (use ACS P, Q, R)
(37.25 Bytes * 100 Storage Count) = 3725 bytes				
4000 bytes / 200 (payload size) = 20= Transmitted in 20 payloads				

Equations for Transponder RSSI, Command RSSI and Command Doppler:

Transponder RSSI // Transponder RSSI
double[,] valToAdc = { { -120, double.MinValue }, { -120, 108 }, { -118, 110 }, { -116, 112 }, { -115, 114 }, { -114, 116 }, { -113, 117 }, { -112, 118 }, { -111, 120 }, { -110, 122 }, { -109, 123 }, { -108, 124 }, { -107, 126 }, { -106, 128 }, { -105, 130 }, { -104, 131 }, { -103, 133 }, { -102, 134 }, { -101, 136 }, { -100, 137 }, { -99, 139 }, { -98, 140 }, { -96, 144 }, { -94, 147 }, { -92, 151 }, { -90, 154 }, { -88, 157 }, { -86, 159 }, { -84, 161 }, { -82, 163 }, { -80, 165 }, { -78, 168 }, { -76, 171 }, { -74, 174 }, { -72, 176 }, { -70, 178 }, { -68, 179 }, { -66, 180 }, { -64, 181 }, { -64, double.MaxValue } };

Command RSSI // Command RSSI
double[,] valToAdc = { { -120, double.MinValue }, { -120, 93 }, { -118, 95 }, { -117, 96 }, { -116, 98 }, { -114, 100 }, { -113, 101 }, { -112, 103 }, { -111, 104 }, { -109, 106 }, { -108, 108 }, { -107, 109 }, { -106, 110 }, { -105, 111 }, { -104, 113 }, { -103, 114 }, { -102, 116 }, { -101, 117 }, { -100, 118 }, { -99, 119 }, { -98, 121 }, { -96, 124 }, { -94, 127 }, { -92, 130 }, { -90, 133 }, { -88, 135 }, { -86, 136 }, { -84, 138 }, { -82, 140 }, { -80, 142 }, { -78, 145 }, { -76, 147 }, { -74, 150 }, { -72, 152 }, { -70, 153 }, { -68, 155 }, { -64, 156 }, { -64, double.MaxValue } };

Command Doppler// Command Doppler
double[,] valToAdc = { { -9.0, double.MinValue }, { -9.0, 140 }, { -8.0, 139 }, { -7.0, 138 }, { -6.0, 136 }, { -5.0, 134 }, { -4.0, 131 }, { -3.0, 128 }, { -2.0, 124 }, { -1.0, 120 }, { 0.0, 115 }, { +1.0, 110 }, { +2.0, 105 }, { +3.0, 100 }, { +4.0, 95 }, { +5.0, 91 }, { +6.0, 87 }, { +7.0, 84 }, { +8.0, 82 }, { +9.0, 80 }, { +10, 78 }, { +11, 77 }, { +12, 76 }, { +12, double.MaxValue } };

Fitter Messages:
Collection Frequency: N/A
Storage Count: 4

Total Bits	Frame Type	Bits per source	Data Source	Bits Per Channel	Data Chanel Name
1600 bits ***200 bytes***	***Fitter Message Data***	**1600**	**RAM**	1600	Fitter message
(200 Bytes * 4 Storage Count) = 800 bytes					
800 bytes / 200 (payload size) = 4 = Transmitted in 4 payloads					

6 Transmission Schedule

The above data collection strategy results in:

20 Whole orbit frames

4 Fitter message frames

Each frame also contains the Real Time Telemetry information. The order of frames will be as shown below:

Frame Type	Frame Type	Frame id
RTT1 + Fitter Message	FM1	01
RTT2 + Whole Orbit	W01	02
RTT1 + Whole Orbit	W02	03
RTT2 + Whole Orbit	W03	04
RTT1 + Whole Orbit	W04	05
RTT2 + Whole Orbit	W05	06
RTT1 + Fitter Message	FM2	07
RTT2 + Whole Orbit	W06	08
RTT1 + Whole Orbit	W07	09
RTT2 + Whole Orbit	W08	10
RTT1 + Whole Orbit	W09	11
RTT2 + Whole Orbit	W10	12
RTT1 + Fitter Message	FM3	13
RTT2 + Whole Orbit	W11	14
RTT1 + Whole Orbit	W12	15
RTT2 + Whole Orbit	W13	16
RTT1 + Whole Orbit	W14	17
RTT2 + Whole Orbit	W15	18
RTT1 + Fitter Message	FM4	16
RTT2 + Whole Orbit	W16	20
RTT1 + Whole Orbit	W17	21
RTT2 + Whole Orbit	W18	22
RTT1 + Whole Orbit	W19	23
RTT2 + Whole Orbit	W20	24

In 1K2 mode, each frame requires 5 seconds to transmit the sequence of frames and will repeat every 120 seconds (two minutes).