Date: December 17, 2022
Version: Version 1.1

Fox-Plus-A

System Requirements Specification

1 Introduction

This document specifies the system level requirements for the first satellite of the AMSAT Fox-Plus satellite project. The initial Fox-Plus satellite will be a 1U CubeSat , designated Fox-Plus-A. Later Fox-Plus satellites are likely to increase in size and capability.

The Fox-Plus project is intended as a follow-on and upgrade to the initial Fox-1 series CubeSat satellites. The first four Fox-1 satellites flew single channel FM repeaters as their communications system. The fifth and final Fox-1 satellite RadFxSat-2, had essentially the same configuration and basic bus structure as the earlier Fox-1 satellites, but with their single channel FM repeater transmitter and receiver replaced with a new wideband linear transponder (LT) This type of amateur radio communications system provides more channels for multiple, simultaneous radio contacts, as well as a higher data rate,. RadFxSat-2 also provided a continuous telemetry downlink.

In addition to its mission as a communications satellite, Fox-Plus-A will have the ability to host an experiment payload. The satellite will reserve mass and volume for the experiment and will provide DC power and communications capability to support experiment data downlinking.

1.1 Document History

DATE	VERSION	AUTHOR	SUMMARY
May 12, 2022	V0.1	M. Moore (K4MVM)	Initial draft
September 23, 2022	V0.2	M. Moore (K4MVM)	Overall content revision including Modes of Operation
October 21, 2022	V0.4	M. Moore (K4MVM)	Comments incorporated
November 14, 2022	V0.5	M. Moore (K4MVM)	Science Mode inserted.
November 18, 2022	V0.6	M. Moore (K4MVM)	General comments incorporated, Figure 1 diagram inserted
December 4, 2022	V0.7	M. Moore (K4MVM)	Clean-up. Comments resolved.
December 7, 2022	V1.0	M. Moore (K4MVM)	Formatted.
December 17, 2022	V1.1	M. Moore (K4MVM)	Changed telemetry downlink, added Daylight Only command

1.2 Document Scope

The purpose of this document is to specify the requirements of the satellite at the system (i.e., "black box") level. It is intended to be used by hardware, software and mechanical designers to develop architecture/high-level design specifications. It is also intended to be used for test planning and development.

1.3 Document Format

This document provides requirements in numbered format. Each requirement is assigned a unique number. Additional information such as comments or examples provided for guidance or clarity is *italicized* to distinguish it from specific requirements.

1.4 References

1. AMSAT Fox-Plus Concept of Operations, Version 1.1, August 16, 2022
2. CubeSat Design Specification, Rev. 14.1, February 2022, The CubeSat Program Cal Poly SLO.
3. Launch Services Program, Program Level Dispenser and CubeSat Requirements Document, LSP-REQ-317.01 Revision B, January 30, 2014, National Aeronautics and Space Administration (NASA).
4. Spaceflight, Inc. General Payload Users Guide SF-2100-PUG-00001, Rev F 2015-22-15, May 22, 2015.
5. ITU Radio Regulations, Edition of 2020, available from https://www.itu.int/pub/R-REG-RR.

2 General Requirements

2.1 CubeSat Requirements

2.1.1 The satellite shall satisfy the requirements specified in Spaceflight, Inc. General Payload Users Guide SF-2100-PUG-00001, Rev F 2015-22-15, May 22, 2015.

2.1.2 The satellite shall satisfy the requirements specified in the CubeSat Design Specification, Rev. 14.1.

2.1.3 The satellite shall satisfy the requirements specified in the NASA LSP-REQ-317.01 Revision B.

2.1.4 The satellite shall satisfy the debris and de-orbit requirements specified in FCC regulations as documented in Title 47 Section 5.64 https://www.ecfr.gov/current/title-47/section-5.64.

2.1.5 The satellite shall satisfy the requirements for a 1 Unit (single) CubeSat.

2.1.6 The satellite shall provide mass for an experiment payload up to 100 g.

2.1.7 The satellite shall provide volume for an experiment payload up to 92 x 92 x 31.4 mm.

2.2 Environmental Requirements

2.2.1 The satellite avionics shall be designed for an operating temperature range of -40^{0}C to +85^{0}C.

2.2.2 The satellite shall be designed to operate in an approximate 500 to 700 km, circular orbit.

2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.

2.3 Reliability Requirements

2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.

2.4 Radio Frequency (RF) Regulatory Requirements

2.4.1 The satellite's RF transmitter shall meet or exceed the requirements specified in ITU Radio Regulations, Volume 1 Articles, Chapter 1 – Terminology and Technical Characteristics of Stations, Article 3.

2.4.2 The satellite transponder uplinks shall be in the 2 meter band of the Amateur Satellite Service.

2.4.3 The satellite transponder downlinks shall be in the 70 cm band of the Amateur Satellite Service.

2.4.4 All satellite transmitter and receiver generated frequencies shall deviate by no more than 5 parts-per-million from their specified values including initial accuracy and temperature variation.

2.4.5 All satellite frequencies shall be coordinated with the IARU.

2.4.6 The command uplink shall be a narrow band FM signal (+/- 5 kHz deviation) located outside of the user transponder passband.
The band plan with the actual coordinated frequencies will be specified in a separate document.

2.4.7 The satellite shall have at least three independent RF inhibits to prohibit inadvertent RF transmissions. (from CubeSat Design Spec 2.3.7)

3 Functional Requirements

3.1 Antenna System

3.1.1 The satellite shall include a deployable antenna system.

3.2 Attitude Control

3.2.1 The satellite shall incorporate passive magnetic stabilization to align the deployed antennas with the magnetic field of the earth.

3.3 Access Ports

3.3.1 The satellite shall include a "Remove Before Flight" (RBF) pin as per the CubeSat Design Specification.

3.3.2 The satellite shall include an umbilical port as per the CubeSat Design Specification.

3.4 Pre-launch Features

3.4.1 The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).

3.4.2 The satellite shall provide a means to charge the battery via the umbilical port while integrated with the dispenser.

3.4.3 The satellite shall provide a means to run diagnostic tests via the umbilical port while integrated with the dispenser regardless of the state of the “Remove Before Flight” pin or the deployment switches.

3.5 Power

3.5.1 The satellite shall produce electrical power from sunlight.

3.5.2 The satellite shall produce electrical power while in sunlight regardless of orientation and while tumbling or spinning.

3.5.3 The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.

3.5.4 The satellite shall not provide battery power to the main bus until approximately 115 seconds after activation of both deployment switches indicating successful launch vehicle dispenser separation.

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3.6 Experiment

3.6.1 The satellite shall provide DC power for an experiment payload.

3.6.2 The satellite shall provide a means to activate and deactivate the experiment payload.

3.6.3 The satellite shall provide a means to telemeter data from the experiment payload.

The experiment payload details will be specified in a separate document.

3.7 RF Uplink

3.7.1 The satellite shall include a linear uplink receiver.

3.7.2 The uplink receiver shall process signals in a linear manner. The receiver will process SSB, CW, PSK, and FSK signals to its intermediate frequency with intermodulation distortion (IMD) products no higher than -50 dBc when the maximum intended level signals are applied to the spacecraft.

3.8 RF Downlink

3.8.1 The satellite shall include a linear downlink transmitter.

3.8.2 The downlink transmitter shall be a linear transmitter with intermodulation products no higher than -20 dBc when the highest level output signal is at maximum output power.

3.9 Transponder

3.9.1 The satellite shall provide linear transponder operation via the RF uplink and RF downlink.

3.9.2 The user transponder shall have a -3dB bandwidth of 30 kHz and a -20dB bandwidth of 50 kHz, referenced to the center of the passband.

3.9.3 The transponder shall be an inverting transponder.

3.9.4 The transponder shall have a means of sensing and adjusting gain so that the highest level throughput signal is not distorted with intermodulation products higher than -20 dBc with multiple signals in the passband.

3.9.5 The transponder gain adjustment shall have a time constant of <TBD> seconds, so that the highest level signal in the passband will not 'pump' other signals in the passband by its modulation.

3.9.6 The transponder shall have a mechanism for detecting the level of signals in the uplink passband. This aggregate level shall have a threshold switching mechanism for deactivating the satellite transmitter when no signals exceed the threshold. The transmitter shall be activated when the threshold is exceeded for approximately one second. The threshold mechanism shall continue to keep the transmitter activated for 30 seconds after the threshold conditions are no longer satisfied.

3.9.7 The transponder shall have a linear gain such that a received CW signal of <TBD> dBm will result in a power output of +20 dBm. Any other signals amplified in the passband shall create IMD products not to exceed -20 dBc in the passband of the transponder.

3.10 Telemetry Data

3.10.1 The satellite shall collect telemetry data.

3.10.2 The telemetry data shall include at a minimum, the measured parameters shown in Table 1.

Table 1

PARAMETER NAME	DESCRIPTION
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
TX T	Temperature of RF transmitter card
RX T	Temperature of RF receiver card
TX PWR FWD	Transmitted RF Power Forward
TX PWR REF	Transmitted RF Power Reflected
RSSI	Received Signal Strength Indication (mW)

3.10.3 The measured parameters shall be sampled at least every 15 seconds.

3.10.4 The minimum and maximum values of each of the measured parameters shall be saved in non-volatile memory.

3.10.5 The telemetry data shall also include at a minimum, the calculated parameters shown in Table 2.

Table 2

PARAMETER NAME	DESCRIPTION
UPTIME	Total seconds since avionics power-up or the last Reset
SPIN	Satellite spin rate and direction

3.10.6 A telemetry frame shall include the current measured values, the saved minimum and maximum values, and the current calculated values.
The detailed telemetry interface will be specified in a separate document.

3.11 Telemetry Transmission

3.11.1 The satellite shall send slow speed telemetry using BPSK on the RF downlink.

3.11.2 The downlink telemetry signal shall be a 1200 bps BPSK signal located outside the user transponder passband and shall be part of the frequency multiplexed downlink. The telemetry signal's peak power level shall be no greater than <TBD> dB below the maximum output power of the transponder.

3.11.3 Telemetry data shall be transmitted simultaneously with user transponder signals, and shall cease to be transmitted when the user transponder threshold signal "hang time' of 30 seconds has expired.

3.11.4 The telemetry transmission shall include telemetry frames. There shall be different types of frames which will be included in a separate document.

3.11.5 The telemetry transmission shall also include experiment data.

3.12 Command Capability

3.12.1 The satellite shall provide a means to process commands sent via the RF uplink from authorized ground control stations.

3.12.2 The command receiver shall be on a frequency outside the transponder bandwidth.

3.12.3 A 1200 bps AFSK-FM via a NBFM channel demodulation capability shall be provided to the IHU for the purpose of transferring data and commands to the IHU. This AFSK-FM channel shall follow the FSK requirements of Bell 202 modems. Commands shall be encrypted as detailed in a seperate document.

3.12.4 The uplink command receiver shall be capable of receiving and demodulating AFSK-FM signals at 1200 bps with an input signal level of -120 dBm with a baseband Bit Error Rate (BER) of 1 x 10^{-4}.

3.12.5 The command uplink receiver will not be responsible for bit or byte synchronization, re-timing, or error correction.

3.12.6 The following commands shall be provided, as a minimum, as shown in Table 3, below.

Table 3

Command	Operation
SAFE MODE	Enter Safe Mode
INHIBIT TX	Inhibit All RF transmission
ENABLE TX	Enable RF transmission
IHU OFF	Power off IHU
IHU ON	Power on IHU
EXP OFF	Power off Experiment
EXP ON	Power on Experiment
CLEAR	Clear stored telemetry
TRANSPONDER MODE	Enter Transponder Mode
ENABLE AUTO-SAFE	Enable Auto-Safe Mode
DISABLE AUTO-SAFE	Disable Auto-Safe Mode
SCIENCE MODE	Enter Science Mode
ANT DEPLOY	Antenna Deploy (Retry)
DAYLIGHT ONLY	Telemetry only during Daylight

3.12.7 A SAFE MODE command shall cause the satellite to enter the Safe Mode.

3.12.8 An INHIBIT TX command shall disable the RF transmitter.

3.12.9 An ENABLE TX command shall enable the RF transmitter.

3.12.10 An IHU OFF command shall cause the IHU System to power off.

3.12.11 An IHU ON command shall cause the IHU System to power on.

3.12.12 A CLEAR command shall cause the satellite to clear the saved minimum and maximum telemetry parameter values.

3.12.13 A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.

3.12.14 An ENABLE AUTO-SAFE command shall enable the auto-safe mode state.

3.12.15 A DISABLE AUTO-SAFE command shall disable the auto-safe mode state.

The control interface details will be specified in a separate document.

3.12.16 A SCIENCE MODE command shall cause the satellite to enter the Science Mode.

3.12.17 ANT DEPLOY command shall cause a resistor burn in an attempt to correct a failed deployment at Startup

3.12.18 An EXP OFF command shall cause the experiment payload to be powered off

3.12.19 An EXP ON command shall cause the experiment payload to be powered on

3.12.20 A DAYLIGHT ONLY command shall allow telemetry only when satellite is in daylight as determined by power sensors.

3.13 On-Orbit Operating Modes

3.13.1 The satellite shall provide on-orbit operating modes as shown in Table 4.

Table 4

NAME	DESCRIPTION
Startup Mode	Wait 50+ minutes and deploy antennas
Safe Mode (Startup)	Wait 120 seconds then begin telemetry beacon sequencing;
Safe Mode (Command)	Inhibit transponder, inhibit experiment. Telemetry active for troubleshooting
Auto-Safe Mode	If enabled, automatically detects a low battery condition and shuts down some major satellite activities
Transponder Mode	All radio, telemetry channel and experiment active (Fully Operational)
Transmitter Inhibit	If no command has been received for <TBD>time all transmitters shutdown, telemetry uplink is monitored for command
Science Mode*	Inhibit transponder. All available downlink bandwidth is used for experiment / science.

3.13.2 The satellite shall transition between its on-orbit operational modes as shown in the State Transition Diagram in Figure 1.

3.13.3 Upon launch, a power cycle of the avionics, or after a reset action, the satellite shall enter the "START" point as shown in Figure 1.

3.13.4 An IHU ON command shall also cause the satellite to begin operation from the "START" point as shown in Figure 1.

3.13.5 The satellite shall have the capability to sense / detect whether the antennas have been deployed.

3.13.6 If the antennas have not been deployed, the satellite shall enter Startup Mode.

3.13.6.1 In STARTUP MODE, the satellite shall wait at least 50 minutes before commanding antenna deployment and initiating RF transmissions.

3.13.6.2 After the antennas have been successfully deployed upon initial orbit, the satellite shall enter SAFE MODE and will send downlink telemetry periodically. Health and Status will be ascertained and the satellite shall be commanded to enter either TRANSPONDER MODE (All Good) or SAFE MODE.

3.13.7 After a Reset action and antennas successfully deployed check, the satellite shall determine whether its last state was SAFE MODE If the last state was SAFE MODE, the satellite shall (re)enter SAFE MODE.

3.13.7.1 1200 bps BPSK telemetry beacon downlink channel operation shall occur during SAFE MODE. There shall be NO CW beacon functionality implemented in the satellite

3.13.7.2 If the last state was not SAFE MODE, the satellite shall enter TRANSPONDER MODE.

3.13.7.3 In TRANSPONDER MODE, the transponder and the telemetry shall be active.

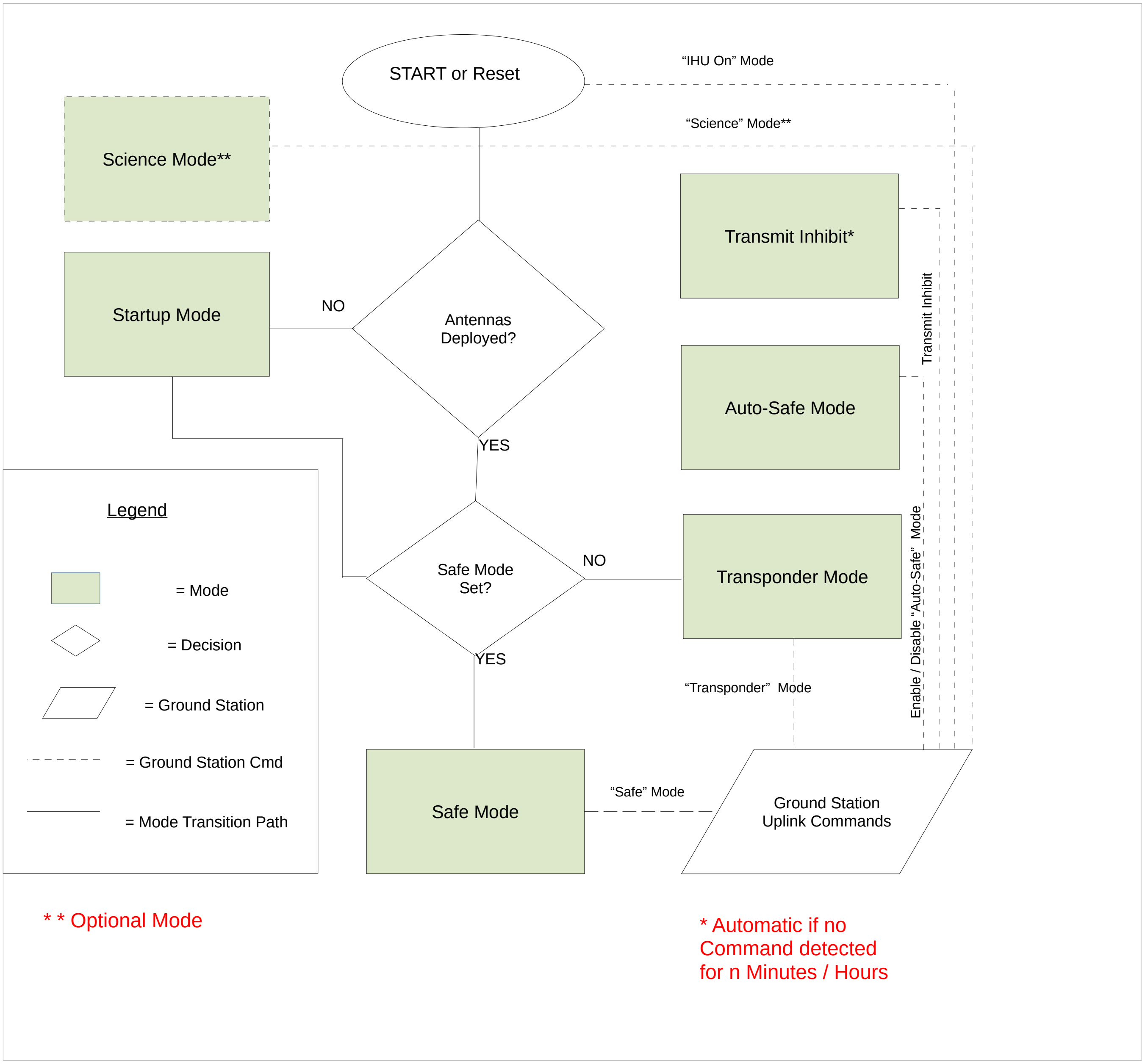
3.13.7.4 If no command has been detected for <TBD>minutes, the satellite shall enter TRANSMITTER INHIBIT MODE.

3.13.8 The command RF uplink shall be monitored for commands in all modes.

3.13.9 The Science Mode* is an optional state which will be determined on exactly how the Fox-Plus experiment / downlink speed / power budget is allocated for the satellite.

3.13.10 In the Auto-Safe Mode, when it is determined that there is low battery power, the transponder is inhibited and the experiment power is powered off. The telemetry downlink is transmitted on a set period <TBD>. A Daylight Only command (determined by power level sensing) may be issued so that the telemetry downlink is activated only when the power level is above a <TBD>threshold.

Figure 1


START or Reset
"IHU On" Mode
"Science" Mode**
Science Mode**
Transmit Inhibit*
Startup Mode
NO
Antennas Deployed?
Transmit Inhibit
Auto-Safe Mode
YES
Legend
= Mode
Safe Mode Set?
NO
Transponder Mode
Enable / Disable "Auto-Safe" Mode
= Decision
YES
= Ground Station
"Transponder" Mode
= Ground Station Cmd
Safe Mode
"Safe" Mode
Ground Station Uplink Commands
= Mode Transition Path
* * Optional Mode
* Automatic if no Command detected for n Minutes / Hours

3.14 Operational Timing Requirements

3.14.1 The satellite shall satisfy the operational times shown in Table 5.

Table 5

FUNCTION	TIME (± 5%)	OPERATIIONAL CONDITIONS
Burn Resistor Activation	≈ 4 seconds	Time allotted for the (activated) burn resistors' initial melting of the deployable antenna restrainers
Burn Resistors RE-activation	≈ 20 seconds	Time allotted for the (RE-activated) burn resistors' subsequent melting of the deployable antenna restrainers
Deployment Switch Notification Delay	≈ 115 seconds	Delay time from deployment switch physical activation to electronic activation report.
IHU Boot-Up/POST	< 20 seconds	Time for the Internal Housekeeping Unit (IHU) to boot-up and run Power On System Tests (POST)
Antenna/RF Initiation Delay	≈ 50 minutes	Antenna deployment and transmission inhibit time after dispenser launch
Beacon (Safe Mode) Duty Cycle	≈ 2 minutes	Elapsed time from end of beacon telemetry transmission to start of next beacon transmission while in BEACON MODE and SAFE MODE
Hang Timer	≈ 30 seconds	RF transmit carrier time after the uplink passband (aggregate) signal(s) no longer satisfy the threshold criteria.
Telemetry Period	≈ 15 seconds	Sampling period for all telemetry parameters
Telemetry Tx Period	~ TBD seconds	Timer for sending telemetry
ENABLE TX Confirm	≈ 3 minutes	Time after receipt of ENABLE TX command before transmitting a telemetry beacon
Watchdog Timer	≈ 10 seconds	If IHU-directed tasks do not report back within this time period, the satellite will reset.
No Command-Detected timer	~ TBD minutes	Timer to determine possible Receiver malfunction. If timer elapses, satellite will enter TRANSMITTER INHIBIT and await command.

4 External Interface Documents

To fully specify the satellite's technical requirements, the following documents should be consulted:

1. IARU Coordinated Frequency Plan
2. Downlink Specification
3. Control Interface Specification
4. Experiment Payload Specification

5 Summary

The *Fox-Plus-A* satellite will be AMSAT's second linear transponder CubeSat; the first being the Fox-1E. Its primary mission is to provide reliable linear transponder communications capability. The secondary mission could be to host an experiment payload.