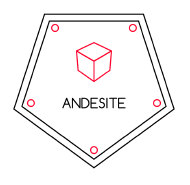
*Mule*

*Concept of Operations*



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**List of Acronyms**

**Acronym Definition**

ADCS Attitude Determination and Control System

ANDESITE Ad-hoc Network Demonstration for Extended Satellite Inquiries and other Team Endeavors

CDH Command and Data Handling

COM Communications

CSD Canisterized Satellite Deployer

EPS Electronic Power System

PCB Printed Circuit Board

WSN Wireless Sensor Node

**Document Notes**

**1 Overview**

The ANDESITE satellite is a 6U CubeSat with an Avionics Hub composed of an Attitude Determination and Control System (ADCS), an Electronic Power System (EPS), a Globalstar duplex radio for communications with the ground station, a BeagleBone Black acting as the flight computer, various data collection sensors, 8 deployable picosatellites, and an additional RF radio to establish and maintain mesh radio network communication with the deployed picosatellites. Throughout this document the 6U CubeSat encompassing the smaller picosatellites and the entire Avionics Hub is referenced as the Mule, and the smaller deployable picosatellites are called Wireless Sensor Nodes (WSN). This document outlines the concept of operations (ConOps) of the Mule as a whole, without detailing the specifics of the processes being executed on the WSN. The Mule is responsible for the managing the Avionics Hub, performing the Attitude Determination and Control System (ADCS) algorithms, monitoring the health beacon status (via requests to the EPS), the deployment of the picosatellites in pairs, the managing of the mesh network comprised of the WSN, and the handling of science data received from the WSN.

The first task the Mule will execute when ejected from the deployed is power up the necessary hardware components and begin its detumbling and pointing algorithms. Then, once the Mule is determined to be sufficiently detumbled it will wait on a command from ground to begin its deployment algorithms, and once that command it received it will begin to eject the first pair of WSN. The mule will then re-asses it’s tumbling rates and if required it will perform any additional detumbling algorithms, then it will wait for GPS verification that a sufficient amount of orbits have passed before it attempts ejection of another pair of WSN. This detumbling, GPS verification, and ejection pattern is repeated until all four pair of WSN are ejected, or a sufficient amount of attempted ejections has been reached. Alternatively, nodes can be automatically, immediately ejected if a command from ground is received commanding the Mule to eject a pair of nodes. Once the first pair of sensor nodes have been ejected, the Mule will begin establishing the mesh network radio communication with the sensor nodes and once all of the nodes have been ejected the Mule will focus primarily on maintaining the mesh network with the sensor nodes and relaying their collected data to the ground network. Communications with the sensor nodes will employ the use of a wireless mesh network of RFM22B radios which will enable the Mule to command the WSN and retrieve their science data.

**2 Phases, Modes, and Transitions**

The ANDESITE mission is comprised of two phases, the first phase is an Initialization Phase, which performs the tasks of initializing the satellite components, stabilizing the satellite after deployment, ejecting the sensor nodes, and initializing the mesh radio network between the Mule and the sensor nodes, collecting and relaying the data from the sensor nodes that have already been ejected, handling any commands received from ground, and performing any necessary maintenance tasks. The second phase is the Science Mission Phase, which performs the tasks of receiving the science data from the sensor nodes, relaying that data to ground, handling ground commands, and performing maintenance tasks.

**2.1 Phase 1: Initialization**

The Initialization Phase executes once ANDESITE is launched from the Canisterized Satellite Deployer (CSD) and the inhibit switches are disabled making the EPS operational, the inhibit switch design is configured with triple redundancy to ensure that the Mule remains powered off the entire time it is in the CSD. In this mode the EPS powers up and enables its 3.3v, 5v, and 12v power lines and all of the hardware components on the power lines. The first state is to initialize all of the sensors, microcontrollers, and communication protocols with the appropriate initialization sequence, as well as initializing a watchdog timer to restart the satellite in the event that the flight computer gets stuck in its process execution. Once all hardware component and communication busses have been enabled, the magnetometer, the gyroscope, the sun sensor, and the GPS are sampled and evaluated through an attitude determination and control algorithm to convert the data to inputs for the magnetorquer board to slow the tumbling rate of the satellite, and maintain the correct orientation for the desired orbit, and to ready the satellite for the deployment of the sensor nodes in pairs. The satellite waits for a command from ground before it begins its WSN ejection attempts. Before each ejection attempt of a pair of sensor nodes, first the detumbling rate must prove that the satellite is stable, and the GPS data must indicate that ten orbits have passed since the last ejection and that the satellite is positioned at the equator. This process is repeated until all eight sensor nodes have been ejected. Once the first pair of nodes have been ejected the Mule begins the initialization of the mesh network of the sensor nodes and as the Mule continues to eject pairs of sensor nodes they will be added to the mesh network. The data retrieved from the sensor nodes will be simultaneously re-packetized and relayed to the ground station via the Globalstar radio. The primary purpose of this phase is to stabilize the satellite and eject the WSN and to transfer any data retrieved from them to the ground station.

**Entrance Criteria:** This phase is automatically entered when the satellite is powered on when it is ejected from the CSD.

**Exit Criteria:** This phase is exited once the mule has successfully deployed all sensor nodes and has either deployed all eight sensor nodes, or in the event that not all sensor nodes were able to deploy, the deployment of each sensor node has been attempted three times.

* + 1. **Hardware Initialization Mode**

Once the satellite is ejected from the CSD and the EPS is powered on, the hardware initialization processes immediately start running. The status of all initialization schemes are logged and are eventually downlinked to ground.

**Entrance Criteria:** Immediately entered upon ejection from the CSD

**Exit Criteria:** Exited once an acknowledgement for the downlink initialization status is received from globalstar radio

1. EPS provides power to the 3.3v, 5v, and 9v power-busses, thus powering up all devices on the power busses.
2. The Mule initializes the globalstar radio and the hardware and communication protocol of the microcontroller drivers responsible for data collection of the IMU, sun sensor, and GPS, as well as the drivers responsible for controlling the WSN deployer board, and the RFM22B radio.
3. Configures the watchdog timer.
4. Downlink ground message detailing the initialization status of all pieces of hardware and communication protocols

**2.1.2 Detumble and Pointing Mode**

If the tumbling and pointing of the satellite are not within satisfactory levels (as is expected after deployment of the satellite and after each deployment of the sensor nodes) it will perform detumbling and pointing algorithms.

**Entrance criteria on primary execution**: Immediately entered after the System Initialization Mode is completed

**Entrance criteria on secondary executions**: Immediately entered once a pair of sensor nodes are ejected

**Exit criteria:** The ADCS must determine that the satellite has sufficiently detumbled and pointed

1. The Mule monitors magnetometer, gyroscope, and GPS data
2. Performs tumbling and pointing algorithms to determine if the satellite is within satisfactory levels
3. Performs detumbling and pointing routines, if required

**2.1.2 Sensor Node Ejection Mode**

The ejection mechanism forces two nodes to be ejected at the same time on opposite sides of the Mule; a shared fishing wire will be coiled with nichrome wire, so that when a current is run through the nichrome, the fishing wire will heat and break. Springs will automatically force the nodes out of the Mule.

**Entrance criteria:** The health beacon must return successful (i.e. the satellite must have sufficient battery levels and must have sufficient power) and the satellite must be at the 0⁰N latitude.

**Exit criteria:** The pair of sensor nodes must have been successfully deployed.

1. On the Mule’s first pass over the equator the CDH system will eject the first two sensor nodes.
2. The Mule will deploy the following pair of sensor nodes with a 180 degrees latitude offset from the previously launched pair. Due to the differences in surface area and mass between the sensor nodes and Mule, the two objects will spread.
3. This process is repeated until all sensor nodes have been deployed.
4. After all the nodes have been deployed the Mule and Sensor Nodes will begin the Science Mission Phase.

**2.1.3 Data Retrieval Mode**

The Mule constantly maintains a mesh network of the sensor nodes radios, whenever a message is receive from a node in the mesh network, the Mule enters Data retrieval mode to receive, parse, store, and transfer the message to the Global Star radio transmission buffer so that it may be relayed to ground.

**Entrance criteria:** A RFM22B radio message is received from a sensor node

**Exit criteria:** The message has been successfully transferred to the Global Star Radio transmission buffer

1. The Mule maintains a mesh network of all of the sensor nodes
2. The Mule receives and parses any RFM22B radio messages received
3. Appends all received and processed messages to the end of the Global Star transmission buffer

**2.1.4 Data Transfer Mode**

When a message is placed in the Global Star transmission buffer, the Mule will execute Data Transfer Mode, and the message will be packetized and relayed to ground via the Global Star network.

**Entrance criteria:** A message is in the Global Star radio transmission buffer

**Exit criteria:** All messages in the transmission buffer have been successfully transmitted

1. Retrieve messages with the highest priority (older messages have higher priority than newer ones, and health status transmissions have higher priority than data transmissions)
2. Packetize the messages such that they fit the required size and attributes of Global Star transmissions.
3. Progress to the next message in the buffer once the Mule receives the acknowledgement that the previous message was successfully transmitted.

**2.1.5 Low Power Mode**

In the event that the satellite doesn’t have sufficient power to execute its tasks, it will turn off unnecessary components and waits for the satellite to recharge.

**Entrance criteria:** This mode is entered if power or current consumption are not within appropriate ranges. Below is the functionality of each component in Low Power Mode.

**Exit criteria:** Once the power levels are back to desirable levels.

1. ADCS is turned off.
2. Magnetometer, Gyroscope, GPS and Sun Sensor are turned off.
3. RFM22B router node remains on.
4. RFM22B router node sends packets of stored data to the RFM22B coordinator.
5. Low Power Mode transitions back into Science Mode or Data Transfer Mode once adequate power levels are reached.

**2.2 Phase 2: Science Mission**

After the Mule has completed Initialization Mode the Mule will enter the Science Mission phase. This phase is comprised of all of the same modes as the Initialization phase, with the exception of the Sensor Node Ejection Mode, as this phase assumes that the network of satellites are already initialized. . Additionally, for this phase there is no explicit state diagram executed by the executive thread, instead the mode transitions are handled implicitly by the threads themselves. The primary purpose of this phase is to transmit the data retrieved from the sensor nodes to the ground station, as well as maintaining the health of the satellite, as determined by the power levels, successful operation of hardware, and detumbling and pointing statuses. The Mule will communicate with the sensor nodes via a mesh network of RFM22B radios. The network will be used by the Atmega2560 to receive the science data which includes magnetometer, gyroscope, and health-status data. The data will then be relayed to a Beagle Bone Black which will transmit it to the GlobalStar Network, and from there the data can be sent to ground.

**Entrance criteria:** Immediately entered after a successful exit from Initialization mode. After successful deployment of sensor nodes, or 3 attempted deployments of each node.

**Exit criteria:** None. The Science Mission will continue execution until end of life.

1. The Mule maintains a mesh network of the sensor nodes
2. Data is retrieved from the nodes, and the messages are parsed and stored
3. The data is relayed to the ground station via the Global Star Network

**2.2.1 Detumble and Pointing Mode**

In the Science Mission Phase the detumbling and pointing routines are not required as frequently as in the Initialization Phase, as sensor nodes are no longer being ejected. However, the routines still need to be executed regularly to ensure that the satellite maintains satisfactory pointing and tumbling rates. The routines are scheduled to be executed approximately 4 times per orbit, and if the tumbling and pointing of the satellite are not within satisfactory levels when the timer elapses, it will perform detumbling and pointing algorithms.

**Entrance criteria**: Executed in regular intervals when the timer since the last ADC routine has elapsed.

**Exit criteria:** The ADCS must determine that the satellite has sufficiently detumbled and pointed

1. The Mule monitors magnetometer, gyroscope, and GPS data
2. Performs tumbling and pointing algorithms to determine if the satellite is within satisfactory levels
3. Performs detumbling and pointing routines, if required

**2.2.2 Data Retrieval Mode**

The Mule constantly maintains a mesh network of the sensor nodes radios, whenever a message is receive from a node in the mesh network, the Mule enters Data retrieval mode to receive, parse, store, and transfer the message to the Global Star radio transmission buffer so that it may be relayed to ground.

**Entrance criteria:** A RFM22B radio message is received from a sensor node

**Exit criteria:** The message has been successfully transferred to the Global Star Radio transmission buffer

1. The Mule maintains a mesh network of all of the sensor nodes
2. The Mule receives and parses any RFM22B radio messages received
3. Appends all received and processed messages to the end of the Global Star transmission buffer

**2.2.3 Data Transfer Mode**

When a message is placed in the Global Star transmission buffer, the Mule will execute Data Transfer Mode, and the message will be packetized and relayed to ground via the Global Star network.

**Entrance criteria:** A message is in the Global Star radio transmission buffer

**Exit criteria:** All messages in the transmission buffer have been successfully transmitted

1. Retrieve messages with the highest priority (older messages have higher priority than newer ones, and health status transmissions have higher priority than data transmissions)
2. Packetize the messages such that they fit the required size and attributes of Global Star transmissions.
3. Progress to the next message in the buffer once the Mule receives the acknowledgement that the previous message was successfully transmitted.

**2.2.4 Low Power Mode**

In the event that the satellite doesn’t have sufficient power to execute its tasks, it will turn off unnecessary components and waits for the satellite to recharge.

**Entrance criteria:** This mode is entered if power or current consumption are not within appropriate ranges. Below is the functionality of each component in Low Power Mode.

**Exit criteria:** Once the power levels are back to desirable levels.

1. ADCS is turned off.
2. Magnetometer, Gyroscope, GPS and Sun Sensor are turned off.
3. RFM22B router node remains on.
4. RFM22B router node sends packets of stored data to the RFM22B coordinator.
5. Low Power Mode transitions back into Science Mode or Data Transfer Mode once adequate power levels are reached.

**3.0 Mule Deployment and Concept of Operations**

**3.1 Mule Ejection and Initialization**

Once the Mule has been ejected from the CSD the system will startup.

**Subsystems Powered on:** Power, CDH

**Software Mode:** System Initialization Mode

**Bus Usage:** 5V power rail

**Success Criteria:** CDH commands Power to turn on loads on power bus.

**Success Verification:** Automatic -- WSN directly connected to 5V rails.

**Critical Impact:** Critical for science mission.

* 1. **Detumble and Pointing Mode**

The Mule performs its detumbling routine and enters its pointing state.

**Subsystems Powered on:** Power, CDH, ADCS

**Software Mode:** Detumble and Rough Pointing Mode

**Bus Usage:** SPI

**Success Criteria:** Mule is rotating at a magnitude < 0.05 rad/s

**Success Verification:** Magnitude of three gyroscope vectors is small

**Critical Impact:** Critical for WSN ejection.

**3.3 Sensor Node Ejection Mode**

Sensors will be ejected, two at a time, at the equator.

**Subsystems Powered on:** Power, CDH, ADCS

**Software Mode:** Sensor Node Ejection Mode

**Bus Usage:** SPI, 5V power rail

**Success Criteria:** All WSN deployed with correct velocity.

**Success Verification:** Future steps will prove accuracy.

**Critical Impact:** Critical for science mission.

**3.2.3 Data Retrieval Mode**

The data will be received by the RFM22B radio on the Mule and stored on the Mule. The data will be stored until data is received from all of the WSN and is eventually transmitted to the ground station.

**Subsystems Powered On:** CDH, COM (with Power and ADCS performing background health monitoring tasks)

**Software Mode:** Data Transfer Mode

**Bus Usage:** SPI, I2C

**Success Criteria:** Magnetometer data is received from WSN and stored on SD card.

**Success Verification:** Messages are successfully received from WSNs.

**Critical Impact:** Critical for successful science mission.

**3.2.4 Data Transfer Mode**

This is the last part in the Magnetometer experiment. Thanks to the Globalstar Network, data can be sent to the ground station at any location. The GlobaIstar radio sends data to a satellite on the Global Star Network which then downlinks data to ground.

**Subsystems Involved:** CDH, COM (with Power and ADCS performing background health monitoring tasks)

**Software Mode:** Data Transfer Mode

**Bus Usage:** I2C, SPI

**Success Criteria:** Ground Station receives magnetometer data.

**Success Verification:** None

**Critical Impact:** Critical for successful science mission.