Form 442, Technical Question 6 Response

ROSE-1 Mission Experimental Program – Spectrum Utilization Details

(Revision 5.0)

6a. *Description of Research Project*: ROSE-1 (RFT Orbital Satellite Experiment) is a 6U experimental spacecraft designed to provide an orbital test-bed for the Phase Four Radio Frequency Thruster (RFT), the first plasma propulsion system to fly on a nanosatellite. This research program is intended to demonstrate that the Phase Four RFT can safely launch, operate and perform experimental orbital course corrections in space. For the ROSE-1 mission, the spacecraft will fly in a LEO near-circular orbit with altitude of approximately 575 km and with inclination of approximately 98°.

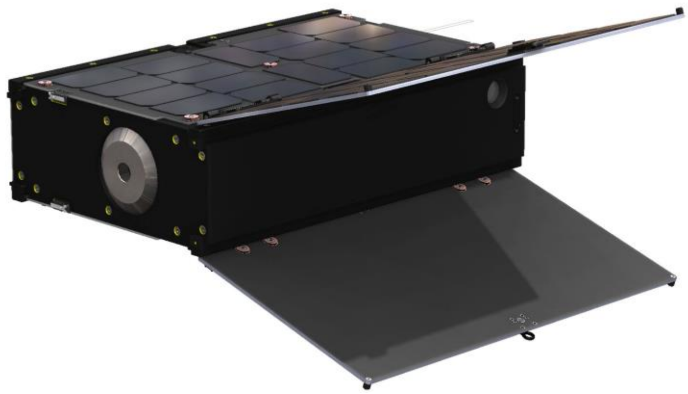
Phase Four and Astro Digital are collaborating on the ROSE-1 mission. Phase Four is the owner of the mission and has procured the satellite hardware from Astro Digital. Astro Digital has provided in-kind contribution to the mission including the shared use of its mission control center and ground station with Phase Four. Astro Digital's interest in the project is in validating Phase Four's propulsion system on-orbit prior to Astro Digital's use of the system for future Landmapper satellites. This Part 5 application is submitted by Phase Four for the ROSE-1 satellite. The ground station will be authorized by Astro Digital through a Part 25 STA.

All experimental data is downlinked over one of two command and telemetry radio transceivers, with a ground station located in Santa Clara, California. A GPS receiver provides precise orbital ephemeris for tracking and propulsion maneuver assessment. The satellite bus uses reaction wheels, magnetic torque coils, a star tracker, magnetometers, sun sensors, and gyroscopes to enable precision 3-axis pointing.

TLM and CMD data transmission from/to the spacecraft are proposed at UHF frequencies. The CMD and TLM links utilize a transceiver system, which operates in half-duplex mode (but, not on a common transmit/receive frequency –as per our filing).

The telemetry downlink data rate for which we are applying is 38,400 bps. The occupied bandwidth of the radio system is 40.0 kHz (at -3 dBc) and employs a very steep skirted bandpass filter to limit its output bandwidth. GFSK modulation is employed on the downlink.

The CMD uplink utilizes EESS spectrum (Earth-to-space) in accordance with ITU Table of Frequency Allocations – within the band 402.0 to 403.0 MHz. The ground station will be licensed through a Part 25 STA applied for by Astro Digital.



ROSE-1 Spacecraft

In addition to the above links, a back-up TLM and CMD relay link will be tested on an experimental basis. These links will make use of the commercial Globalstar satellite system. This demonstration will take place using satellite-to-satellite communications between the ROSE-1 spacecraft and the Globalstar MSS system. The Command Relay link will use the Globalstar transmission frequency band from 2483.5 – 2500 MHz. The TLM Relay Link will make use of a portion of the Globalstar mobile uplink band from 1615.035 to 1617.495 MHz. It is anticipated that a specific frequency assignment will be made in both of these broader frequency bands used by the Globalstar system. The frequency selection process will be made closer to the launch date. As these links are operating in the Intersatellite Service, this application must consider that circumstance. Protection to the Radio Astronomy Service is assured by operating our satellite transmitting modem in the higher band segment above the Co-Primary allocation to MSS and RAS. The data rates to be used in both link direction (CMD and TLM) are 9,600 bps gross and 8,550 bps after removal of system overhead bits.

6b. *Specific Objectives of the Research Project*:

The research objectives of this project are:

a) To demonstrate the novel use of RF waves in heating a thruster propellant, thereby accelerating a spacecraft. The ROSE-1 propulsion system is called the Phase Four Radio Frequency Thruster, or RFT. RFT uses 6 to 16 MHz RF wave absorption to heat a xenon plasma (ionized gas) in a propellant chamber. The hot xenon plasma expands outward from the thruster, generating thrust. For the ROSE-1 mission, the spacecraft will fire the thruster for 60 to 300 seconds per orbit, adjusting the altitude of the spacecraft's orbit. The change in the orbit will be measured through GPS tracking. The change in orbit versus the known firing cycle uploaded to the spacecraft will allow the users to determine if the imparted impulse on the spacecraft was as predicted from lab testing of the Phase Four RFT.

b) To demonstrate that such thrusters can be used without disrupting the communication bands also used by the spacecraft. Naturally, the use of RF waves on a spacecraft – those not used for observation or communication – opens the situation for interference between RFT and other communication and observation subsystems on board the spacecraft. The ROSE-1 mission and RFT have been designed to mitigate any harmful RF interference from the outset; however, the shielding design will be confirmed by successful on-orbit operations without any data corruption or missed command sequences. Therefore, should the ROSE-1 mission successfully demonstrate its primary mission, it will also demonstrate that RF thrusters can be used for spacecraft propulsion without the worry for RF interference between the thruster and the spacecraft.

c) To demonstrate that small satellite systems, such as this remote sensing mission, can reliability use satellite-to-satellite relay for Command and Telemetry support of our mission and that connection to the space segment can be made more frequently and over a broader area of coverage that would be possible with one to several ground-based stations.

We note that none of these objectives are possible using currently existing commercial ground stations, particularly because they do not employ low cost telecommunications equipment. Therefore, the utilization of a Part 5, Experimental License is appropriate and this project is in the public interest.

6c. *How will the program of experimentation demonstrate a reasonable promise of contributing to the development, expansion or utilization of the radio art, or is along a research line not already investigated?*

Phase Four has developed what we believe is a state-of-the-art spacecraft propulsion system that will allow the following extensions of a research line not already investigated:

a) The use of RF waves for heating allows the thruster electronics to leverage advances in metal-oxide-semiconductor field-effect transistor (MOSFET) technology for DC-RF convertors, which effectively miniaturizes the electric propulsion system by an order of magnitude in mass compared to existing solutions on the market. The use of RF heating also allows for the system to operate without some of the main mechanical failure points of existing propulsion systems, such as "hollow cathodes." Other RF thrusters have been launched and demonstrated in space, specifically the Hayabusa 1 and 2 missions. Those systems used a large (several kg) RF thruster and used S band waves to heat the plasma propellant. The Hayabusa thruster did not take advantage of the miniaturization of RF electronics. Furthermore, the use of S band waves prevents the concept from wide adoption due to the use of S band waves for spacecraft communications across the industry. RFT represents the first RF thruster in the HF band ever to be launched into space. The successful use of the Phase Four RFT will herald in a new, promising propulsion option for satellite systems that is small, mass manufacturable, and lacks the failure points of much larger electric propulsion systems. Therefore, the launch and use of the RFT represents a discrete leap forward in the progress of electric propulsion technology, as well as opens a new field for RF electronics and in space radio applications.

b) While the Globalstar MSS system has been used experimentally by other small satellite missions, this system demonstration fully quantifies how it might be used in an operational mode to control a constellation of LEO spacecraft situated at an altitude well below the Globalstar constellation altitude. The evaluation will test the limitations of the satellite-to-satellite relay function as the Globalstar design was not originally intended to offer beams whose coverage is optimized for MSS stations in orbit. Our simulations, however, still show that the percent coverage increase for CMD & TLM support is well worth the inclusion of a Globalstar modem on-board our ROSE-1 spacecraft. We expect to demonstrate that the in-orbit performance actually is better than our static link simulations.

By granting this experimental license, we will demonstrate technology that will extend the current state of propulsion for small satellites. The experiments are expected to demonstrate improvements in on-orbit maneuverability for microsatellites, allowing for the first time satellites of this size to perform rapid multi-plane constellation deployment, station-keeping, collision avoidance maneuvers, and end-of-life burns. Effective small satellite maneuverability is absolutely essential for the responsible stewardship of the outer space environment, especially considering the growing threat of space debris. As such, we believe this demonstration is definitely in the best interest of the public sector.