

IAC-13,B4.4.10x18317

SPACE BASED AIS DETECTION WITH THE MARITIME MONITORING AND MESSAGING MICROSATELLITE

Nathan G. Orr

Space Flight Laboratory, University of Toronto, Canada, norr@utias-sfl.net

Jeff Cain

COM DEV Ltd, Canada, jeff.cain@comdev.ca

Luke Stras

Space Flight Laboratory, University of Toronto, Canada, lstras@utias-sfl.net

Robert E. Zee

Space Flight Laboratory, University of Toronto, Canada, rzee@utias-sfl.net

In 2008, a 6.5 kg nanosatellite called NTS was launched with the challenging and pioneering mission of demonstrating that Automatic Identification System (AIS) signals transmitted by maritime vessels could be received from space. NTS exceeded all mission objectives and provided valuable input into the research for an operational microsatellite called the Maritime Monitoring and Messaging Microsatellite or M3MSat. M3MSat was developed in a partnership between COM DEV Ltd and the UTIAS Space Flight Laboratory (SFL), with COM DEV as the prime contractor. In addition to building upon the innovative AIS receiver technology developed for NTS, M3MSat will provide enhanced data collection and handling capabilities. The mission also entails detecting and de-colliding AIS signals in an operationally timely manner providing a responsive ship tracking capability to both commercial customers and the Canadian government. M3MSat is based on the COM DEV AIM multi-mission bus which is a highly flexible platform that is 0.6 x 0.6 x 0.8 m in size with a mass of 85 kg. This paper describes the transition from a nanosatellite to a microsatellite platform, the development of the AIM multi-mission bus and the capabilities of M3MSat. M3MSat is funded by Defence R&D Canada (Ottawa), the Canadian Space Agency, exactEarth and COM DEV Ltd.

I. INTRODUCTION

Maritime domain awareness has always been of key importance to governments and commercial organization around the world. Until recently, this has been primarily achieved using maritime radar, and by the use of the ground based Automatic Identification System (AIS). The situation changed with the launch of a nanosatellite called NTS in April of 2008. NTS was the first nanosatellite to successfully detect an AIS message from orbit and was the precursor to an operational mission called the Maritime Monitoring and Messaging Microsatellite (M3MSat).

M3MSat's primary mission objective is to provide maritime surveillance for both commercial customers, and for the Canadian government, by detecting AIS messages from space. Building upon the technology developed for NTS, M3MSat provides enhanced data collection and handling capabilities to permit detecting and de-colliding AIS signals in an operational and

timely manner. This is critical in order to provide a responsive ship tracking capability to clients.

AIS transmissions were designed for ship-to-ship and ship-to-shore reception to aid in collision avoidance and vessel traffic management. The AIS message is broadcast at 162 MHz and includes ship identification information as well as position, course and speed. The use of AIS is mandated by the International Maritime Organization aboard ships of more than 300 gross tons, and aboard all passenger ships. AIS uses a self-organized time division multiple access scheme (SOTDMA) to permit ships in the same "cell" to broadcast messages without interference. This feature presents a challenge when detecting these messages from space, as multiple self-organized cells are simultaneously in the field of view of the spacecraft. To deal with the inevitable message collisions caused by this overlap, specialized signal processing techniques are required to extract the majority of the original AIS messages.

M3MSat uses the COM DEV AIM multi-mission bus platform, and is a microsatellite with dimensions of approximately 0.6 x 0.6 x 0.8 m and mass of 85 kg. In addition to the primary AIS receiver payload, M3MSat will also carry a Low Data Rate (LDR) payload used to demonstrate a satellite based AIS data relay capability and a Deep-Dielectric Charging Monitor (DDCM) payload which is an experiment to observe spacecraft charging and material behaviour[5].

and LDRS payloads. SFL was contracted to provide the spacecraft power, attitude determination and control and the command and data handling subsystems.

Funding for the mission is provided by Defence R&D Canada (DRDC), the Canadian Space Agency (CSA), exactEarth and COM DEV Ltd. In addition, the CSA is providing the DDCM payload while spacecraft operations will be performed by DRDC. AIS data from M3MSat will be jointly utilized by the Canadian government for coastal monitoring and commercially by exactEarth for their global AIS data services.

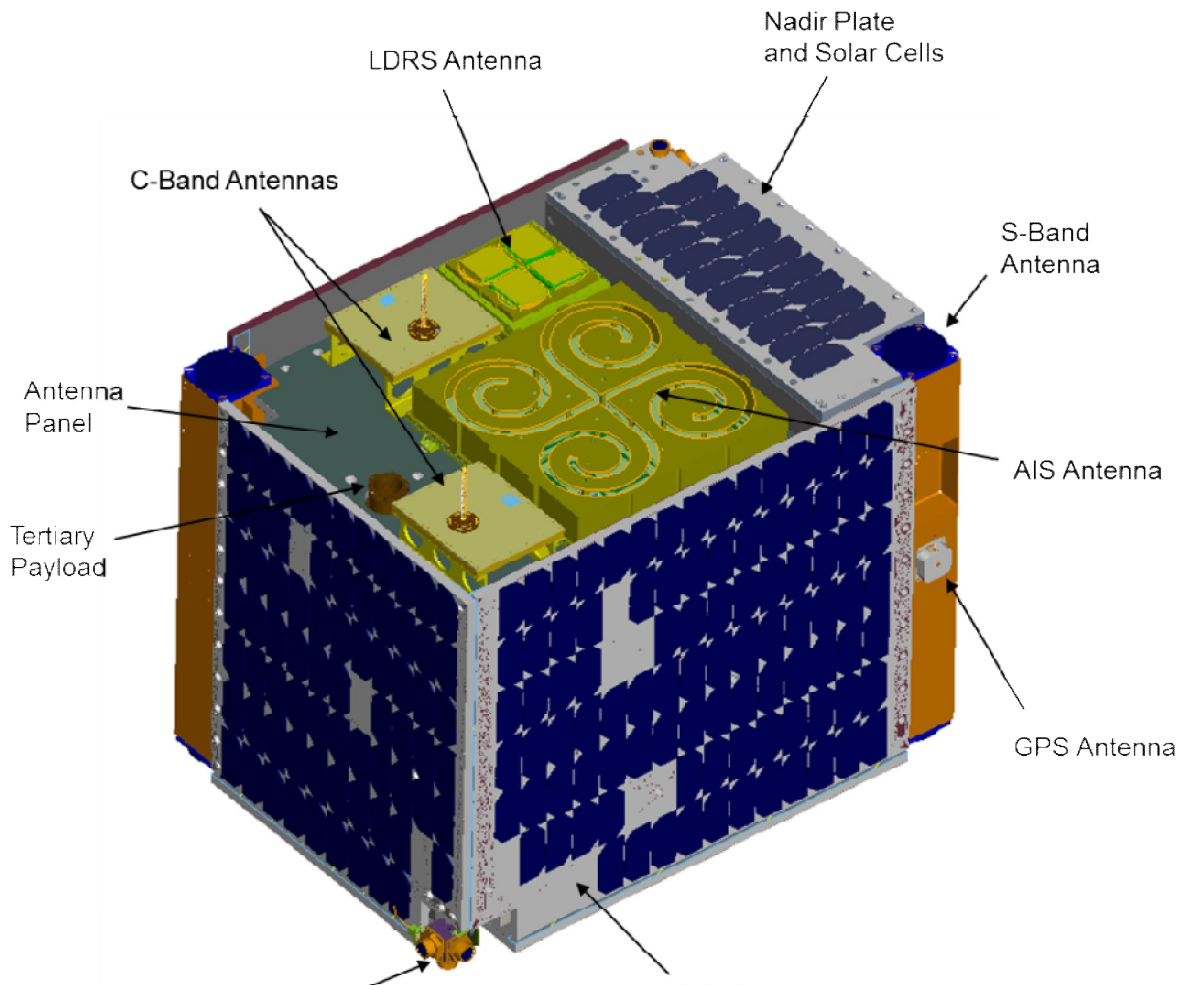


Figure 1: Solid model of M3MSat.

II. ORGANIZATIONS

M3MSat builds upon the strong partnership between COM DEV Ltd. and the Space Flight Laboratory (SFL) that led to the successful NTS mission. COM DEV, as the prime contractor, is responsible for spacecraft integration and testing as well as development of the spacecraft structure, the TT&C subsystem and the AIS

III. NTS

The satellite, Nanosatellite Tracking of Ships or NTS (see Figure 2) was launched on an Indian PSLV on April 28, 2008 into a polar sun-synchronous orbit. Shortly thereafter (on May 6, 2008) the first set of AIS data was captured and downloaded, marking the first

time an AIS message was received by a nanosatellite[1]. This was a significant achievement considering that NTS was conceived of and launched within a 7 month period. This mission demonstrated the utility of nanosatellites to rapidly deploy and demonstrate new technology in space.



Figure 2: The NTS Nanosatellite

The rapid development cycle of NTS required full use of several heritage technologies including the SFL Generic Nanosatellite Bus (GNB) and electronics from the CanX-2 nanosatellite[2]. The spacecraft was a 20 cm cube with a mass of 6.5 kg. The AIS payload was developed by COM DEV and included a pre-deployed 46 cm VHF monopole antenna. The spacecraft had no active attitude control and used permanent magnets and hysteresis rods to align the payload antenna with the local earth magnetic field.

With an original goal for an operational lifetime of 6 months, NTS continues to exceed expectations with five years of on-orbit operations and counting. To date, NTS has been used to monitor shipping traffic across the globe (see **Error! Reference source not found.**) and contribute to important events such as the marine security program for the 2010 Olympics [3].

With the successful demonstration of COM DEV Ltd.'s space-based AIS technology on NTS, it was evident that the concept was viable and that a more capable platform would be beneficial. In addition, to manage and market

the data produced by these AIS assets, COM DEV Ltd. spun off exactEarth, a partially owned subsidiary company. At the time of the NTS mission, the M3MSat phase A study had been completed and a proposal for the design and build of the spacecraft had begun. The NTS mission provided valuable insight into the performance of a true system and produced high confidence that the mission objectives of M3MSat would be achieved. These events set in motion the development of M3MSat, which would add an upgraded payload, a 20 Mb/s downlink and a 500-fold increase on-board data storage.

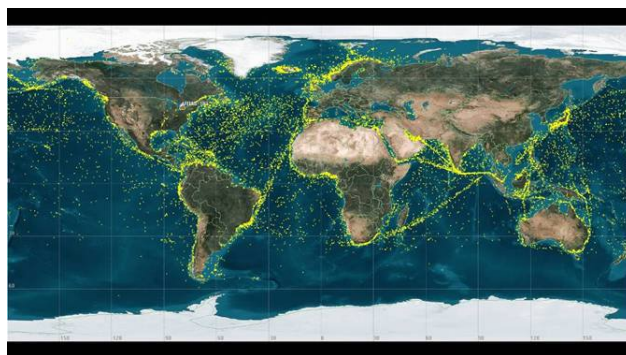


Figure 3: Composite image of ships detected by NTS [1].

IV. M3MSAT SPACECRAFT BUS

Physically, AIM-class spacecraft are a 60 x 60 x 80 cm rectangular prism with a launch mass of 85 kg. The spacecraft structure consists of a set of panels, each of which provides support for the various sub-systems that make up the spacecraft. During integration, individual modules are installed into aluminium boxes both for physical isolation and EMC control. Several of the flight modules for the C&DH, power and ADCS subassemblies are shown in Figure 4.

These boxes are then bolted to panels (generally in stacked configurations), and a wiring harness is installed. Interconnection is simplified by the fact that all modules use a common connector interface that carries bus power and connection to the redundant CAN bus. Finally, the panels are brought together and bolted creating the spacecraft primary load-bearing structure. This design allows for easy integration and debugging: modules can be added one by one, and any difficulties resolved before adding more modules. Should problems arise late during the AI&T process, it is relatively easy to open the spacecraft up again and debug.

The AIM bus is fully redundant. The majority of the redundancy is provided by two independent strings, each of which contains a full complement of the

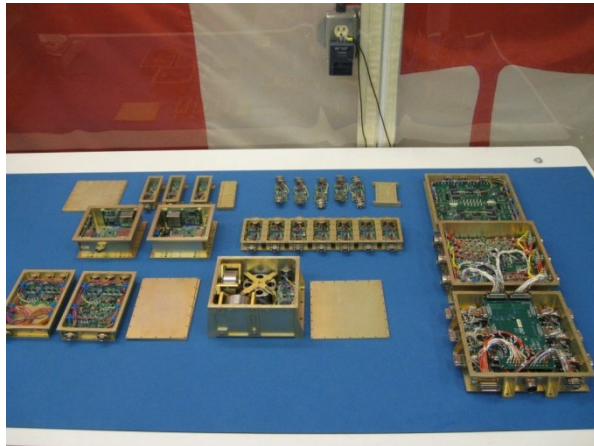


Figure 4: Power, C&DH and ADCS subassemblies in the SFL clean room.

systems required to operate the spacecraft. A few items – further described below – offer redundancy in different ways. Regardless of how the redundancy is provided, the spacecraft bus is single-failure tolerant. Payload redundancy is mission-dependent; in the M3MSat spacecraft, the AIS transponder is dual-string redundant, while the low data rate service and dielectric charging experiments are single-string.

Power

The AIM bus ultimately derives its power from a set of six body-mounted solar panels. These are connected to a set of six battery charge regulators (BCRs), which provide peak power tracking, and regulate the charging current into a lithium ion (Li-Ion) battery. Power is

distributed to the loads by a pair of power distribution modules (PDMs) which provide protected switched and unswitched power outputs. Figure 5 shows an overview of the power system.

Each face of the spacecraft includes a set of triple-junction GaInP/GaAs/Ge solar cells; three faces have a large number of cells, and are intended to supply power for nominal operations, while the other three faces have a smaller number of cells, and are intended to provide “keep-alive” power. The spacecraft is power-positive in all orientations, though payload operations can only be sustained indefinitely with the high-power faces oriented towards the sun. This design allows for extended contingency operations and a passive safe-hold mode.

The panels are then connected to the six BCRs as shown in Figure 5. To ensure that a BCR failure does not compromise spacecraft availability, each of the high-power panels are connected to two BCRs each (by splitting the strings between the BCRs). In the event of a BCR failure, the panel will continue to provide power (albeit with some degradation) through the second BCR.

BCR outputs are in parallel and connect to the spacecraft battery. The battery consists of 24 Li-Ion cells arranged in an 8-series/3-parallel (8S3P) configuration. The battery pack has a nominal full voltage of 29.6 V, and a capacity of 480 Wh. Because there are three strings in parallel, a failure of any single string does not preclude the continued operation of the spacecraft. In the event of a cell failure, the battery will continue to function, though at a reduced capacity.

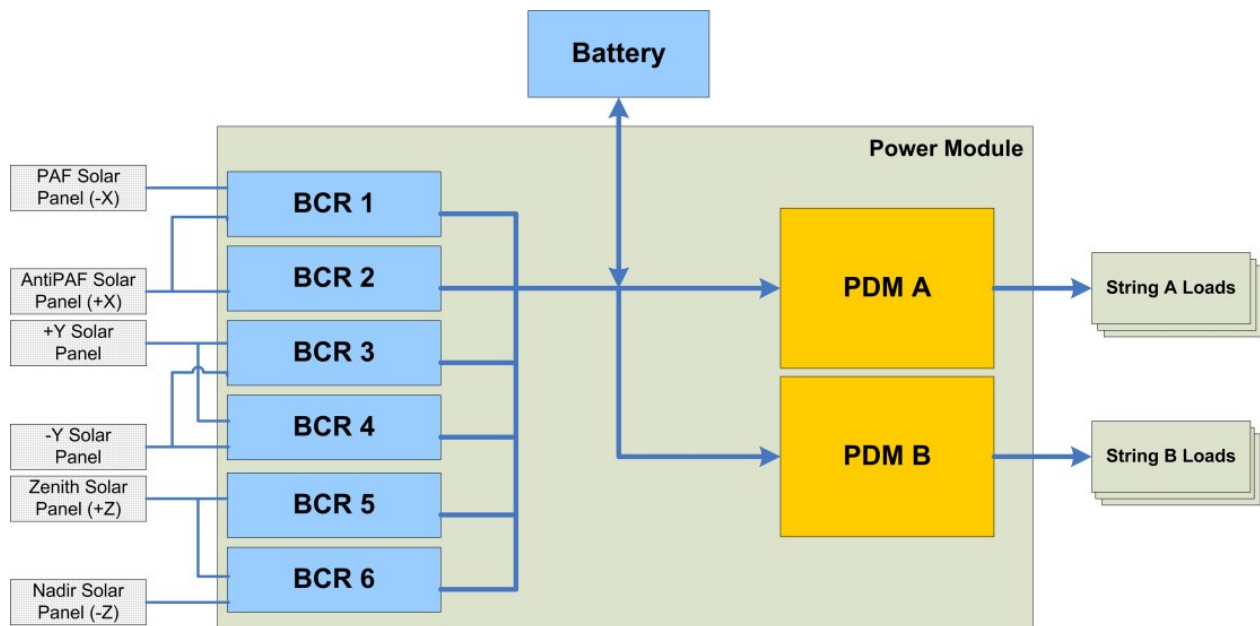


Figure 5: Power system block diagram

The battery is connected directly to the spacecraft bus and so it regulates the bus voltage. The bus voltage will vary with the battery state of charge, between 25.5 V and 32.4 V. While this necessitates that the spacecraft systems be tolerant of the full battery voltage range, it has several advantages. First, the battery provides a high-bandwidth, low-impedance voltage source. This allows for fast transient response to peak current demands, reduces bus voltage ripple, and helps stabilize the power system. Second, there is no need for a complex, high-power battery discharge regulator, improving system efficiency.

The PDM provides both switched and unswitched outputs. Unswitched outputs are used for subsystems which are associated with the reception of telecommands from the ground: the command receivers, and the command decoders. These outputs are always on whenever the spacecraft is on; in the event of an over-current fault, the outputs briefly turn off, and then turn on after a short delay. This is intended to allow transient faults to clear via a power cycle. Switched outputs are off by default at spacecraft power-up. Upon receipt of a command the load can be turned on or off. As with the unswitched outputs, the switched outputs are protected against over-current fault; in the event of a fault, the switch is turned off, and the event is logged.

As noted above, the majority of the spacecraft systems are dual-string. By connecting each string to a separate PDM, redundancy can be achieved. Should a PDM fail, only the string to which it is connected is lost; the other PDM, and its loads, remain active, and can be used to continue mission operations.

C&DH

The AIM bus uses a distributed command and data handling (C&DH) architecture. The majority of all commands and telemetry are carried over a pair of CAN buses. By using two buses, the spacecraft can achieve redundancy. By default, each node listens to the primary CAN bus. If it does not receive a special synchronization message within a specified timeout, it switches to the redundant bus and begins listening. This process repeats with the node switching buses until it receives the synchronization message. The synchronization messages are generated by the communications node (see below); in the event of a bus failure, an operator would command the communications node to switch buses. Within 60 seconds of a bus switch command, all units in the spacecraft will switch to the new bus, and receive all of their commands on that bus.

The AIM bus uses industry-standard protocols (the Space Packet Protocol, and the Packet Utilization Standard) to communicate with all nodes. The use of a common protocol suite greatly simplifies the entire data link, from the spacecraft to the user, as all communications are in a well-defined format, and the tools for interacting with the spacecraft are proven, off-the-shelf hardware and software. Third-party hardware is also easy to integrate into the system, as the protocols used are commonly used in spacecraft hardware.

The AIM bus uses a pair of on-board computers (OBCs) to perform housekeeping and attitude-control tasks. Under normal operations, these are functionally partitioned into a housekeeping computer (HKC), and an attitude determination and control computer (ADCC). In the event of a failure of either of these computers, the software on the remaining unit can be merged, so that the single computer performs both tasks, albeit with reduced memory and throughput margins. Each OBC is based on a 32 bit microprocessor, and has 2 MB of error-corrected RAM, as well as 2 GB of non-volatile (flash) storage.

The HKC software is responsible for collecting and storing spacecraft telemetry, providing time synchronization and the storage and release of time-tagged commands. Both the HKC and ADCC software is based on SFL's CANOE operating system. This is a priority-driven pre-emptively multi-tasking operating system, with substantial flight heritage (CanX-2, NTS, BRITE (x2) and AISSat-1[4]). The use of pre-emptive multi-tasking substantially simplifies software development, as independent functions can be broken down into separate threads, and thus isolated from each other.

A large number of the spacecraft units are either legacy devices, or are commercial off-the-shelf hardware which are not equipped with a CAN interface or do not use the protocol suite that is used on the AIM bus. In order to adapt these devices for use on the AIM bus, a CAN interface module (CIM) was developed. The CIM are configured to use a standard RS-485 or RS-232 serial interface and simply bridge data between the serial ports and the CAN bus. It is the responsibility of the software that communicates with the device to provide interpretation of the device's data stream.

Finally, the payload is accommodated via a centralized data storage unit (CDSU). The CDSU can be thought of as a general-purpose bus terminal: it provides a variety of inputs and outputs that can be used to control payloads, and to store payload telemetry. The CDSU provides discrete digital inputs, analog inputs, thermistor inputs, pulsed power outputs (both at 12 V

and at the bus voltage), and multiple RS-485 input/output ports. It also provides a high-speed (1.25 Mb/s) serial input, which can be buffered in 2 GB of on-board non-volatile storage; the CDSU can then downlink the data at high speed (4 Mb/s) when the spacecraft is in view of a ground station. Note that, being a part of the payload accommodation, the CDSU is normally not redundant.

ADCS

The AIM bus provides an agile, three-axis stabilized platform for payloads. The ADCS suite can point at either an inertial or nadir target to within 5°, and can execute a 180 degree slew in less than 15 minutes. The ADCS software, and much of the hardware used on the AIM bus has substantial flight heritage.

The AIM attitude determination suite consists of a pair of three-axis magnetoinductive magnetometers, a pair of three-axis MEMS rate sensors, and a set of six dual-axis sun sensors. The magnetometers have a full-scale range of $\pm 100 \mu\text{T}$, and, after calibration, a mean error of $< 35 \text{ nT}$ over the full range. The rate sensor assembly will produce a random walk of less than 7 degrees over the worst-case expected eclipse period (40 minutes) and the sensor rate bias drifts less than 0.3 %/s over the operational temperature range. Each sun sensor has a field of view of 140°, and reads out a sun vector with a calibrated accuracy of 0.1° over the full field of view.

The attitude actuation suite consists of a set of reaction wheels, and a set of magnetic torque rods. The reaction wheels are organized as two redundant sets of three orthogonal wheels each. Each wheel has a momentum capacity of 80 mNms at 1000 rad/s angular speed, and can generate a maximum torque of 5 mNm. The torque rods are capable of 15 Am² each and are used for initial detumbling, and for reaction wheel desaturation. Each torque rod is dual-wound, with each winding providing enough dipole to desaturate the wheels.

The ADCS software is based on SFL's OASYS attitude determination and control suite, which has flight heritage from the CanX-2 and AISSat-1 mission. OASYS consists of an extended Kalman filter (EKF), which reads information from the attitude sensor suite, and estimates the current attitude of the spacecraft. This estimate is then compared against the target quaternion, and the error is filtered through a PID controller. Based on the filtered error estimate, target wheel speeds are computed and transmitted to the wheels. Simulations of the M3MSat mission, using a high-fidelity model of the spacecraft and the disturbance environment, indicate

that a pointing error between 2.5° and 5° (3σ) can be achieved.

TT&C

The AIM telemetry, tracking, and command (TT&C) system is based on COM DEV Ltd.'s flight-proven hardware. The TT&C system operates in the space science segment of S-band. The system is fully redundant and made up of parallel sets of communications nodes and transceivers which are connected to four antennas.

The satellite has a pair of receive and a pair of transmit patch antennas arranged on opposite corners, resulting in 4π steradian coverage. The two S-band transceivers are connected to the receive antennas via a hybrid (which combines the signals and routes them to each receiver). The transceivers are connected to the transmit antennas via a coaxial switch. Each transmitter can be routed to either of the transmit antennas. The transmitter provides up to 2.2 W of RF power, and supports data rates between 32 kb/s and 6.25 Mb/s, using BPSK, QPSK, and OQPSK modulation. The data is downlinked in ECSS format. The receiver supports a rate of 4 kb/s.

Each communications node is attached to both receivers, but only to one transmitter. When data is received over the radio link, the communications node performs bit, word, and frame detection, error correction, and packet integrity checking. Valid packets are examined, based on their destination address. Packets containing hardware-decoded commands or TT&C subsystem commands are immediately acted on by the communications node. All other packets are formatted using the correct framing, and are transmitted on the CAN bus. This enables the ground to communicate directly with any unit in the spacecraft (power system, reaction wheel, etc...) without first routing the data through an OBC.

Data arriving on the CAN bus that is destined for the ground, or via the high-speed link from the payload (via the CDSU), is broken down into frames and ECSS formatting is added. If selected, error-correction coding is added, and the resultant data is sent to the transmitter for downlink.

Multi-Mission Bus

In parallel with the development of the M3MSat mission was the design of the AIM multi-mission bus itself. The AIM bus is intended to be a generic microsatellite platform suitable for a wide range of space missions including earth observation and science.

The flexible nature of the bus is achieved through a combination of generic interfaces, modular avionics, reconfigurable power system, and a large payload volume and mass allocation. The AIM bus will be flight qualified with the launch of M3MSat and will provide a unique Canadian capability for the rapid deployment of new technologies, operational missions and science experiments in space.

The AIM multi-mission bus has a large payload bay for housing mission specific payloads as shown in Figure 6. The payload area has dimensions of 53.5 x 54.5 x 28.5 cm with access to the +X, ±Y, and -Z panels for payload specific sensors or antennas. The payload mass allocation can be up to 30 kg which gives a payload to bus mass fraction of 40%. Payload thermal management is achieved with a combination of a well thermally-coupled corner post accessible from the payload bay, customizable thermal coatings for the panels and payload power ports that can be dedicated to heaters.

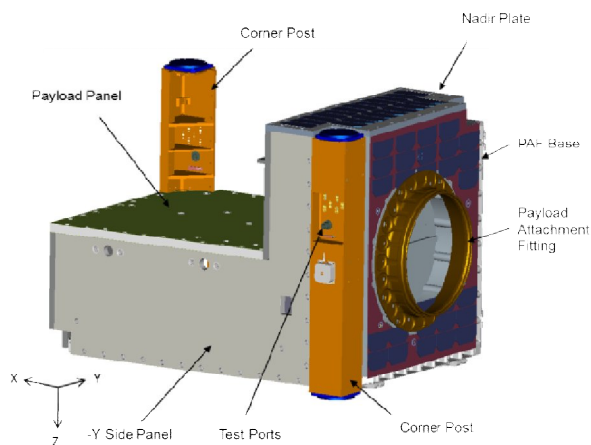


Figure 6: AIM Multi-Mission Bus payload bay.

The AIM power system is highly modular and permits mission specific customization. The number and length of solar cells strings on each panel can be adapted to fit around sensors and antennas or to optimize power generation. The bus also supports the attachment of an optional deployable solar panel to further expand power generation capability. With body mounted panels alone, the bus is capable of producing between 80 W to 120 W on average depending on the attitude and orbit for a particular mission with 50% - 60% of the power typically available for the payload. By default, six 3A power switches are dedicated to the payload(s) which can be further expanded with an additional power distribution module. Finally battery mass and capacity can be traded depending on mission requirements in one of three possible configurations: 133 Wh/1.3 kg, 233 Wh/2.6 kg or 400 Wh/4 kg.

Payload communication and telemetry interfaces are also highly modular. A single payload interface module provides two RS-485 channels, six 16-bit analog inputs, two thermistor inputs, six discrete inputs, six 12V command lines and three 28V switch driver command lines. Depending on the payload requirements, up to three payload interface modules can be utilized for a particular mission. These modules satisfy the CSA multi-mission bus interface requirements. The redundant multi-drop CAN bus used for housekeeping command and telemetry can also be extended to the payload and CIMs are available for payloads that do not support CAN or the bus protocols. Several options are also available for high speed non-volatile payload data storage.

V. PAYLOADS

There are three payload chains onboard the M3MSat spacecraft. These enable the spacecraft to fulfil its mission goals, provide a limited amount of redundancy as well as the potential for long term operational activities. The bottom of the flight antenna deck is shown in Figure 7.

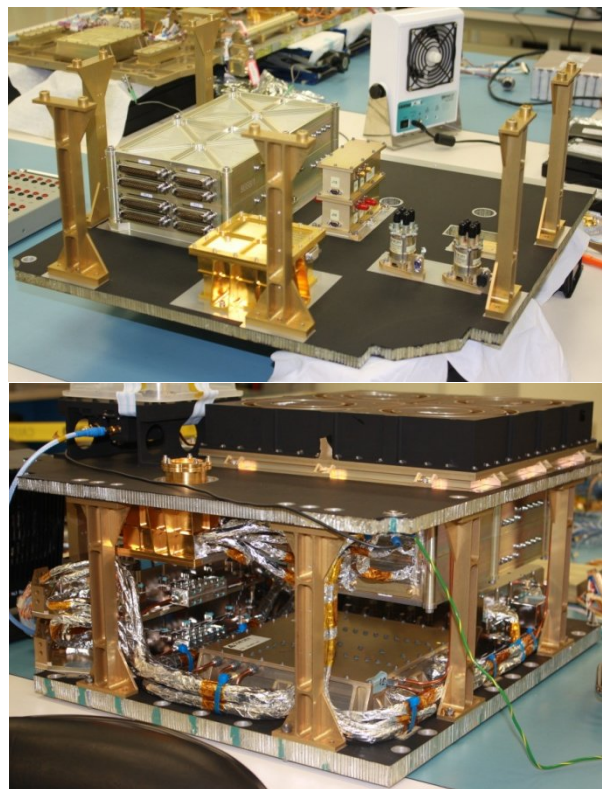


Figure 7: Photograph of the partially assembled (top) and fully assembled (bottom) M3MSat payload deck

The primary objective of the mission is fulfilled through the use of redundant AIS payload chains. Each of these chains consist of a VHF antenna, specially designed to meet the mechanical volume requirements in addition to having stringent gain profile required to receive the AIS signals from space. As the antenna is large, approximately 30 x 30 cm, only one is used on for the mission. The AIS antenna was a joint development between the University of Waterloo and COM DEV Ltd. The signal is split and then passed to a VHF receiver built by COM DEV Europe. The receiver performs RF filtering, down-sampling and signal digitization. The RF spectrum is then recorded within a data recorder (a customized unit from Surrey Space Technology Limited). The raw data is transmitted to the ground through a dedicated 20 Mb/s C-band link.

The two AIS chains each have a C-band transmitter and cross-strapping to provide a measure of control over the downlink of data. Nominally, the raw sampled spectrum will be downlinked; however, the system also allows the possibility of adding the ability to perform real-time or post collection message extraction within the data recorder. The advantage is would be to provide in-orbit verification of processing capabilities with the potential of providing a method of minimizing the amount of data transmitted to the ground stations.

The secondary objective of the M3MSat mission is to demonstrate the use of a low data rate system for use in the collection of sensor or other data. The UHF system collects data from small ground terminals and then downlinks the data using the C-band link. Testing of this system will be performed with the assistance of DRDC-Atlantic and will involve relay of AIS base station data. The LDR payload makes use of one of the AIS chains by down-converting the UHF signals from 400 MHz to 162 MHz and then passing it into the AIS NCAP receiver. With this approach, the amount of new hardware is limited and the cost and complexity of the demonstration is kept to a minimum. Currently, the LDR demonstration is planned to occur during the commissioning phase and then only sporadically for the remainder of the mission.

The final payload unit on M3MSat is the DDCM. This mission provides a “first flight” opportunity for a Dielectric Deep Charge Monitor (DDCM) designed and built by DPL Science [5] and sponsored by the CSA. The DDCM data is collected by a payload interface module and then stored in the CDSU. The data is collected as part of the standard housekeeping telemetry and transmitted to the ground over the spacecraft TT&C link. The DDCM is operated continuously when the spacecraft is in nominal operations.

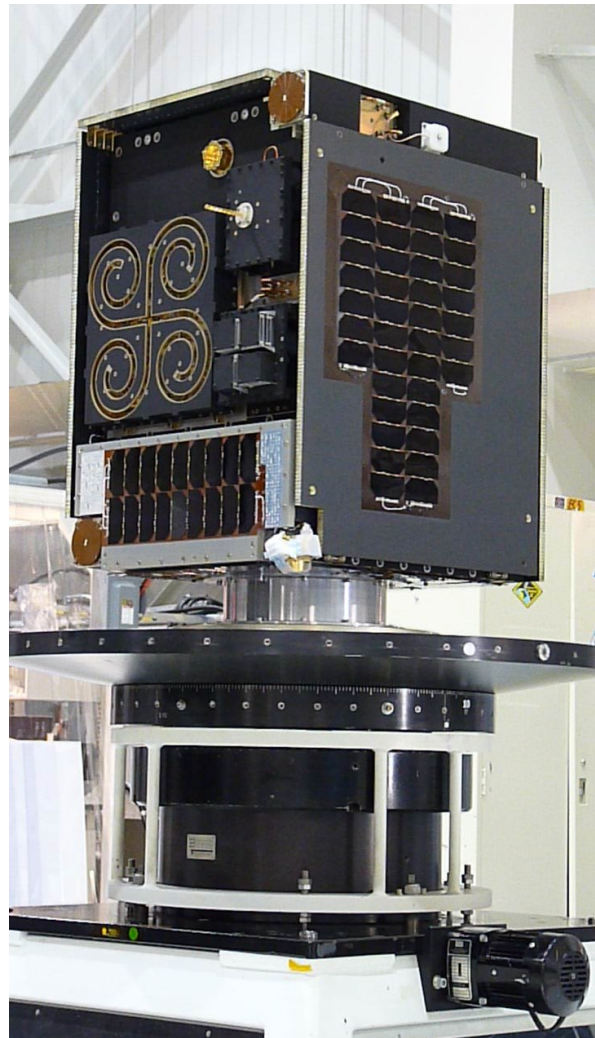


Figure 8: The fully integrated M3MSat microsatellite during mass properties testing.

VI. CURRENT STATUS

M3MSat has been fully integrated and all spacecraft level environmental testing has been completed successfully. A photograph of M3MSat is shown in Figure 8 which was taken during mass properties testing. M3MSat is scheduled to launch aboard a Soyuz Frigate in December 2013.

VII. CONCLUSION

With its small beginning in a nanosatellite, the advanced AIS technology utilized by M3MSat is poised to make a significant contribution to marine domain awareness for the Canadian government and industry. Several years of hard work and dedication by the skilled staff at SFL and COM DEV will come to a culmination when M3MSat is launched at the end of 2013. The AIM multi-mission bus will be demonstrated on-orbit and

prove to be a versatile platform for a host of new and challenging missions planned for the near future.

VIII. ACKNOWLEDGEMENTS

The authors would like to acknowledge the Canadian Space Agency, Defence Research and Development Canada, exactEarth and the staff at COM DEV and SFL for their support and contributions throughout the development of M3MSat.

IX. REFERENCES

- [1] Pranajaya F.M., Zee R.E., Cain J., Kolacz R., Nanosatellite Tracking Ships: Cost-Effective Responsive Space, Proceedings of the 4S Symposium 2010, Madeira, Portugal
- [2] Sarda K., Grant C., Eagleson S., Kekez D.D., Zee R.E., Canadian Advanced Nanospace Experiment 2: Two Years of Pushing the Nanosatellite Performance Envelope, Proceedings of CASI ASTRO 2010, Toronto, Canada
- [3] exactEarth Space-Based AIS Data Makes Contribution to Security Efforts for 2010 Olympics and Paralympics, <http://www.exactearth.com/news-folder-2/exactearth-space-based-ais-data-makes-contribution-to-security-efforts-for-2010-olympics-and-paralympics/>, last accessed April 26, 2012.
- [4] Narheim B.T., Olsen O., Hellenen O., Olsen R., Beattie A.M., Zee R.E., A Norwegian Satellite for Space-based Observation of AIS in the High North, Proceedings of the 21st Annual AIAA/USU Conference on Small Satellite, Logan, UTAH
- [5] Dielectric Deep Charge Monitor, Company Brochure, DPL Science.<http://www.dplscience.com>, last accessed April 25, 2012.