Foresail-1p

Spacecraft Space/Ground Interface Control Document

(Draft: Housekeeping TBU)

PUBLIC DOCUMENT

Aalto University

School of Electrical Engineering

Authors

Name	Worked with parts
Petri Niemelä	Whole Document
Markus Hiltunen	Skylink
Baris Dinc	Radio Amateur Repeater
Topi Räty	Updates for FS1p

Table of Contents

1 General

1.1 Scope

This document describes the complete interface description between the Foresail-1p satellite and the ground segment. In context of this document, the ground segment term covers any ground based satellite receiving station capable of receiving at the 70 cm radio amateur band. This document has been written to be complete, without referring to the project's internal documentation and targeted for the radio amateur and satellite tracker community around the globe.

1.2 Reference documents

RD-01	FS1 UHF Skylink Protocol specification
RD-02	ECSS-E-ST-70-41C Packet Utilization Standard (PUS-C)
RD-03	AX.25 & APRS specification

1.3 Document-specific Abbreviations and Acronyms

APR	Amateur Packet Repeater
GMSK	Gaussian Minimum Shift Keying
HAM	Radio Amateur
IARU	International Amateur Radio Union
MAC	Medium Access Control
TDD	Time Division Duplex
UHF	Ultra High Frequency (generally 300 - 3000 MHz, 430 MHz in this document) Used to refer to UHF-band Telemetry, Tracking and Commanding subsystem.
BATT	Battery Subsytem
OBC	On-board Computer
EPS	Electrical Power System (consists PCDU and BATT)
PB	Plasma Brake
PCDU	Power Conditioning and Delivery Unit
PATE	Particle Telescope
ST	Telecommand/Telemetry Service Type following the PUS
SST	Telecommand/Telemetry Service Sub Type
TM(*A*,*B*)	Telemetry Service Type A and Sub Type B.

2 Foresail-1p Communication System

The Foresail-1p satellite is a 3U cubesat which operates at the 70 cm (436 - 438MHz) radio amateur band. The mission is a successor to Foresail-1 and utilizes the same communication scheme, but has an updated telemetry structure. The satellite operates at a 437.125 MHz frequency with +/- 10kHz of Doppler shift and covers a 20 kHz bandwidth. The frequency has been coordinated with the Finnish radio amateur community and the International Amateur Radio Union (IARU application), and has been accepted by the International Telecommunication Union (ITU). The same operating frequency is used for both satellite telecommanding and telemetry, and it also implements amateur radio repeater functionalities.

The satellite's general transmission parameters are:

- Center frequency: 437.125 MHz with +/- 10kHz Doppler shift
- Bandwidth: 20 kHz
- Modulation: GMSK
- Data/Symbol rate: 4800, 9600 (nominal), 19200, or 38400 bauds
- Output power 1.3 Watts (32 dBm)
- Polarization: Circular polarization
    - Handiness of the circular polarization depends on the satellite attitude.
    - With any linear polarization the satellite can be received with 3dB attenuation and minimum fading.
- Framing: Skylink PHY (GOMSpace Mode 5 Compatible) [RD-01]
    - Preamble: 6 x 0xAA (5 ms @ 9600 bauds)
    - Sync word: 0x1A 0xCF 0xFC 0x1D
    - Length: 24-bit long Golay-24 coded field
        - Lower 8 bits codes the payload length. Rest of the bits are zeros.
    - Payload/RS codeword: max 223 bytes
    - RS Parity bytes: 32 bytes long Reed Solomon. CCSDS RS(255,223)
- Windowed Time Division Duplex (TDD)
    - Window lengths will vary based on transfer demand.
- The satellite can be expected to be active every 60 seconds on average broadcasting a multiframe beacon. Regularly transmitted beacon frames are:
    - OBC Housekeeping TM(5,2) on VC1
    - EPS Housekeeping TM(5,3) on VC1
    - ADCS Housekeeping TM(5,4) on VC1
    - UHF Housekeeping TM(5,5) on VC1
    - Deployment Housekeeping TM(5, 6) on VC1:
        - Transmitted only for a period after the launch.
    - Radio amateur packet repeater beacon messages on VC3.

2.1 Ground Segment

The primary ground station used for commanding the Foresail-1p satellite is located in Otaniemi, Espoo, Finland at Aalto University's premises. The satellite is usually commanded on passes over Finland and the satellite's two-way communication can be generally received all over Europe. The mission has been designed to support 3rd party ground stations and Foresail-1p also supports a downlink-only style file transfer mode whose transmissions can be heard over mission 3rd party ground stations. The feature is included to increase downlink potential via collaborating radioamateur networks.

TODO

Figure 1: Coverage of the Otaniemi ground station

The Foresail-1p mission control software can utilize incoming telemetry frames from various sources, such as SiDS databases. Received telemetry frames from the HAM radio community are also greatly appreciated.

2.2 Skylink Protocol

The Foresail-1p satellite uses the Skylink protocol for its communication. The protocol was designed for the mission and is designed to push forward from the AX.25-era. The detailed protocol specification can be found from RD-01 and the implementation is freely available at: https://github.com/aaltosatellites/skylink

Briefly describing, the Skylink protocol contains a physical layer specification which closely follows the widely adopted "industry standard", which has evolved during the last years, with a transport layer protocol on top of it.

The transport layer protocol implements many features useful for implementing a small satellite commanding link. The general specifications are:

- Four logical virtual channels for mission specific purposes
- Windowed Time Division Duplexing (TDD)
- Reliable data transfer using automatic retransmission (ARQ)
- Uplink and downlink data authentication

The Skylink's simplified frame format is illustrated in Figure 2.

Figure 2: Simplified Skylink frame structure

- Protocol Identifier and identifier length (1 byte)
  - Fixed 0x66 ('`f`' in ASCII)
- Satellite Identifier: (6 bytes)
  - 0x4F 0x48 0x32 0x46 0x31 0x53 ('`OH2F1S`' in ASCII)
- Flags: (4-bits)
  - Reserved 2 bits (MSB)
  - HAS_PAYLOAD
    - Shall be 1 if payload. 0 only for idle and other control frames.
    - If 0 and the payload field has non zero length, the payload content shall be ignored.
  - ARQ_ON
  - HAS_AUTHENTICATION
    - If set, the last 8 bytes in the frame are authentication code.
    - The satellite uplink and downlink are authenticated for VC0 to VC2. The VC3 can be without authentication and the downlink is not authenticated.
- Virtual channel: (3-bits)
  - Virtual channel index to differentiate the logical channels.
  - The VC index also determines the protocol used inside the payload field!
  - The virtual channels for Foresail-1p are listed in Table 1.
- Extension Header length (8-bits)
  - The length of the extension header field immediately followed this field.
- Frame Sequence counter (16-bits)
- Extension header: N x (8-bits)
  - Header section for varying header and control data.
  - The content of the field can be ignored by the telemetry receivers.

    - The details for decoding the field can be found from RD-01.
- Payload: N x (8-bits) (max 205 bytes)
    - The actual telemetry data.
- Authentication: 8 x 8-bits
    - Field used to authenticate the source of the frame and only present if the HAS_AUTHENTICATION flag in the header is set.
    - Used only by the Foresail mission control software. The field can be ignored by other telemetry receivers.
- FEC: 32x 8-bits
    - Reed Solomon error correction code as in RS(255,223) defined by CCSDS. (TODO REF)

The Skylink protocol specification has been written to be generic and suitable for any mission. As a general description of the protocol and how the channels are used, please see the Table below.

Table 1: FORESAIL-1 virtual channels

Virtual Channel #	Name	Description
0	Commanding	• Used for satellite telecommanding and telemetry/acknowledgment reception. • Conveys CCSDS/ECSS PUS frames. • Can be configured for reliability. • Authenticated channel.
1	Mass data transfer	• Used for mass data transfer such as file transfer. • Conveys CCSDS/ECSS PUS frames. • Can be configured for reliability. • Authenticated channel
2	Service channel	• Can be configured for reliability. • Custom control protocol for the radio and electrical power system. • Authenticated channel.
3	HAM repeater	• Used for HAM repeater functionalities. • Conveys AX.25 UI-frames. • Unreliable transfer only. • Non-authenticated channel.

2.3 ECSS PUS Telemetry format

The satellite's main telemetry data is generated by the On-Board Computer (OBC) and conveyed inside the Skylink data transfer frames on virtual channels 0 and 1. The telemetry frame format follows the ECSS Packet Utilization Standard (PUS-C) with heavy tailoring [RD-02].

The simplified PUS frame format structure is illustrated in Figure 3. Standard PUS frame formats

are used for service numbering and only service type 1: Telecommand verification follows exactly the standard. Each telemetry (and telecommand) frame type can be identified with service type and subtype numbers. This naming followed later in the document and for example TM(5, 2) where service type is 5 and service subtype is 2. Satellite uses alway Application Process ID (APID) 820.

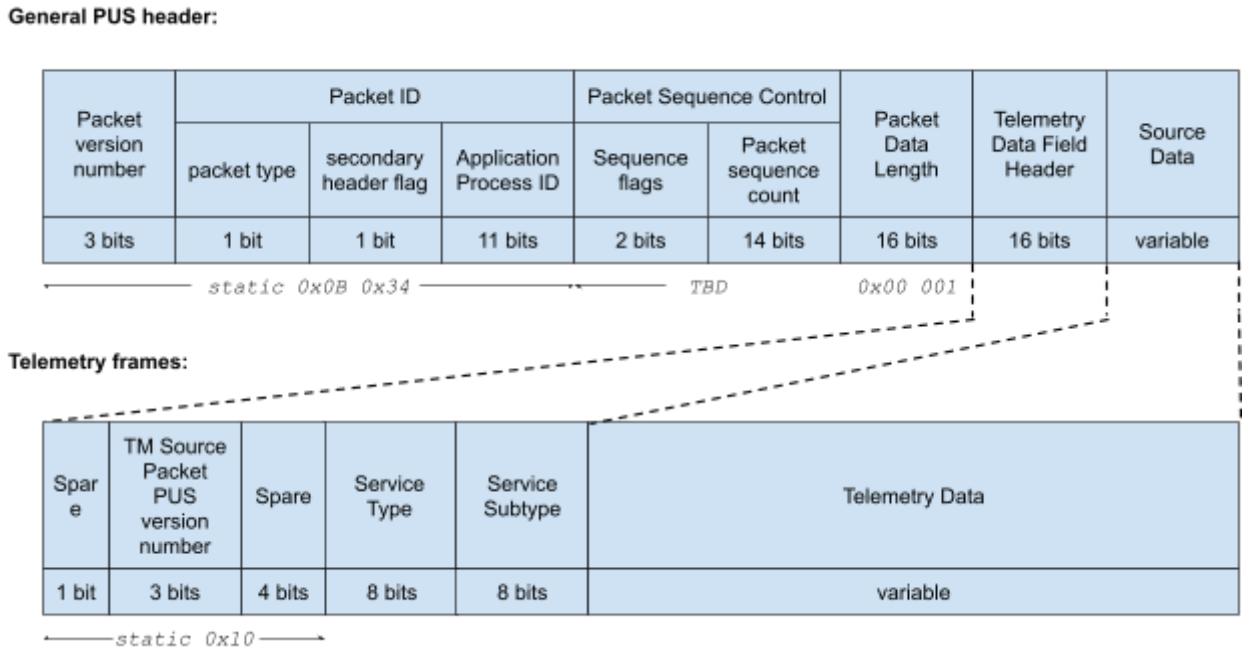

Figure 3: Simplified PUS Telemetry frame format used for Foresail-1p satellite

3 Housekeeping Data Structures

The Foresail-1p housekeeping data is transmitted on PUS telemetry frames using service type 5. Housekeeping service subtypes are described in the following subsections.

Each housekeeping payload structure starts with a big endian 32-bit unsigned integer which conveys the timestamp when the data was collected as an UNIX timestamp (seconds since the UNIX epoch 00:00:00 1.1.1970 UTC). During passes over commanding ground stations, the same telemetry types are used to downlink historical housekeeping. Thus, the housekeeping frame timestamp might indicate a time in the past 0 to 24 hours (TBU).

3.1 OBC Housekeeping (TBU)

The OBC housekeeping data is transmitted using housekeeping service TM(3, 2). The telemetry frame's payload section has the following structure:

Table 2: OBC Housekeeping structure

Pos	Type	Name	Description
0	UINT8	Redundancy Side	Currently running OBC side/configuration 0 = Side-A 1 = Side-B 2 = Side-A recovery 3 = Side-B recovery

1	UINT8	FDIR state	OBC SW FDIR state/mode
2	UINT8	Scheduler state	OBC SW Scheduler state
3	UINT8	Software Revision	The running software revision number.
4	UINT32	Uptime	OBC uptime in seconds
8	UINT8	Heap Free	Heap free (0 = 0%, 255 = 100%)
9	UINT8	CPU Load	Estimate CPU load (0 = 0%, 255 = 100%)
10	UINT16	File System free space	Free space in the filesystem (multiply of 4kBytes).
12	UINT16	Arbiter uptime	Arbiter uptime in seconds. Overflows every 18.2 hours
14	UINT16	Arbiter age	Arbiter's monotonic slow rate counter
16	UINT16	Arbiter bootcount	Arbiter bootcount
18	INT16	Arbiter temperature	Arbiter MCU temperature in desi Celsius degrees.
20	UINT8	Side A Bootcount	OBC Side-A total bootcount
21	UINT8	Side A Heartbeats	Last heartbeat count received from the OBC Side-A
22	UINT8	Side A Fail Counter	OBC Side-A failure counter
24	UINT8	Side A Fail Reason	OBC Side-A failure reason
25	UINT8	Side B Bootcount	OBC Side-B total bootcount
26	UINT8	Side B Heartbeats	Last heartbeat count received from the OBC Side-B
27	UINT8	Side B Fail Counter	OBC Side-B failure counter
28	UINT8	Side B Fail Reason	OBC Side-B failure reason
29	4*UINT16	Arbiter log	Binary formatted log of arbiter's actions

3.2 EPS Housekeeping (TBU)

The EPS housekeeping data is transmitted using the housekeeping service TM(3,3). The telemetry frame's payload section has the following structure:

Table 2: EPS (PCDU+BATT) Housekeeping structure

Pos	Type	Name	Description
0	UINT32	Uptime	PCDU MCU Uptime in seconds.
4	UINT8	PCDU Boot count	PCDU MCU boot count
5	UINT8	PDM Expected	Power distribution switch expected enable states: bit 0: PDM0 PATE Batt bit 1: PDM1 PB Batt bit 2: PDM2 PB 3.6V bit 3: PDM3 CAM 3.6V bit 4: PDM4 MAG 3.6V bit 5: PDM5 OBC 3.6V bit 6: PDM6 UHF 3.6V bit 7: PDM7 ADCS 3.6V

6	UINT8	PDM Faults	Power distribution switch fault states. The bit definitions are same as for PDM Expected.
7	UINT8	PCDU Peak Detect Idx	
8	UINT16	Panel X- voltage	Panel X- voltage in milliVolts
10	UINT16	Panel X+ voltage	Panel X+ voltage in milliVolts
12	UINT16	Panel Y- voltage	Panel Y- voltage in milliVolts
14	UINT16	Panel Y+ voltage	Panel Y+ voltage in milliVolts
16	UINT16	Panel X- max voltage	Panel X- maximum voltage in milliVolts[1]
18	UINT16	Panel X+ max voltage	Panel X+ maximum voltage in milliVolts
20	UINT16	Panel Y- max voltage	Panel Y- maximum voltage in milliVolts
22	UINT16	Panel Y+ max voltage	Panel Y+ maximum voltage in milliVolts
24	UINT16	Panel X- current	Panel X- DC/DC converter’s output current in milliAmps.
26	UINT16	Panel X+ current	Panel X+ DC/DC converter’s output current in milliAmps.
28	UINT16	Panel Y- current	Panel Y- DC/DC converter’s output current in milliAmps.
30	UINT16	Panel Y+ current	Panel Y+ DC/DC converter’s output current in milliAmps.
32	UINT16	Panel X- max current	Panel X- DC/DC converter’s maximum output current. in milliAmps.
34	UINT16	Panel X+ max current	Panel X+ DC/DC converter’s maximum output current. in milliAmps.
36	UINT16	Panel Y- max current	Panel Y- DC/DC converter’s maximum output current. in milliAmps.
38	UINT16	Panel Y+ max current	Panel Y+ DC/DC converter’s maximum output current. in milliAmps.
40	UINT16	Batt bus voltage	Battery bus voltage in milliVolts. (nominal 6500 - 8200 mV)
42	INT16	Panel X- temperature	Panel temperature in desi Celsius degrees.
44	INT16	Panel X+ temperature	Panel temperature in desi Celsius degrees.
46	INT16	Panel Y- temperature	Panel temperature in desi Celsius degrees.
48	INT16	Panel Y+ temperature	Panel temperature in desi Celsius degrees.
50	INT16	PCDU temperature	Panel temperature in desi Celsius degrees.
52	UINT16	Buck 1 voltage	Output voltage of the buck converter 1 (UHF & ADCS) in milliVolts. Nominal 3700 mV
54	UINT16	Buck 2 voltage	Output voltage of the buck converter 2 (MAG & OBC) in milliVolts. Nominal 3700 mV
56	UINT16	Buck 3 voltage	Output voltage of the buck converter 3 (PB & CAM) in milliVolts. Nominal 3700 mV
58	UINT16	PATE batt switch: current	PDM0: The immediate PATE batt bus current consumption in milliAmperes. [2]

[1] The nominal panel voltages vary from 0 to 16 Volts and current up to 600 mA.
[2] The power distribution switch minimum and maximum currents are minimum current from the last TBD seconds (configurable).

60	UINT16	PB batt switch: current	PDM1: The immediate Plasma Brake batt bus current consumption in milliAmperes.
62	UINT16	PB 3.6V switch: current	PDM2: The immediate Plasma Brake 3.6V bus current consumption in milliAmperes.
64	UINT16	Cam 3.6V switch: current	PDM3: The immediate Camera 3.6V bus current consumption in milliAmperes.
66	UINT16	Mag 3.6V switch: current	PDM4: The immediate Magnetometer 3.6V bus current consumption in milliAmperes.
68	UINT16	OBC 3.6V switch: current	PDM5: The immediate OBC 3.6V bus current consumption in milliAmperes.
70	UINT16	UHF 3.6V switch: current	PDM6: The immediate UHF Radio 3.6V bus current consumption in milliAmperes.
72	UINT16	ADCS 3.6V switch current	PDM7: The immediate ADCS 3.6V bus current consumption in milliAmperes.
74	UINT16	PATE batt switch: max current	PDM0: The maximum PATE batt bus current consumption in milliAmperes.
76	UINT16	PB batt switch: max current	PDM1: The maximum Plasma Brake batt bus current consumption in milliAmperes.
78	UINT16	PB 3.6V switch: max current	PDM2: The maximum Plasma Brake 3.6V bus current consumption in milliAmperes.
80	UINT16	Cam 3.6V switch: max current	PDM3: The maximum Camera 3.6V bus current consumption in milliAmperes.
82	UINT16	Mag 3.6V switch: max current	PDM4:The maximum Magnetometer 3.6V bus current consumption in milliAmperes.
84	UINT16	OBC 3.6V switch: max current	PDM5: The maximum OBC 3.6V bus current consumption in milliAmperes.
86	UINT16	UHF 3.6V switch: max current	PDM6: The maximum UHF Radio 3.6V bus current consumption in milliAmperes.
88	UINT16	ADCS 3.6V switch max current	PDM7: The maximum ADCS 3.6V bus current consumption in milliAmperes.
90	UINT16	PATE batt switch: min current	PDM0: The minimum PATE batt bus current consumption in milliAmperes.
92	UINT16	PB batt switch: min current	PDM1: The minimum Plasma Brake batt bus current consumption in milliAmperes.
94	UINT16	PB 3.6V switch: min current	PDM2: The minimum Plasma Brake 3.6V bus current consumption in milliAmperes.
96	UINT16	Cam 3.6V switch: min current	PDM3: The minimum Camera 3.6V bus current consumption in milliAmperes.
98	UINT16	Mag 3.6V switch: min current	PDM4:The minimum MATTI (Magnetometer) 3.6V bus current consumption in milliAmperes.
100	UINT16	OBC 3.6V switch: min current	PDM5: The minimum OBC 3.6V bus current consumption
102	UINT16	UHF 3.6V switch: min current	PDM6: The minimum UHF Radio 3.6V bus current consumption in milliAmperes.
104	UINT16	ADCS 3.6V switch min current	PDM7: The minimum ADCS 3.6V bus current consumption in milliAmperes.
106	UINT16	Battery Board: State	bits 6-15: Reserved bits 4-6: Heater state (0=off, 1=on, 2-4=fault states) bits 0-3: Balancer state (0=idle, 1=balancing upper cell, 2=balancing lower cell, 3-4=fault states)

108	UINT8	Battery Board: Boot count	Battery board boot count
109	UINT8	Battery Board: WDT reset	Battery board watchdog timer resets
110	UINT8	Battery Board: Bus timeouts	Battery board no communication timeouts
111	UINT8	Battery Board: BPC fails	Battery Protection Circuits failures (overcurrent trips)
112	UINT16	Battery Board: Battery pack voltage	Voltage over the complete battery pack (2S2P) in milliVolts.
114	UINT16	Battery Board: Lower cell voltage	Voltage at the middle of the battery pack in milliVolts.
116	UINT16	Battery Board: Switch Current	Immediate battery switch current
118	UINT16	Battery Board: Min Current	The minimum current measured during the last TBD seconds.
120	UINT16	Battery Board: Max Current	The maximum current measured during the last TBD seconds.
122	UINT16	Battery Board: Battery pack temperature	Battery Pack temperature in desi Celsius degrees.
124	UINT16	Battery Board: Battery board temperature	Battery Board temperature in desi Celsius degrees.
126	UINT16	Battery Board: Heater PWM	Battery heater PWM on-time 5000 count = 100%

3.3 ADCS Housekeeping (TBU)

The ADCS housekeeping data is transmitted using the housekeeping service TM(3,4). The telemetry frame's payload section has the following structure:

Table 2: ADCS Housekeeping structure (58 bytes)

Pos	Type	Name	Description
0	UINT8	Determination State	0 = Off 1 = Triad 2 = Kalman
1	UINT8	Control State	0 = Off 1 = Bdot 2 = Spin Control 3 = PD Control
2	FLOAT	MJD	ADCS systems current time as Modified Julian Date
6	3x FLOAT	Position vector	Orbit propagators output position vector in ECI frame. Units in kilometers.
18	3x FLOAT	Velocity vector	Orbit propagators output velocity vector in ECI frame. Units in kilometers per second.
30	3x FLOAT	Angular Rate	Satellite angular rates (Pitch, Yaw, Roll) as radians per second.
42	4x FLOAT	Attitude Quaternion	Satellite attitude as a quaternion in ECI frame. Element order: x,y,z,w

3.4 UHF Housekeeping (TBU)

The UHF housekeeping data is transmitted using the housekeeping service TM(3,5). The telemetry frame's payload section has the following structure:

Table 2: UHF Housekeeping structure (42 bytes)

Pos	Type	Name	Description
0	UINT32	Uptime	MCU uptime in seconds
4	UINT16	Bootcount	Number of boots
6	UINT8	WDT Resets	Watchdog Timer resets
7	UINT8	SBE Count	Single Bit Errors fixed in memories
8	UINT8	MBE Count	Multi Bit Error fixed in memories
9	UINT8	Bus Sync Errors	
10	UINT8	Bus Len Errors	
11	UINT8	Bus CRC Errors	
12	UINT8	Bus Bug Error	
13	UINT32	Total TX frames	Total number of transmitted frames
17	UINT32	Total RX frames	Total number of received frames
21	UINT32	Total TX HAM frames	Total number of transmitted HAM frames
25	UINT32	Total RX HAM frames	Total number of received HAM frames
29	UINT8	Side	Current hardware redundancy side: 0 = Side-A, 1 = Side-B
30	UINT8	RX mode	
31	UINT8	TX mode	
32	INT16	MCU Temperature	Temperature of the Radio MCU in desi Celsius degrees.
34	INT16	PA Temperature	Temperature of the active side Power Amplifier in desi Celsius degrees.
36	INT8	Last RSSI	RSSI (Relative Signal Strength Indicator) of last received frame. Calibration: rssi = value - 111dBm
38	INT8	Background RSSI	RSSI of the background noise. (Same calibration as on previous field)
40	INT16	Last frequency offset	Frequency offset of last received frame . offset = value * 19.07 Hz

3.5 File Transfer

The Foresail-1p satellite mission supports reliable data transfer based on files. The files are transferred by the file transfer system in blocks of 160 bytes which are transmitted as individual frames. These frames can be received during over passes over Finland/Europe or at other times when a downlink-only file transfer has been scheduled.

The file transfer service has the Service Type code 6 and has the following downlink telemetry service types:

- TM(6,7) Downlink Init Report
- TM(6,13) Downlink Transmit

TM(6,7) Downlink Init Report
The downlink init report is a response frame to the downlink init TC or it can be broadcasted when a file dump has been autonomously initialized. Init reports contain crucial information such as its filename, file size and CRC-checksum. The frame payload field has the following structure:

Table: TM(6,7) Downlink Init Report structure

Transfer Index	File size	CRC32	Filename
uint8_t	uint32	uint32	N x char

TM(6,13) Downlink Transmit
The transfer indexes are automatically coordinated by the Foresail-1p mission control software. The standard file block size is 160 bytes. All the blocks except the last one are this length. The frame payload field has the following structure:

Table: TM(6,13) Downlink Transmit structure

Transfer Index	Block Index	Block Data
uint8	uint16	N x uint8

4 Radio Amateur Repeater

The Foresail-1p Amateur Packet Repeater is implemented on the virtual channel number #3 of the Skylink Protocol. This is used for forwarding encapsulated AX.25 / APRS (Automatic Position Reporting System) messages defined by the APRS Protocol Reference V1.0

4.1 Functional Overview

Encapsulated APRS Packets transmitted by Hamradio stations will be forwarded back to Earth by the satellite. These repeated packets include the satellite callsign and can be forwarded for example to APRS.fi by gateway stations operated by HamRadio enthusiasts. Otherwise the repeater can be also used as a general AX.25 repeater without any structure in the information field. No validation or checking is performed for the data inside the AX.25 information field on board.

4.2 Operational description

The Amateur Packet Repeater will function as follows:

- Amateur ground stations can send packets using the Skylink protocol with APRS messages encapsulated as a payload to the targeted Virtual Channel #3
- Any packet arriving on the Skylink Virtual Channel #3 of the satellite link, starting with a known valid AX.25 header (see below), will be modified using the satellite callsign as the repeating station and will be re-transmitted back to the Earth.
- These AX.25 packets will not be forwarded to the satellite internal bus in any situation but repeated during the next available free TDD window on Virtual Channel #3. Exact response time will vary and depends on the Skylink protocol configuration.
- After successful APRS repeating the satellite stores the repeated frame to its non-volatile memory (up to 8 frames) and re-transmits frames from memory.
- The default re-transmit repetition count and repetition interval is 4 times every 4 minutes. These configurations may change during the mission.
- For each forwarded incoming or outgoing APRS packet a counter is increased. These

counters are included in UHF subsystems in housekeeping telemetry.

4.2 APRS Packet Encapsulation

The payload of the Skylink Protocol on Virtual Channel #3 can include an AX.25 frame APRS message described below. The maximum length of an APRS frame (included header, data etc.) is **128 bytes.**

The satellite will add itself to the "Digipeater Addresses" as a digipeating (repeating) station and forward the packet back with a small latency.

The AX.25 Frame All APRS transmissions use AX.25 UI-frames, with 9 fields of data:

	AX.25 UI-FRAME FORMAT								
	Flag	*Destination Address*	*Source Address*	*Digipeater Addresses (0-8)*	*Control Field (UI)*	*Protocol ID*	*INFORMATION FIELD*	*FCS*	*Flag*
Bytes:	1	7	7	0–56	1	1	1–256	2	1

The Field Descriptions are as follows:

- Start flag: Static 0x7E
- Destination Address - This field should contain an APRS destination callsign or APRS destination
    - Accepted destinations are: OH2F1S, APRS, ALL*, BEACON, CQ*
- Source Address - This field should contain the callsign and SSID of the transmitting station
- Digipeater Addresses - Up to 8 digipeater callsigns may be included in this field, the satellite adds its own callsign to this list. If the list already has 8 repeaters then the first one will be discarded and the satellite callsign will be added as the last repeater
- Control Field - This field must always be set to **0x03** (UI-frame)
- Protocol ID - This field must always be set to **0xF0** (no layer 3 protocol)
- Information Field - This field contains APRS data. The first character of this field should be the APRS Data Type Identifier that specifies the nature of the data that follows, which might be;
    - Location information,
    - Weather information,
    - Telemetry,
    - Messages and bulletins,
    - Queries,
    - Query responses
    - Content of the field is not validated.
- Frame Check Sequence: X.25 CRC-16 checksum
- Eng flag: Static 0x7E

A generic APRS Information Field can be seen as;

	Generic APRS Information Field			
	Data Type ID	APRS Data	APRS Data Extension	Comment
Bytes:	1	n	7	n

A basic packet identification on the satellite will be done by checking that the;

- First and last bytes are 0x7E
- Control Field is 0x03
- Protocol ID field is 0xF0
- Checking the FCS (X.25 CRC-16)

Note: Frames not complying to this format will be ignored!

Any HDLC related features (bit stuffing etc.) are not applied and shall not be applied for the payload.

4.3 APRS Packet Encapsulation Examples

Uplink:

0x7E	Start flag
	Destination address: ALL
	Source address: OH2AGS-0
0x30	Control Field: UI-Frame
0xF0	Protocol ID: No layer 3 protocol implemented
…	APRS data or any other message
0x?? 0x??	FCS
0x7E	End flag

Downlink:

0x7E	Start flag
	Destination address: ALL
	Source address: OH2AGS-0

	Repeater address : OH2F1S-11
0x30	Control Field
0xF0	Protocol ID
…	APRS data or any other message
0x?? 0x??	FCS
0x7E	End flag

Broadcast:

0x7E	Start flag
	Destination address: BEACON
	Source address: OH2F1S-11
0x30	Control Field
0xF0	Protocol ID
…	APRS data or any other message
0x?? 0x??	FCS
0x7E	End flag

Appendix A: List of used Telemetry service types

Complete list of all telemetry service type and subtype codes can be found from Telemetry receiver softwares source code in JSON-format.

Service Type	Name	Description
1	Telecommand Verification	Telecommand verification (acknowledgements)
2	Ping	Ping service
3	Housekeeping	Housekeeping service (real-time and historical)
4	Events	On-board Event service
5	Time	Time management service
6	File Transfer	File Transfer service
7	File System	File System service
8	Configuration	On board Configuration System
9	Bus	Bus commanding service
10	FDIR	Failure Detection, Isolation and Recovery service
11	OBC	On-Board Computer commanding service
128	Scheduler	On-Board telecommand scheduler service
129	EPS	Electrical Power System commanding service
130	UHF	UHF TT&C commanding service
131	ADCS	Attitude Determination and Control System (ADCS) commanding
132	ADCS Sensors	ADCS sensor commanding service
133	ADCS Recorder	ADCS data recorder service
134	Compressor	Data compressing and decompressing service
135	PATE	Particle Telescope commanding service
136	Plasma Brake	Plasma Brake commanding service
137	MATTI	Magnetometer commanding service
138	Camera	Camera commanding service
139	ADCS Magnetorquer	Magnetorquer commanding service
140	Sequence	Telecommand sequencer service

Appendix B: Example Frames (TBU)

OBC housekeeping frame (updated)

```
66 4F 48 32 46 31 53 09 C6 7F 05 44 00 FA 00 FA 0B 34 0B 34 00 2D 10 03 02 69 29 A3 6C
00 00 02 00 00 1F 43 3E 00 00 89 00 00 00 51 3E 19 66 A7 00 EE 00 CA 00 03 01 AA 11 00
05 46 04 46 24 E4 05 E4 25 C2 D0 AE F9
```

EPS housekeeping frame (TBU)

```
66 4f 48 32 46 31 53 28 05 00 00 54 00 fa 00 f9 0b 34 0b 34 00 87 10 03 03 62 45 bc d9
19 0d 00 00 39 70 00 9e 8f 0a 00 00 12 0a f9 0a 8f 0a 00 00 1b 0a 02 0b 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 48 1c 25 01 75 fe 25 01 26 01 45 01 a4 0e c8 0e 17 0f
00 00 00 00 00 00 00 00 30 00 4c 00 42 00 00 00 00 00 00 00 00 00 00 00 22 00 46 00 3e
00 00 00 00 00 00 00 00 00 00 00 23 01 53 00 5e 00 00 00 00 00 5c 00 00 00 50 1c 24 0e
a3 00 96 00 27 01 3a 01 2e 01 00 00 57 a1 49 ec b4 c7 9b 06
```

UHF Housekeeping Frame (TBU)

```
66 4f 48 32 46 31 53 28 05 00 01 54 00 fa 00 60 0b 34 0b 34 00 2f 10 03 04 62 45 bc d8
2f 0d 00 00 50 00 04 00 00 87 08 03 00 7e 8a 00 00 71 0c 00 00 24 00 00 00 00 00 00 00
00 02 02 42 01 3c 01 fd 42 d4 ff 98 f5 80 7c 2e 8c a6 98
```

ADCS Housekeeping Frame (TBU)

```
66 4f 48 32 46 31 53 28 05 00 00 54 00 fa 00 f1 0b 34 0b 34 00 41 10 03 05 62 45 bc d8
00 00 9c 15 69 47 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
c4 8d 8e ee 03 d6 4f a3
```

Deployment Housekeeping Frame: (TBU)

```
66 4f 48 32 46 31 53 28 05 00 01 54 00 fa 00 2b 0b 34 0b 34 00 11 10 03 06 62 45 bc d9
11 00 01 02 0a 00 02 00 00 00 5e 5f 88 54 73 7e 90 47
```

Nominal Event (RID: 1011, Timestamp 2022-04-01T12:15:16Z) (TBU)

```
66 4f 48 32 46 31 53 28 05 09 06 54 00 fa 00 f3 0b 34 0b 34 00 0a 10 04 01 62 46 ec d4
03 f3 00 6d 3b 8d dd ad 2a b8 48
```

Execution Completion success acknowledgement TM(1,7)

```
66 4f 48 32 46 31 53 28 05 07 44 54 00 fa 00 f5 0b 34 0b 34 00 09 10 01 07 1b 34 c4 48
00 00 74 23 8b 76 f8 97 dc 9b
```

Ham Repeater Frame

```
66 4f 48 32 46 31 53 23 05 00 02 54 00 fa 00 fa 7e 84 8a 82 86 9e 9c 60 9e 90 64 8c 62
a6 77 03 f0 48 65 6c 6c 6f 20 77 6f 72 6c 64 1c 14 7e
```