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Preparation and Validation of Defence Research and Development Canada's (DRDC) Microsatellite Ground Station

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Budgets for traditional "big" space mission are generally higher in comparison to those of "microspace" missions. Defence Research and Development Canada (DRDC) used the Maritime Monitoring and Messaging Microsatellite (M3MSat) project [4, 7], a Canadian maritime surveillance satellite, to apply this low cost microspace approach [3] when building the primary Ground Station (GS). DRDC prepared a GS that will operate the microsatellite with a small operations team. Key to DRDC's implementation of the GS was satellite control automation to conduct operations with M3MSat. This paper will document how DRDC designed, implemented, built, and validated their Mission Operations Centre (MOC) and GS as well as the training of their operators.

I. INTRODUCTION

In preparation for the operation of a new microsatellite, M3MSat, DRDC stepped away from the traditional big-space philosophy and applied the micro space approach when developing their GS and Mission MOC The satellite will carry an Automatic Identification System (AIS) [2] payload in Low Earth Orbit (LEO) and DRDC, with a 4.6m and 9.1m antenna, was to host the primary GS.

M3MSat is a microsatellite whose primary mission is to demonstrate the use of Automatic Identification System (AIS) signals from marine vessels in space. Com Dev International [8], a designer and manufacturer of space hardware, was contracted to build the satellite. As per the contract, they were to build the microsatellite, secure a launch into LEO, train the DRDC satellite operations team, and deliver a flatsat to. The flatsat is a 'spare' satellite kept on the ground consisting of flight and engineering model components for testing, training, and troubleshooting. Aside from risk reduction for integrating and testing, the flatsat also provides a great source for hands on training, as will be discussed further on. The project consists of multiple phases from the preliminary Requests for Proposals (RPF) to Operational Readiness Review (ORR) and throughout each milestone, a Mission Review Board (MRB), consisting of project managers from the Canadian Space Agency (CSA) and DRDC, gives the final word of proceeding to the next phase of the project.

Although the M3MSat launch is slated for 2015, for this paper we'll still be able to focus on the steps DRDC took, with the help of CSA, to address the manning, validation of the ground segment, and training of DRDC staff, while maintaining a readiness for satellite operations, while retrofitting the aging GS.

II. BACKGROUND

One of the greater challenges that was tackled was the number of operators available to support this mission. While the operational team consisted of six people for this mission, four of those were military personnel. Military personnel are generally posted into new positions every few years and, during the lifetime of M3MSat DRDC would've experienced 100% turnover rate of the military staff during the satellite operations phase. Any handover process, however comprehensive it may be, is hard to replace the hours of hands-on time and training done by the original operators on the console with the Flatsat led by Com Dev, the company who was contracted to build the satellite. So the handover process was flagged as a point of focus for incoming replacements when scoping our training requirements. This drove the heavy emphasis on the documentation of our work, lessons learned, trouble shooting, observed issues, etc. yet it had to be generic enough to accommodate the technical background of the incoming personnel. Much effort was put into the recruitment of CAF personnel with satellite communication experience and through Royal Military College (RMC)'s exchange program with United States Air Force Academy (USAFA), as well as their own internal GS for high altitude balloon trials with radiation detection payloads, and alumni of the International Space University (ISU), DRDC was able to put together a diverse team. Even so, the documentation that was created included very clear step-by-step instructions.

As mentioned earlier, the MRB consisted of project managers from DRDC and CSA to give the go/no-go criteria for each milestone of the project. Applying a microsatellite approach to this mission, there was heavy focus on the validation of the readiness of the GS, which inherently is less robust, as well as the readiness of the operators who will play multiple roles throughout the satellites lifetime. The End to End (ETE) test played a critical role in demonstrating the readiness of operators and the GS for these milestones.

III. GROUND STATION ARCHITECTURE

There were two phases for each microsatellite mission; the Launch and Early Operations (LEOP) and Commissioning (C) following the separation of the satellite from the launcher, and the transition to satellite operations, once all subsystems are running and deemed healthy. The LEOP/C phase is to consist of around the clock manning with 6 people taking shifts, taking all passes available. The work would include switching on and checkup of the Attitude Determination Computer (ADC) sensors and actuators, the GPS unit and orbit data processing, and tuning the attitude control. Once the satellite health and safety has been confirmed through telemetry and LEOP/C has been declared successful by the MRB, routine operations will take place and the team would scale back to staffing the GS during regular business hours. The station would then be run largely autonomously.

Figure 1 shows the GS with a brief description of the products going from unit to unit. While the Station Operator is the DRDC GS team, the Mission User is also present to show the requestor of the AIS data. The mission user makes their requests in the form of payload taskings that get converted into sensor commands that the satellite understands. These commands are known as Telecommands (TC) and are uplinked to the satellite when in view, while satellite Telemetry (TM) are downlinked to the GS. On the tracking side of the GS, the antenna planning system generates two products: Pointing (PNT) files and Station Contact Times (STC). The PNT files are a set of Azimuth, Elevation (Az/El) and time data that's fed to the antenna controllers to drive the dishes to track.

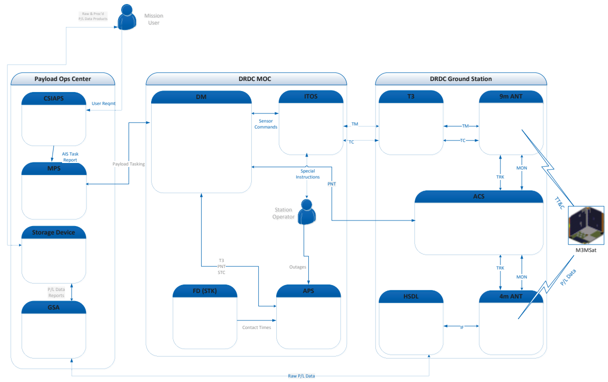

Figure 1: Ground Station Architecture

Areas of Automation

There are 3 main areas that the GS and MOC can run without an operator in the loop: antenna tracking, RF control, satellite payload tasking, and payload data exfiltration.

Tracking

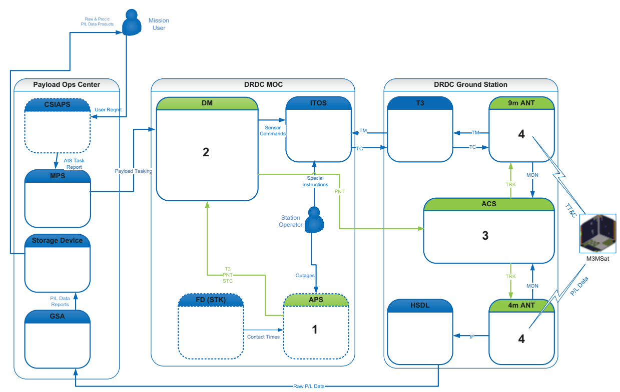

Figure 2: Data Path during Automatic Satellite Tracking

The first automated step occurs with the Antenna Planning System (APS). This is a Perl script run daily on the Windows daily task manager that polled Systems Toolkit (STK) and STK Scheduler [5] for updated TLEs and satellite priority values. Pointing (PNT) files would be generated that contain information such as satellite name and pass information such as timestamp, azimuth, and elevation, for seven days. Seven PNT files were selected as a preventative measure, in case there are any disruptions, so that there would be seven days' worth of pointing files for the antennas to continue tracking while, buying time to troubleshoot and address the issue. This pointing file is uploaded into the antenna controllers located in the antenna pedestal via the Track Data Manager (TDM) software so the dishes will track all satellites of interest as they come into line of sight of our GS. Following the green blocks and the numbering scheme the order and direction of flow can be followed in Figure 2. Note that, unlike Figure 3, the users in Figure 2 are blue indicating that their input is not required and that the process is continuous autonomously.

RF

The Antenna Control System (ACS) is a program written in Agilent VEE to control the IF/RF switching, down converters, up converters, and power amplifiers. This program also reads from the pointing file. Each satellite of interest has their polarization, uplink and downlink frequencies stored within a satellite database inside the program so when a satellite enters line of sight, it will set the correct polarizations and frequencies for the GS to communicate with the satellite on their respective equipment.

Payload Tasking and Satellite Commands

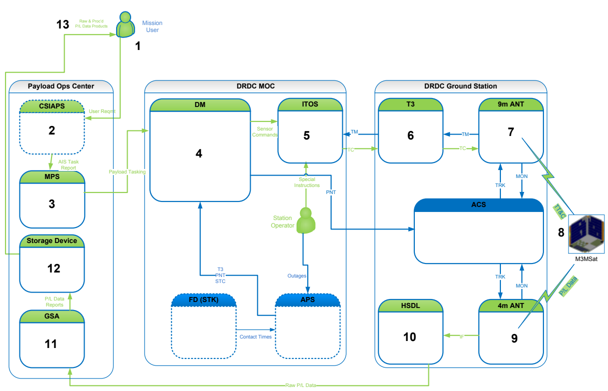

Figure 3: Data Path during Payload Tasking

The users of the scientific data are able to task M3MSat's payload. Using the Commercial Satellite Imagery Acquisition Planning System (CSIAPS) [6] GUI , a tool to plan the AIS payload data acquisition opportunities, they're able to select areas on the globe from which they want to gather AIS data. From the mission planning side the Mission Planning System (MPS) translates these requests into macro-commands that give the AIS antenna and receiver activation times. Note that CSIAPS and the MPS are both physically separated from the GS. The MPS automatically pushes these macro-commands to the GS at which point an operator is required to convert these macro-commands into spacecraft commands via a tool in the Integrated Test and Operations System (ITOS), or the operator's console to control the satellite. There are two users in Figure 3: the data user making their initial data request, and the MOC operator who would push the satellite payload taskings.

Payload Data Exfiltration

The AIS data aboard the satellite needs to be downlinked to our GS as frequently as possible to prevent the memory onboard to fill up, as well as to ensure the science users can get the latest AIS data that they requested in CSIAPS. The payload tasking commands generated in the MPS include commands to M3MSat to downlink the scientific data back to the GS during a satellite pass. Once it is received on the ground, it's then automatically routed away from the GS and MOC to our science labs and the science users.

IV. VALIDATION

Tracking and Testing

Tracking validation was accomplished using several methods. Aside from regular calibration, major motor and software retrofits were performed in 2013 on the 9.1m S-band and 4.6m C-band antennas to achieve finer pointing accuracies. To validate the accuracy of our antennas two methods of calibration were used: peaking the dishes onto the sun and other relatively stationary objects such as GPS satellites and tracking actual Low Earth Orbit satellites. By peaking on stationary objects it was possible to compare our antenna's Az/El reading from the motors to a set of Az/El generated off the object's Two Line Element (TLE) orbital data. Since M3MSat will be in low earth orbit, LEO satellites known to transmit at S-band, such as Radarsat 1 and 2 [1], SCISat and, more recently, NEOSSat were used to continue the tests. These satellites were tracked and the signals peaked on by applying offsets in the tracking software. Algorithms to compensate for atmospheric refractions were implemented on the tracking software. C-band LEOs were more scarce and DRDC approached exact Earth for support. Exact Earth, a global maritime traffic data provider has an interest in the AIS data is planned to receive this data off M3MSat and they had assisted us in the validation work of our GS, which included our antenna tests. By allowing time on their satellite, exact View 1 (eV-1) for these trials, they scheduled their eV-1 microsatellite to downlink their AIS payload data to our GS via C-band for us to confirm our tracking accuracy on the 4.6m antenna. Again, the signal peaks were taken and the antenna pointing offset angles logged, and good signal levels were received, validating our 4.6m tracking after antenna retrofit.

To see the improvement in tracking performance after the antenna retrofit figure 4 compares a LEO satellite that was tracked in February of 2011 and the results of signal strength to elevation angle that was taken. Figure 5 shows the same antenna tracking a LEO satellite in January 2014, after the antenna retrofit. It can be seen that prior to the upgrade the 9.1m antenna was having troubles with passes starting as low as 20 degrees while the readings in 2014 showed much less signs of degradation even up to 40 degrees. Although the improvement is not shown, the results of the exact View 1 trial verified the 4.6m antenna tracking accuracies met the requirements of the retrofit contract and M3MSat mission.

After the M3MSat mission ends there may be future plans for the GS antennas to track multiple missions concurrently so the tracking algorithm was also tested against multiple satellites, each with different priorities set by the operators. A group of satellites ranging from LEO satellites to Medium Earth Orbit (MEO) satellites were tracked to ensure the accuracy of the new antenna motors, its software, and that it maximizes its on-target time for objects of a higher priority.

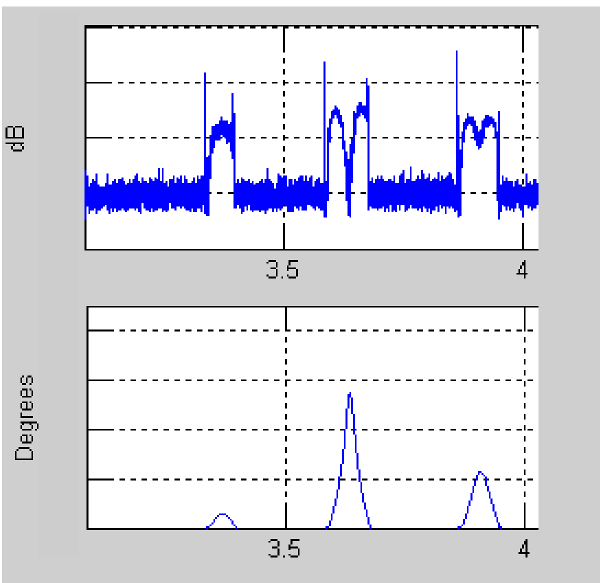

Figure 4: Receive Signal (dB) vs Antenna Pointing Elevation (Deg) vs Time (x10000 seconds) Pre Retrofit - Feb 2011

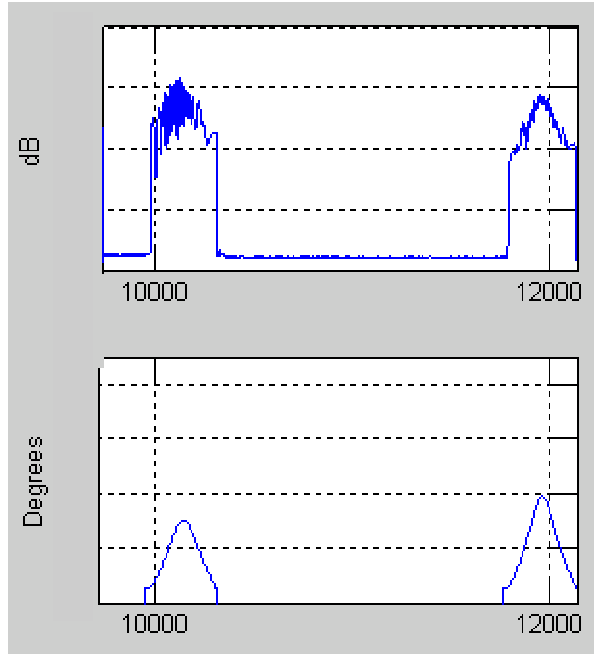

Figure 5: Receive Signal (dB) vs Antenna Pointing Elevation (Deg) vs Time (seconds) Post Retrofit – Jan 2014

V. TRAINING

DRDC committed six staff to operate M3MSat. Although each operator has gone through the standard training package of the GS, each satellite is unique in its mission, payloads, and sensors. So a specific training plan was required to bring the operators up to speed with M3MSat. As part of the contract with Com Dev the training of the GS operations team came from multiple sources. This included classroom training from the Com Dev functional leads, and hands-on involvement in the Integrated Systems Tests (ISTs) while the satellite was at the David Florida Lab (DFL) [9] for thermal and vacuum testing, and the ETE test. The ETE test was a week-long full chain test between M3MSat and its primary GS. In July of 2013, M3MSat was brought to the DFL, which is located on the same campus as the DRDC GS. Horn antennas on the roof of DFL were hooked up to the transmit and receive ports of the satellite and padded down to simulate the distances expected for the intended orbit of the satellite while the DRDC operational team prepared the GS to perform a series of tests over the air to simulate the LEOP and commissioning activities developed by Com Dev. This activity, aside from validating the ground hardware, also served to reinforce the team's knowledge and 'muscle-memory' of the pre-pass checks/activities, our efficiency to perform tasks during the short pass windows, perform post-pass analysis, and finally log the telemetry/payload data retrieved from the satellite. Aside from the tracking system, which is autonomous anyways, everything the team had to do during the real LEOP was done during the ETE. The test was successful in that good training was gained and the communications link between the microsatellite and prime GS was validated.

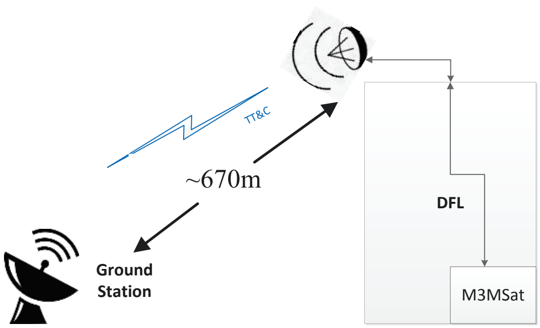

Figure 6: End to End Test

VI. CONCLUSION

This paper explored DRDC's experience with preparing a primary GS for a microsatellite mission, M3MSat. We've looked at the staffing considerations, the equipment validation process and the training of personnel as operators, engineers, and mission planners. While a relatively small space mission makes it hard to justify the large staff and robust systems of the traditional big space philosophy, this paper documented the paths DRDC took to try and make it operationally ready. Through the ETE test we found the short GS pass windows made us heavily reliant on automation to complete the required tasks and it demanded a broad range of proficiencies from the team with training in multiple systems, as opposed to specialty areas. In particular, hands on experience were in great demand to build that muscle memory. No time on the Flatsat was wasted and often times validating the system was a great experience since the more issues we encountered the more we strengthened our understanding and the more documentation was built for the actual mission and for our future successors.

VII. REFERENCES

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