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In addition to an AIS receiver and VDES two-way communication device with Yagi antenna, NorSat-TD carries four experimental payloads ●●●

Norway maintains leadership role in space-based maritime situational awareness with small satellite program

Launch of the Norwegian NorSat-TD technology demonstration microsatellite earlier this year marked the latest success in an extraordinary space program that has delivered some of the most significant advancements in maritime navigation and vessel safety since the advent of GPS. The program was the first in Norway to receive Automatic Identification System (AIS) signals from ships at sea by a satellite in orbit, thereby dramatically enhancing marine situational awareness over a wide area.

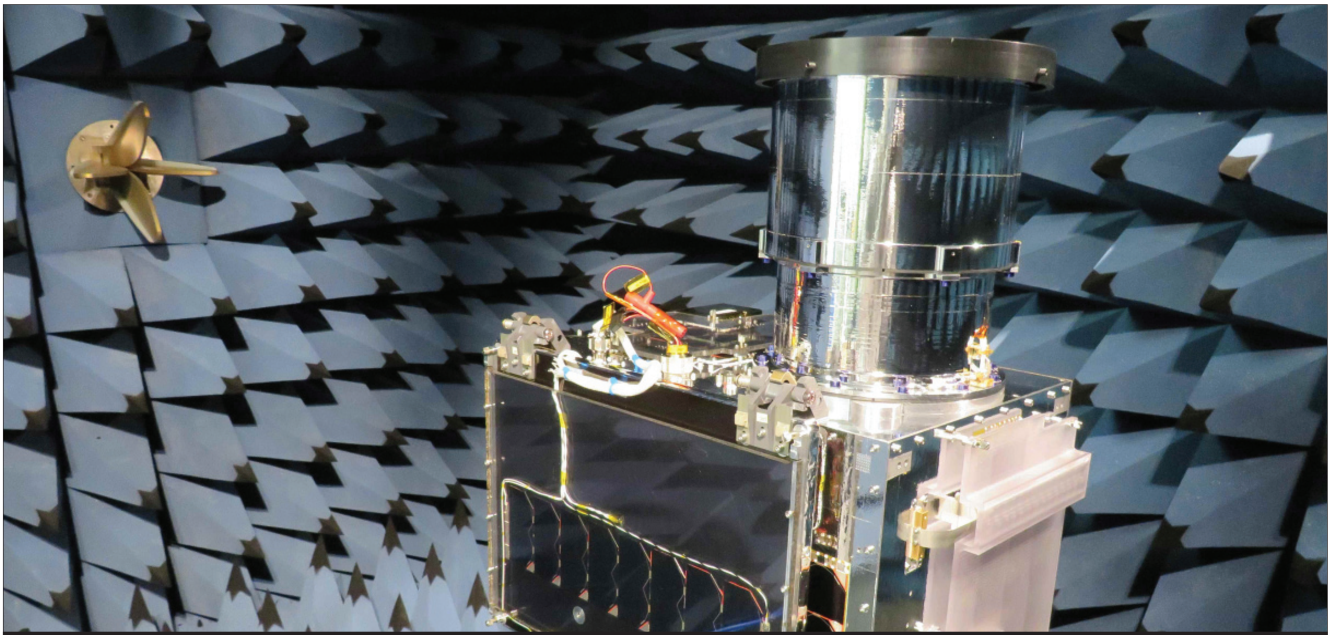
Kevin Corbley, CEO of Corbley Communications, Inc.

Norway's tradition of testing cutting-edge onboard technologies for space-based ship tracking and communications is scheduled for more advances in 2024. The seventh mission in the program, the NorSat-4 microsatellite equipped with a low-light imaging camera, is nearing completion in Toronto, Canada, at the micro space development facility of Space Flight Laboratory (SFL), which has built the entire series of satellites for Norway.

Each satellite has presented unique development challenges posed by accommodating one or more payloads on extremely small spacecraft platforms within limited budgets. The satellite-based situational awareness activities have been unquestionable successes for Norway, especially given the budget constraints.

BEYOND LINE OF SIGHT

Large vessels at sea are mandated to operate AIS transponders that send and receive location identifier signals so ships can avoid collisions. Some ports also monitor AIS for traffic management. While these line-of-sight signals support safe navigation, the Norwegian Coastal Authority (NCA) saw an opportunity to expand utility of AIS for regional ship tracking, rescue activities, and illegal fishing enforcement by capturing the signals from space.



The NorSat-4 microsatellite is nearing completion in Toronto, Canada, at the microspace development facility of Space Flight Laboratory (SFL) ●●●

NCA teamed with the Norwegian Space Center (NOSA) and the Norwegian Defence Research Establishment (FFI) to determine if AIS signals could be captured by satellite. Under an extremely tight budget, NOSA contracted SFL to develop a satellite carrying an AIS receiver/transmitter designed by Kongsberg Seatex AS of Trondheim, Norway. SFL integrated the device and antenna into its mission-proven 20x20x20 cm Generic Nanosatellite Bus (GNB). Despite its 7-kg mass, the AISSat-1 nanosatellite included an onboard computer and three-axis attitude control.

NOSA launched AISSat-1 in 2010. Within 24 hours, the space-based AIS reception concept was proven, and the satellite was transferred to operational status. The nanosatellite captured the AIS signals from hundreds of ships in an expansive geographic area and transmitted them to an NCA base station on land. This enabled NCA to accurately track the locations of identifiable vessels far from shore in thousands of square kilometers of Arctic waters, ultimately creating a National Maritime Tracking Information System that could relay AIS info to vessels.

NOSA launched AISSat-2, a twin of the first, in 2014 which continued to operate for nine years until October 2023. AISSat-1 remained operational until 2022. NCA relies on AIS data for many applications, including guiding its frigates and aircraft to vessels in distress. Precise ship location is critical, particularly for helicopters, which sometimes arrive for a rescue with only minutes of fuel remaining to evacuate the vessel crew and return safely to shore.

AISSAT EVOLVES INTO NORSAT PROGRAM

Based on the success of AISSat-1 and -2, NOSA opted to expand the satellite program and rename it NorSat. While the primary application remained ship tracking, the satellites would also carry scientific instruments for a variety of projects. Following an international open bid process, NOSA awarded the contract for the NorSat satellites to SFL.

"SFL beat out other suppliers based on technical merit, price, and schedule," confirms Tyler Jones, Norwegian Space Center (NOSA) Senior Advisor and NorSat-TD Project Manager. "SFL agreed to a contract for NorSat-1 with options for extra satellites…and that made the acquisition process for the other satellites a breeze."

"SFL is proud to have played a key role in expanding the applicability of a crucial maritime safety technology," notes SFL Director, Dr. Robert E. Zee.

Plans called for NorSat-1 to carry an upgraded AIS receiver with improved signal detection. In addition, the satellite would test two new payloads – a multi-needle Langmuir probe for space plasma measurements in low-Earth orbit, and a Compact Lightweight Absolute Radiometer (CLARA) to record solar output from the sun. The CLARA experiment will contribute to the long-term monitoring of the total solar irradiance (TSI) variability to support the analysis of potential trends in the Sun's variability. It complements other TSI monitors like the Virgo instrument on SOHO.

Continuous and precise TSI measurements are indispensable to monitoring short and long-term solar radiance variations. The existence of a potential long-term trend in solar irradiance and how much a trend could affect the Earth's climate is of great interest.

Three payloads required a larger platform, and SFL transitioned the program to its Next-generation Earth Monitoring and Observation (NEMO) small microsatellite bus. NEMO gave NorSat-1 the physical size (20x30x40 cm), attitude control, high-speed downlink, and power to carry and operate the three payloads. The total satellite mass at launch in 2017 was 15 kg.

"A major challenge in NorSat-1 development was ensuring electromagnetic compatibility of the upgraded

AIS receiver with the satellite systems and payloads," says Alex Beattie, a Senior Mission Manager at SFL.

The new AIS device was more susceptible to electromagnetic noise than previous receivers which meant SFL had to carefully situate the payloads on the platform and plan their operation in orbit to avoid interference. Another challenge was incorporating the deployable Langmuir probe onto the bus for extension after launch without damaging the fragile elements. NorSat-1 and its payloads still operate today.

NorSat-2 posed even bigger challenges with the addition of the world's first VHF Data Exchange System (VDES) payload for high-bandwidth two-way communications. This meant the AIS data could be transmitted directly down to ships at sea, especially to NCA rescue frigates, giving them real-time visibility to other vessels hundreds of kilometers away. More importantly, NCA and ships could communicate with each other beyond line of sight, sharing vital information such as sea ice maps and weather updates.

"VHF data exchange had never been attempted from a satellite," explains SFL's Zee. "Although NOSA provided the VDES device, there was no directional high-gain VHF antenna available for operation from a microsatellite in space."

To assist with antenna electromagnetics design, SFL initiated collaboration with the Electrical Engineering Department at the University of Toronto. An electromagnetics professor and his research group engineered the RF aspects of a VHF Yagi antenna based on initial specifications from SFL. To achieve the effective performance, the antenna had to extend more than twice the length of the NEMO bus. SFL leveraged its internal mechanical engineering expertise to create a foldable Yagi, compact for launch and then deployable in orbit. Both the deployable antenna and first-of-its-kind VDES were operational shortly after the 2017 launch of the 15-kg NorSat-2 microsatellite.

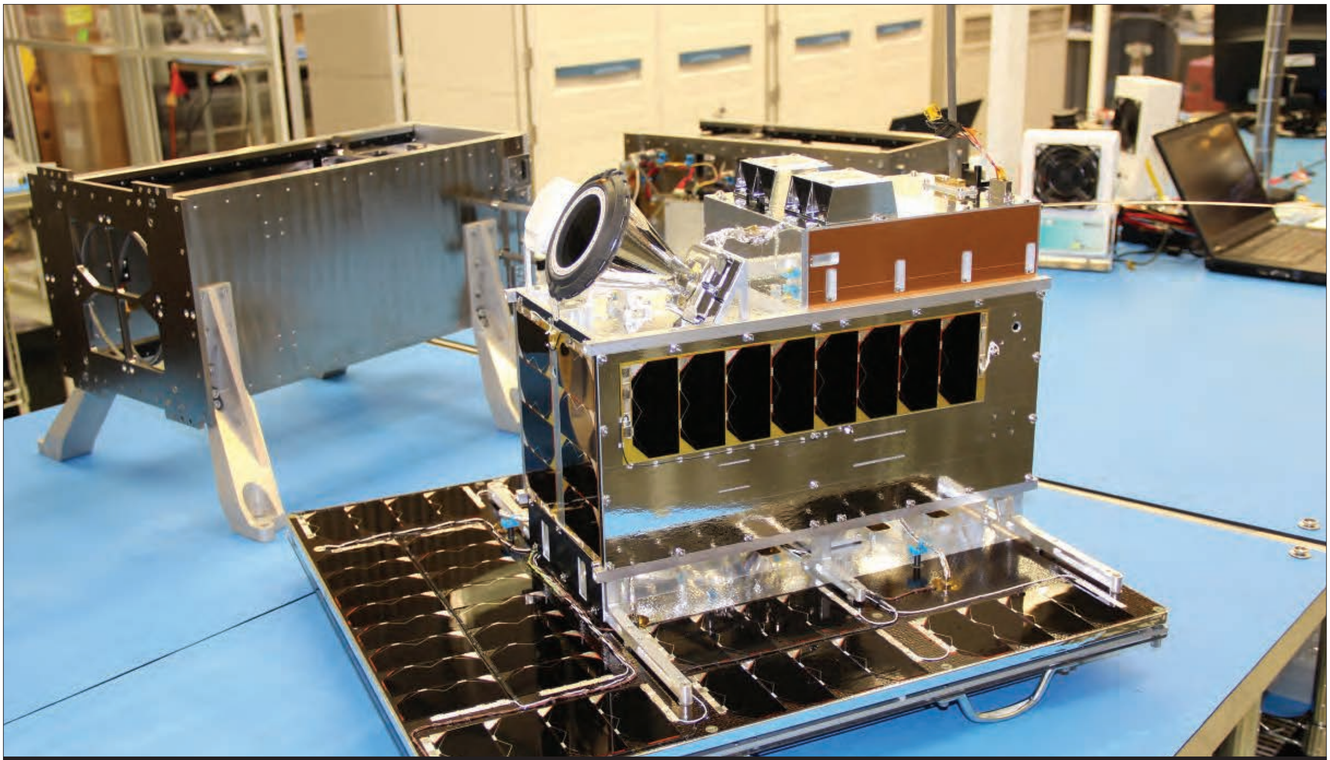
DETECTING "DARK" SHIPS

With concerns over ship piracy, sanction breaking, and illegal fishing growing worldwide, NOSA collaborated with NCA to include an FFI-developed experimental Navigation Radar Detector (NRD) on NorSat-3, along with the AIS receiver. Ships operating with nefarious intentions often turn off their AIS transponders or spoof the signal with incorrect location data, making the vessel appear to be somewhere else.

The NRD was added to provide supplemental ship detection and identification for more accurate marine situational awareness desired by NCA, Norwegian Armed Forces, and other maritime authorities. As the name implies, the new device detects signals emitted from navigation radar systems during regular operation aboard ships. Even if the AIS is turned off or manipulated, the detector can still pinpoint a "dark" vessel and its location.

"The NRD posed two major challenges – development of a first-of-its-kind rigid antenna array and a new attitude control mode," notes SFL Mission Manager, Brad Cotten.

While FFI was responsible for the RF aspects of the NRD antenna, SFL designed the antenna structure with carbon fiber since it was lightweight and unsusceptible to thermal deformation. After manufacture and calibration, the antenna underwent extensive thermal and vibration



An experimental Navigation Radar Detector (NRD) on NorSat-3 provides supplemental ship detection and identification capabilities ●●●

testing. SFL engineers then had to reconfigure the payload layout on the NEMO bus to accommodate the rigid NRD antenna and avoid radio frequency interference.

"The antenna is very sensitive," adds NOSA's Jones. "They had to build a very, very quiet satellite."

In terms of attitude control, SFL had pioneered the precise pointing of low-mass satellites for Earth observation, atmospheric monitoring, and space astronomy. The NRD, however, required development of innovative attitude control algorithms to maximize scanning of large maritime regions with a very narrow field of view on each orbit. The unique new mode enables the detector to pan across the horizon while maintaining the orientation of the antenna relative to the vertical direction.

NOSA launched NorSat-3 in 2021. The onboard ship detection capabilities have contributed to Norway's efforts to expand its fight against illegal fishing in multiple international programs, including one called Blue Justice. Through the initiative, Norway is sharing NorSat data with developing countries to help them track illicit fishing in their territorial waters.

"Norway's maritime territory is seven times its land area, and we don't have enough frigates and helicopters to patrol everything," admits Jones. "We wanted to be able to verify what's out there, and we've been able to do that. NRD is a very powerful tool."

Concurrent with NorSat-3, the NorSat-TD (Technology Demonstration) microsatellite was under development at SFL and undergoing an intriguing evolution. The original design called for a duplicate of NorSat-2 carrying an AIS receiver and VDES two-way communication device with Yagi antenna. Both instruments, however, had been upgraded since the earlier mission and would require greater onboard power to operate.

SFL recommended transitioning the mission to its larger microsatellite bus, the 30x30x40 cm DEFIANT platform. This spacecraft offered more power and greater size at 35 kg. NOSA decided to take advantage of the extra capacity and added four experimental instruments from European partners to the manifest. These included satellite-to-ground optical communications, a payload to enhance GPS precision for space situational awareness, a retroreflector to aid in spacecraft tracking by laser, and iodine-fueled propulsion system.

"Volumetrically, the platform was big enough to fit all the payloads but getting them to point in the right direction was a challenge," explains Jakob Lifshits, SFL Mission Manager.

The operation of NorSat-TD in orbit required careful planning because all instruments couldn't function at the same time due to conflicting power demands, thermal thresholds, and frequency interference. In addition, NorSat-TD would have to maneuver in orbit to orient the various instruments in a required direction for optimal performance. The solution involved a combination of strategic device placement on the bus and writing custom software to achieve balanced payload operation.

NorSat-TD's ship tracking capabilities were performing as planned shortly after launch with evaluation and characterization of the experimental payloads ongoing.

As noted, NorSat-4 is under development at SFL in Toronto. Like NorSat-TD, this mission requires the DEFIANT microsatellite bus to carry a new, relatively large instrument. In addition to a fifth-generation AIS receiver, NorSat-4 includes a unique low-light sensor designed to capture optical imagery in the Arctic.

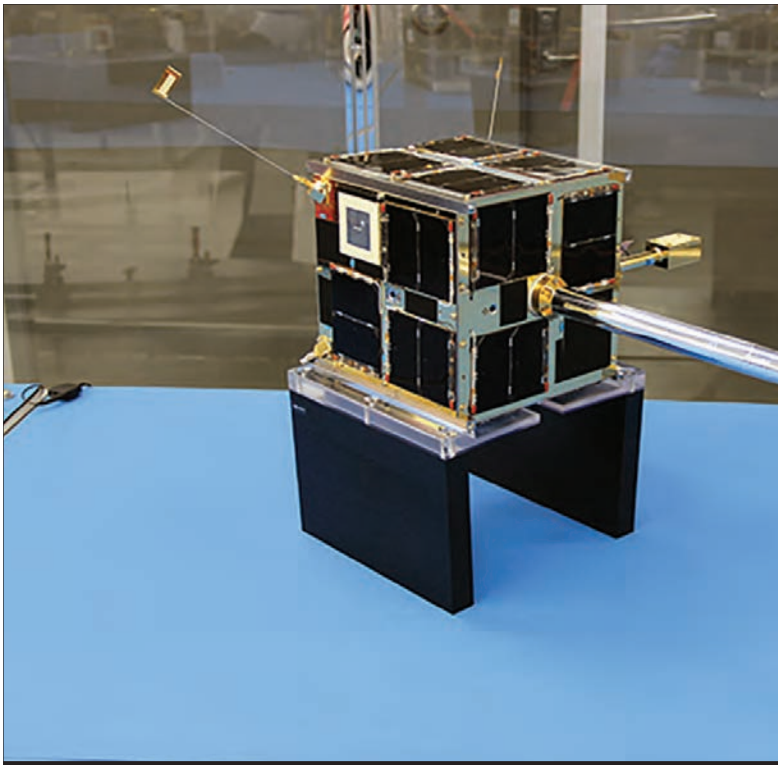
The imager will further expand Norway's ability to detect dark or AIS-spoofing vessels. Its imagery will have the spatial resolution to differentiate ships of various types. For example, the sensor can distinguish a fishing trawler that may be manipulating its AIS signal to appear digitally as a cargo ship.

"The imaging system, however, is a demanding payload from a satellite development perspective, explains SFL Mission Manager, Brad Cotten, "The imager requires active thermal control to maintain low-light image quality and needs extremely precise attitude control for exact image geolocation."

Another first-of-its-kind development challenge for NorSat-4 has been the design and manufacture of a very compact mechanical iris shutter for the sensor aperture. This SFL-developed shutter will open and close as needed in orbit to protect the sensor from direct sun exposure. The microsatellite is on track for launch in 2024.

SUCCESSES SHAPING NORSAT FOLLOW-ON PROGRAM

NOSA and FFI are planning additional maritime situational awareness missions, according to Jones. The next satellite will likely build on the advancements in dark ship detection capabilities made possible by the addition of NRD technology first introduced on NorSat-3. The next operational satellite developed by Norway after NorSat-4 will launch in the 2026-27 timeframe.



AISSat-1 and 2 expanded the utility of AIS for ship tracking, rescue activities, and illegal fishing enforcement ●●●