Form 442, Technical Question 6 Response

Corvus-BC Mission Experimental Program - Spectrum Utilization Details

(Revision 4.1)

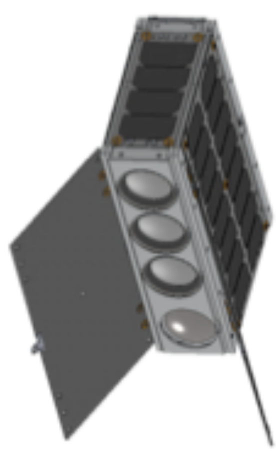
6a. *Description of Research Project*: The Corvus-BC-4-7 spacecraft mission is a continuation of the research program intended to demonstrate that operational quality (17 m GSD resolution) remote sensing data can be collected, processed and successfully downlinked by 4 very small 6U CubeSat space vehicles and that this data can be routinely transmitted to the Earth using Ka-Band transmitters utilizing the DVB-S2 data system standard. For the Corvus-BC-4 through Corvus-BC-7 segment of our constellation, the spacecraft will fly in a LEO circular orbit, at a circular altitude of 500 km (apogee = perigee = 500 km) and with an inclination of approximately 97.4°. The spacecraft will each carry three cameras, each with a focal plane array containing more than 70 megapixels. Each of the three cameras on all four spacecraft will operate in a different spectral band (GREEN, RED and NEAR INFRA-RED). Hence each composite (G+R+NIR) image (or scene) will contain more than 210 million pixels where each pixel is represented by 12 bits. Lossless compression is used to reduce the total data stored in spacecraft memory and on the downlink data path by nearly a factor of 2. The Corvus-BC-4 through BC-7 spacecraft will join with the Corvus-BC-1 and BC-2 spacecraft to begin the formation of the Astro Digital Landmapper Constellation, which will ultimately consist of 30 spacecraft (10 will carry the 3 camera X 20 m (±4 m) GSD resolution configuration and 20 will carry a 1 camera X 2.5 m (± 0.5 m) resolution configuration. This latter spacecraft will be approximately three times larger in volume. The Corvus-BC-4 through BC-7 spacecraft will be the first to demonstrate reduced revisit times for agricultural imagery around the world, an important element of a new concept of enhanced data delivery in the commercial remote sensing industry. Once these spacecraft have demonstrated this capability they will be commercially re-licensed as the first elements of the Land mapper commercial constellation.

High-speed data transmission of the 17m GSD data will occur using a millimeter wave (Ka-Band) transmitter operating in EESS spectrum at a frequency of 26.800 GHz. Data rates using the DVB-S2 data system standard will range from 35.3 Mbps to 320.6 Mbps. The emission bandwidth of the Ka-Band transmitter is constant (independent of modulation and coding) at 86.4.00 MHz (this corresponds to a fixed symbol rate of 72 Msps). Spectral efficiencies range from 0.49 bits/Hz to 4.53 bits/Hz. The Ka-Band transmitters, while operating here under an experimental license, will be re-licensed under a commercial license using the same selected frequency band at some point in the near future. Part 25 license applications are in process, however, we believe a Part 5 Experimental License is still appropriate for these four spacecraft as various experimental procedures as well as market demonstrations need to be carried out using them before they will be ready for commercial service.

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 TLM downlink, while operating under a proposed experimental license, could operate on these frequencies, once a commercial license has been applied for, as the proposed spectrum is already allocated to the SRS in all three ITU Regions. 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. This system may also be operated at 19,200 and 9600 bps as alternative data rates, selected by telecommand. At lower data rates, the spectrum occupied is correspondingly lower.

The CMD uplink, could also be used under a future commercial license as it utilizes EESS spectrum (Earth-to-space) in accordance with ITU Table of Frequency Allocations - within the band 402.0 to 403.0 MHz. While we do not comply with US Footnote 384 (as we are not transmitting to a US Gov. spacecraft) we have been mindful of the utilization made by the NOAA GOES DCS system and have avoided the use of those uplink frequencies. We are currently using this uplink frequency under experimental license WH2XCA (File No. 0139-EX-RR-2015) as a command uplink to our Perseus-M1 and –M2 spacecraft and have received no notice of interference to other systems or services. The command uplink 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. GFSK modulation is employed on the command uplink. Lower command data rates of 19,200 bps and 9,600 bps are also possible.



Corvus-BC 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 Corvous-BC spacecraft and the Globalstar MSS system. In this instance the cross-linking capability will demonstrate the ability to operate with multiple spacecraft, thus demonstrating two constellations interacting with one another. We believe this is another space first. The Command Relay Link will use the Globalstar transmission frequency band from 2483.5 – 2500 MHz. The TLM Relya Link will make use of a portion of the Globalstar mobile uplink band from 1616.5 to 1626.5 MHz. It is anticipated that a specific frequency assignment will be made in both of these broader frequency bands used by the Globalstar system. This 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 directions (CMD and TLM) are 9600 bps gross and 8550 bps after removal of system overhead bits.

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

The research objectives of this project are:

a) To investigate the image quality, of our system under constant altitude conditions, yielding images with a 17 m GSD resolution and to determine the commercial implications of improved image site revisitation rates. Corvus-BC-4 through BC-7 will add four new spacecraft to a growing constellation, so that imagery can be routinely obtained using a small constellation of low cost space imaging satellites (these four additional spacecraft, with slightly different orbital characteristics will be added to two additional spacecraft, Corvus-BC-1 & 2).[1] Corvus-BC-3 (to be launched first, despite the numbering of the satellites) will be used to demonstrate a variety of new technologies of the space platform as well as to investigate the processing of images at different resolution (varying between 16.5 m and 26.4 m GSD). The objective of the three-color bands selected is to observe changes in the agricultural land areas over the entire Earth with time. The specific objective, in this case, is to verify that between 10-14 passes per day of data can be downloaded from each of seven spacecraft. This amounts to >150 GBytes of image data transmitted to the Earth each day from each spacecraft and more than 1 TByte/day for the constellation of seven satellites, if this

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[1] We have also applied for and received an Experimental License for the Corvus-BC-1 & -2 spacecraft under a previously submitted Form 442. That Part 5 license has been granted under call sign WH2XXT. The Part 5 license for Corvus-BC-3 has been granted under call sign WI2XCP.

passes-per-day objective can be met. We believe this is a significant amount of data for such small space systems.

b) To demonstrate that EESS spectrum in the band 25.5 to 27.0 GHz is suitable for operational remote sensing missions, particularly as carried out by small, low cost space systems. A specific objective is to utilize the DVB-S2 data system standard (at first in VCM mode and ultimately in ACM mode) to allow for adaptation of our Ka-Band link to a variety of meteorological conditions encountered during downlink data transfers. Using this technology we will verify the operational capability of *this* radio spectrum to produce the highest average data rate possible. In other words, we hope to demonstrate a technology that has the highest spectral efficiency possible at the lowest cost, using the 25.5 to 27.0 GHz frequency band.

c) To demonstrate that small satellite systems, such as this remote sensing mission, can reliably use satellite-to-satellite relay for Command and Telemetry support of such a mission and that connection to the space segment can be made more frequently and over a broader area of coverage than would be possible with one to several ground-based stations. We also wish to demonstrate this process can be semi-automated using the seven satellites in the emerging Landmapper constellation. This is also an experimental objective. Further, we expect to demonstrate that, eventually, small space systems could operate using an MSS system like Globalstar as an alternative to a UHF SRS assignment. If this can be demonstrated and if the arrangement remains cost effective we will have been able to demonstrate, as with our mmW activities, that alternative spectrum choices to those currently in use (e.g., UHF SRS or Amateur Radio assignments) are possible and practical. A further objective in this case is to demonstrate that we do not cause harmful interference to any Radio Astronomy operations.

We note that none of these objectives would be 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, even as we progress into the initiation of the constellation phase of our system deployment.

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?*

Astro Digital has developed what we believe is state-of-the-art transmitter technology that will allow the following extensions of the radio arts and sciences, at least so far as spaceflight communications are concerned:

a) It is well known that transmitters operating in the mmW portion of the radio spectrum (in this case, within the range 20 to 30 GHz) are subject to excess path losses caused by atmospheric absorption and meteorological effects, including precipitation and cloud cover. We will demonstrate that the radio frequency band at 25.5-27 GHz can be used for routine high-speed data links from LEO spacecraft, despite these effects, even using very low cost radio equipment carried on-board very small space vehicles. We have developed a very small transmitter system that contains a DVB-S2 standard modulator/coder, which allows us to adjust the modulation and coding of the transmitter over 28 different options of modulation and coding ("MODCOD"), thus demonstrating that data rates can be adapted to the radio link over a range of spectral efficiency from 0.5 to 4.5 bits/Hz. This also corresponds to a data rate agility of from 35.3 to 320.6 Mbps. Initially, we will utilize the system in what is known as VCM (variable coding and modulation mode). This allows the MODCOD setting to be changed "manually" over 28 steps of MODCOD by ground command. Once this has been demonstrated the system will then be placed into ACM (adaptive coding and modulation mode). In this second case the ground station measures the downlink Eb/No performance continuously and then commands the spacecraft to automatically adjust its MODCOD setting to produce the highest possible data rate for which the link will close. This feedback loop is closed using the CMD uplink to the spacecraft as the return path. The loop created can operate with a closed loop rate of up to one adjustment per 2 seconds. So far as Astro Digital is aware, this technology has not yet been demonstrated at mmW frequencies by any commercial company or even the by the US Government (so far as the civil sector is concerned).

b) In addition to the adaptability of the transmitter to changing meteorological conditions, the system also will produce the highest spectral efficiency possible, consistent with the prevailing link meteorological and orbit conditions. With the equipment described herein we intend to demonstrate spectral efficiencies up to 4.5 bits/Hz. The baseband filter of the transmitter has a very steep skirted FIR filter that maintains the output bandwidth to exactly 86.4 MHz, independent of data rate. We now contemplate the use of the new and emerging DVB-S2X standard that will allow spectral efficiencies greater than 7 bits/Hz and with even better Nyquist Roll-Off characteristics.

c) The Ka-Band transmitter operating in these four satellites use built-in high gain horn antennas. Operating with a -3 dB beamwidth of 10.2° the space segment is designed to communicate with a 2.8 m parabolic dish antenna at the Earth station, which has a beamwidth of ≤ 0.26°. The spacecraft and the ground station track each other throughout the satellite pass. Hence, by using antennas with narrow beamwidths on both ends of the link, we will be able to demonstrate that such systems have a very high degree of spatial frequency reuse. ***Using such systems, hundreds of NGSO spacecraft can share the same frequency assignment and downlink data to multiple ground station locations within view of one another.***

d) While the Globalstar MSS system has been used experimentally by other small satellite missions, this system demonstration will be the first to fully quantify 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 system design was not originally intended to offer beams whose coverage is optimized for MSS stations in LEO orbit (operating below the altitude of Globalstar space stations). Our simulations to date, demonstrate that the percent coverage increase for CMD & TLM support is well worth the inclusion of a Globalstar modem on-board our Corvus-BC spacecraft. We expect to demonstrate that the in-orbit performance is actually better than our static link simulations indicate. This is simply because the link analysis carries significant margin.

By granting this experimental license, we will demonstrate technology, which will extend the current state-of-the-radio-arts-and-sciences. The experiments are expected to demonstrate improvements in both spectral efficiency and spatial frequency reuse as well as demonstrate these benefits in a constellation configuration. We believe this demonstration is definitely in the best interest of the pubic sector.

The bands Astro Digital are using to carrying out the objectives of this experimental program are also shared by government licensees. We have been in discussion with several US government agencies who are now using these bands (or plan to use these bands in the near future) and we believe that our technologies would also benefit many government licensees as the technology to be demonstrated is lower in cost and meets higher performance standards than are being achieved even by large government space systems. We therefore believe that even government interests are served by allowing such experiments to be carried out in shared bands. We anticipate that the results of these radio frequency demonstrations will be published in the literature and that similar equipment will soon become available in the marketplace.