
KA-BAND AND THE FUTURE OF BIG DATA FROM SPACE
KSAT
KONGSBERG
KONGSBERG SATELLITE SERVICES
ASTRO DIGITAL

PART I

Introduction

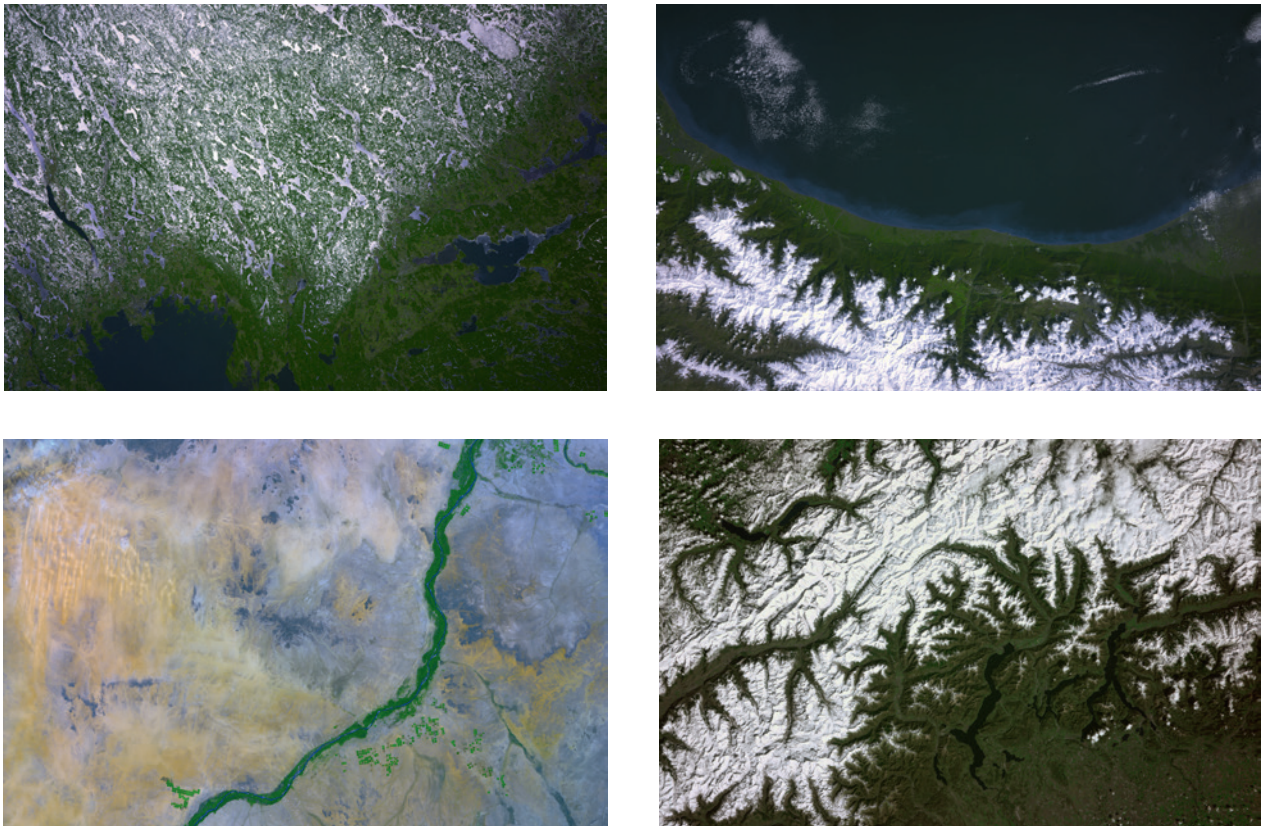
Satellite data have become essential in supporting operations whenever time is critical: for decision-making during humanitarian and disaster relief operations and in international peacekeeping and security missions, among other unique contexts. Well-established satellite service providers are partnering with smallsat companies to meet this explosive rise in demand for data. The recent partnership between Norway's Kongsberg Satellite Services (KSAT) and Santa Clara's Astro Digital US, Inc. (AD) is transforming how Low Earth Orbit (LEO) satellites deliver big data from space. KSAT and Astro Digital have worked together to bring each other's complementary technology and infrastructure into a new Ka-band offering in the KSAT^{LITE} portfolio. Alongside S- and X-band, KSAT^{LITE} now offers a turnkey Ka-band solution that enables smallsat companies to deliver big data frequently and affordably to their end-customers.

Astro Digital manufactures and operates micro-satellites supporting a broad range of applications for itself and 3rd party customers through a smaller, faster, and lower-cost "NewSpace" constellation approach – designed for high performance and maximum throughput of data from space to earth. KSAT^{LITE} offers flexible Ka-band ground station services to Astro Digital while maintaining critical features associated with the highly successful KSAT network: unique pole-to-pole ground station coverage, central network operations, and high-quality network dependability. Together, Astro Digital and KSAT are paving the way for commercially available high bandwidth through Ka-band applications, designed for high throughput and at an optimized price point. This white paper describes the evolution and technical features of this partnership and highlights how smallsat companies can leverage KSAT^{LITE} to enhance their operational success.

PART II

Astro Digital's Needs to Deliver Big Data frequently

To meet the accelerating demands of their customers, Astro Digital's founders imagined a constellation of high-performance micro-satellites capable of wide-scale imaging of the Earth's land-mass at a frequent, persistent, yet affordable rate. But the combined cost of building a satellite constellation, securing launch services, and establishing worldwide ground stations created unique challenges for raising capital and providing frequent data access. Until their partnership with KSAT and their joint development towards a Ka-band solution, no existing set of technologies or group of companies allowed for the implementation of Astro Digital's vision. Cost-effective downlinks of high throughput and high frequency data were out of reach for small satellites.



Images taken by Astro Digital's Landmapper series spacecraft and downlinked via Ka-band by KSAT.
Clockwise from top left: Swedish countryside, Iranian coast, Italian & Swiss Alps, Sudanese Nile River Valley

This problem has remained intractable for the last decade. As small satellite operators first attempted to monitor and image the Earth, it became clear that sensors would be limited by the ability to transmit the large quantities of data when and where it is needed on the ground. Although small satellites had, to a large extent, overcome the limitations of power, on-board memory size, and attitude control pointing accuracy/precision, the down-link data rate of small satellites – never more than 60 to 80 Mbps at X-band (8.0–8.4 GHz) – remained too slow for emerging high value applications. Satellites could collect large volumes of data but lacked the downlink capacity to bring the data to earth in a timely and cost effective manner.

To increase the effective downlink throughput, one conventional workaround existed: building hundreds of satellites to form new constellations and a corresponding number of ground stations to support these massive systems. In this model, data is downlinked in near-real time in the vicinity of where the images are taken. Thus the option was either to A) implement this workaround, increasing the number of satellites and downlink locations globally, and continue business as usual, or B) find a new way to significantly increase downlink rates, downlink at strategic locations, and store the data on-board for some short period of time. The solution had to meet market timeliness as well as economic feasibility. Astro Digital identified a huge opportunity with KSAT, the first and only commercial operator of Ka-band ground stations in the "NewSpace" market with the ideal location "on top of the world" at 78° North. Together, they innovated toward a new solution in the KSAT^{LITE} portfolio.

KSAT^{LITE} SG-44 INITIAL PERFORMANCE

Aperture Diameter	2.80 m
Aperture Efficiency	55%
Antenna Gain	55.3 dBi
-3 dB Beamwidth	0.28°
-1 dB Beamwidth	0.08°
LNA Noise Figure	1.65 dB°
LNA Noise Temp.	125 K
System Noise Temp.	
99.5% Link Availability (Rain)	372 K
Clear Sky	225 K
System G/T	
99.5% Link Availability (Rain)	28.5 dB/K
Clear Sky	30.7 dB/K

KSAT 2.8 M APERTURE AT SG-44; SVALBARD.

ASTRO DIGITAL KA-BAND RADIO CHARACTERISTICS

	Gen 1	Gen 2	Gen 3	Gen 4	Gen 5
Peak Data Rate	1 Mbps	37 Mbps	320 Mbps	>800 Mbps	>2 Gbps
Protocol	DVB-S2	DVB-S2	DVB-S2	DVB-S2X	DVB-S2X
Rx Data Rate	Tx Only	Tx Only	Tx Only	25 Mbps	100 Mbps
Status	On Orbit Since June 2014	Delivered 2015	Launched January 2018	Est. Launch Q4 2019	Est. Launch Q4 2020

PART III

KSAT in the Satellite Services Industry

KSAT is well known among leading space agencies and satellite operators as the preferred ground partner for all polar orbiting satellites. It operates from EHF to Ka-band and has developed a robust infrastructure and network operations expertise that can handle tens of thousands of satellite contacts monthly. KSAT has obtained all regulatory licenses needed to provide seamless global satellite services and is the go-to service provider for fully integrated, global ground station solutions.

For decades, KSAT has been the selected vendor for leading commercial space organizations and the largest space agencies. KSAT works with the Japanese Space Agency, the European Space Agency, and U.S. government agencies such as NASA, NOAA, and USGS to deliver satellite services in bands from UHF to EHF. Currently, KSAT supports missions such as the NASA Joint Polar Satellite System (JPSS) and NPP with Ka-band but uses larger antenna systems than the new KSAT^{LITE} offering.

PART IV

KSAT^{LITE} and the Ka-Band Solution in NewSpace

KSAT^{LITE} leverages KSAT's 50-year experience in the satellite world to provide capabilities never before achieved: it offers cost-optimized S-, X-, and now Ka-band services for smallsats. Astro Digital proves the tremendous value of KSAT^{LITE}, having successfully demonstrated that, using a 2.8 m dish at KSAT in Svalbard and the Astro Digital AKAT Ka-band small satellite communications system, it is possible to download more that 10 GBytes of data from even a small 6U CubeSat spacecraft during a single 10-minute pass. Astro Digital's set of miniaturized Ka-Band transmitter and receivers, with integrated directive horn antennas, can support downlink data rates (adaptively) from 35 Mbps to 2.2 Gbps.

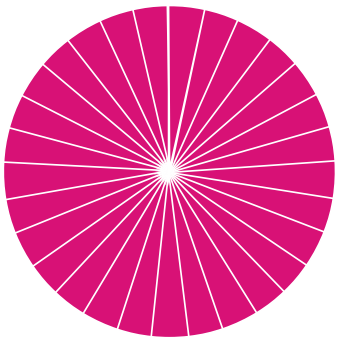
KSAT is committed to providing full value chain services so that satellite operators and service providers can focus on their core competency: collecting and transforming satellite data into ready-to-use information for their customers. Operators can draw upon KSAT's leadership, technical know-how, experience with regulatory agencies, and agile mindset to deliver cost-effective market-ready solutions with their adapted KSAT^{LITE} network.

KSAT Ground Stations: Situated in the Most Ideal Locations on Earth

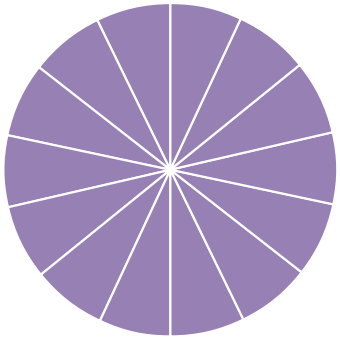
KSAT^{LITE} draws upon KSAT's strategically positioned ground stations located on all continents of the world. KSAT owns and operates ground stations spanning from 78° north in Svalbard to 72° south in Troll. The pole-to-pole services are ideally located for polar orbiting satellites, and the mid-latitude stations are ideally located for satellites in lower inclinations.

The Svalbard site, located 1,300 km from the Arctic North Pole, is the largest polar ground station in the world. Svalbard is the only commercial ground station that can provide all-orbit support – 14 of 14 passes per day – to polar orbiting satellites. KSAT's smaller and even more remotely located Troll site, an Antarctic ground station, and the new South Chilean Punta Arenas ground station provide a unique capacity in the southern hemisphere that is unparalleled in the market. In combination these three stations offer a pole-to-pole solution: with all-orbit coverage from Svalbard, 12 out of 14 orbits from Troll, and 8 out of 14 orbits from Punta Arenas, KSAT can deliver a record 28 out of a total 28 passes.

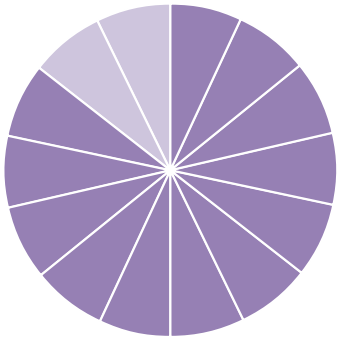
FIGURE: KSAT^{LITE} extends KSAT's pole-to-pole coverage for Ka-band services. It uniquely provides almost two contacts per orbit from only two ground stations.



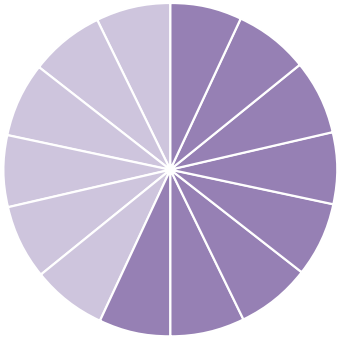
KSAT POLE-TO-POLE
28/28 visible passes



ARCTIC SVALBARD
14/14 visible passes



ANTARCTIC TROLL
12/14 visible passes



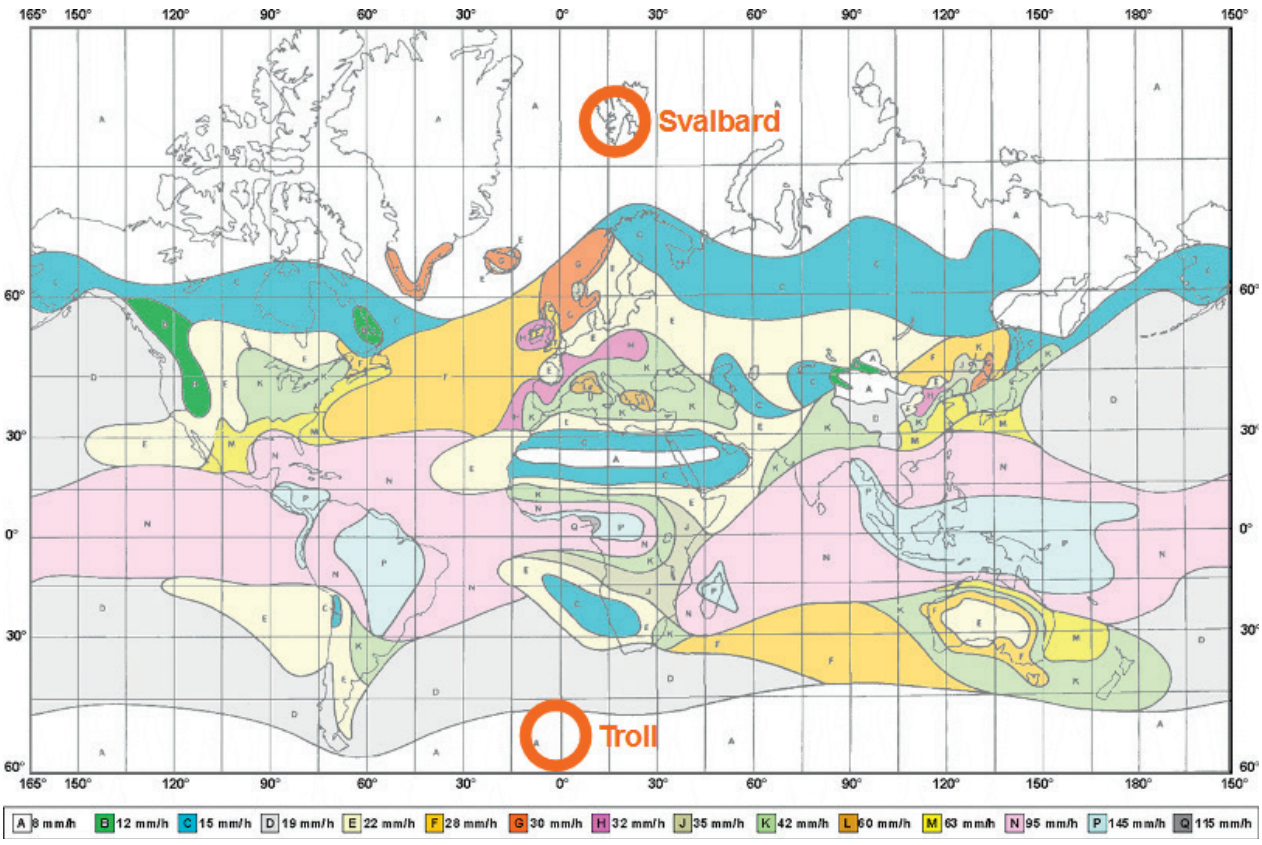
PUNTA ARENAS
8/14 visible passes

Svalbard and Punta Arenas ground stations are connected to an optical fiber-based backbone and Troll ground stations communicate via a high-capacity GEO relay satellite link. All three sites provide rapid access to satellite data globally, with data latency from a LEO satellite in sun-synchronous orbit typically between 50 minutes and 100 minutes from collection to Acquisition of Signal (AOS) when both Svalbard and Troll sites are utilized.

Managed by KSAT's state-of-the-art Tromsø Network Operating Center (TNOC), all three sites have secure and reliable site infrastructure and provide around-the-clock service using experienced professionals. TNOC handles all aspects of satellite passes including scheduling, data acquisition and data handling, reporting, interfacing, and management: it is the single point of contact for all KSAT users.

KSAT Ground Stations: Situated in the Driest Conditions on Earth

The higher frequency of Ka-band is more susceptible to radio signal attenuation in high moisture conditions than lower frequency bands. KSAT's ground stations – at Svalbard and Troll – are located in the best climactic zone for the Ka-band spectrum. The reliably dry conditions of these locations allow for robust Ka-band transmission without interference from rain or snow.



Two unique ground stations, operated and owned by KSAT, are located in Svalbard (78° north) and in Antarctica (72° south). Both locations are desert-like and allow data downlink without degradation caused in high-moisture locations.

Ka-band: Advantages Over Lower Frequency Bands

The benefits of KSAT[LITE]'s Ka-band solution for small satellites are currently unmatched, even as X-band is today's gold standard for remote sensing satellites.

1. The high frequency Ka-band provides a larger pipe to bring down higher amounts of data from satellites. The 1.5 GHz of bandwidth available in the EESS band at 26 GHz is four times the bandwidth of the X-band EESS allocation. Space applications supported by this transmitter are not limited to the EESS band (remote sensing); Astro Digital's next generation Ka-band system will also be capable of operating within other spectral bands, using frequencies as high as 42 GHz. Astro Digital's AKAT downlink transmitters currently offer up to 320 Mbps using just 87 MHz of this available bandwidth, and will soon be able to offer data rates higher than 800 Mbps within just 220 MHz of the same spectrum.

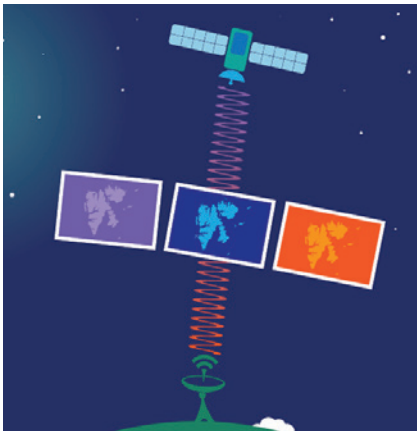
2. From a regulatory perspective, X-band spectrum is more heavily used, especially by space agencies around the world. New commercial satellite companies must coordinate interference right-of-way with respective government entities, e.g., with NASA in the U.S. While similar coordination must also be done in Ka-band, Ka-band offers a step towards offloading the frequency congestion of X-band: Ka-band "unlocks" new capacity in otherwise saturated regions. In addition, more frequency reuse is possible as the beamwidths of both satellite and earth station antennas are narrower, thus further reducing the chances for in-line interference between any two systems sharing the same frequency "channel."

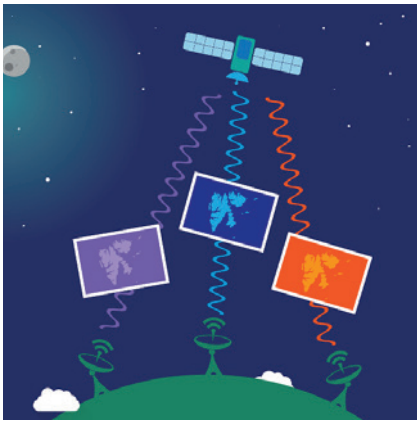
3. Ka-band allows for a much smaller antenna system on the ground. The performance gained from a relatively small antenna in Ka-band is higher than a similar-sized antenna in X-band. Since the size of the ground antenna is a key driver of investment cost and correlates to the service price, the use of smaller antennas keeps the KSAT[LITE] service at an affordable level.

4. The physical parameters of Ka-band allow for a smaller transmitter and antenna to be utilized on-board the satellite. The Astro Digital transmitter (with its high performance reference oscillator and a directive antenna) is contained within an envelope of only 10x10x10 cm. This small form factor and the lack of need for a deployment mechanism reduces overall spacecraft mass and volume, further reducing launch costs while also increasing the available payload volume inside smallsats.

Together, these factors generate high value because more data is downloaded more frequently at a lower cost. This is why Ka-band is a perfect fit for the NewSpace market: high throughput and optimized price!

FIGURE: The Astro Digital Corvus-BC spacecraft consists of three image sensors on the spacecraft for multi-spectral imaging. These sensors triple the data volume downlinked to the ground compared to a typical single color or panchromatic image sensor. The traditional method for downlinking this large volume of data is to have many ground stations around the globe. With high bandwidth Ka-band capacity, Astro Digital is able to downlink all the sensor data through one ground station, a highly cost-efficient solution. The Ka-band AKAT horn antenna is visible below the three sensor lens assemblies.





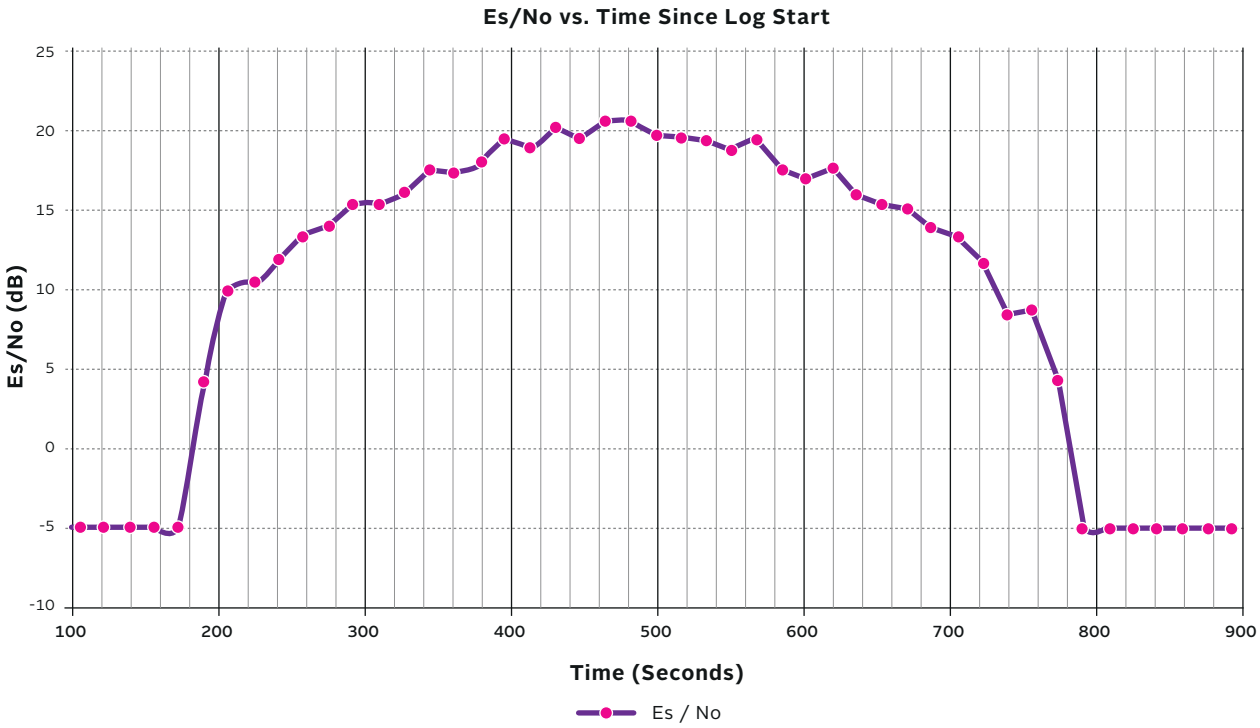


FIGURE: Working Together – Signal performance during a typical Ka-band pass of AD's Landmapper over Svalbard. The Landmapper-BC satellite is directed to point at KSAT/Svalbard, while the ground station simultaneously tracks the spacecraft. This plot shows the Es/No achieved during an entire pass. Any Es/No greater than –2 dB Es/No will result in error-free decoding of the Ka-band link. During this particular pass, the AKAT transmitter was set in CCM mode at 185 Mbps. 185 Mbps x 600 seconds during lock resulted in >13 GB of downloaded raw data during this trek of the satellite over Svalbard. This data was taken during a Svalbard pass on 7 September 2018.

PART V.

KSAT and Astro Digital: Innovations for NewSpace

KSAT and Astro Digital collaborated intensely to perfect a Ka-band solution that may now be adopted by other smallsat companies. KSAT^{LITE} adapted the existing KSAT infrastructure to support Ka-band antennas and ground stations, while Astro Digital designed radios and antennas to communicate seamlessly with KSAT's Ka-band ground stations. Together, these new standards and technologies provide a cost-effective utilization of Ka-band.

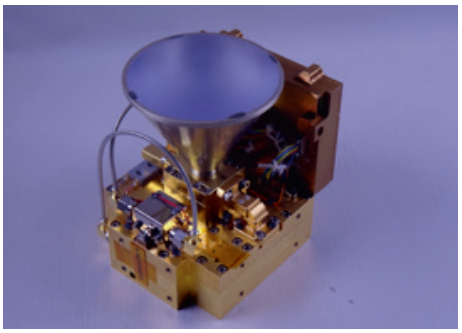
KSAT and Astro Digital have innovated from three different perspectives:

1. KSAT has been the financial stakeholder and the leader in developing an antenna system for Ka-band specific satellite hardware and ground station infrastructure for high-volume data capture and downlink with input from Astro Digital's Engineering team.

2. KSAT offers an attractive "springboard," flexible pricing model to Astro Digital and has established a business model that makes the massive data download possible for a smallsat startup.

3. Astro Digital has implemented an enhanced DVB-S2 (and now DVB-S2X) data standard system and has developed software, firmware, and hardware that allows its satellites to maximize throughput when meteorological limitations or elevation angles affect signal acquisition. In the next phase of development (now well underway), Astro Digital will increase its use of downlink transmission bandwidth while adding a new uplink receiving capability. This will allow for very rapid adaptive modulation and coding (ACM) as well as high-speed data uploading and rapid re-transmission of any missed downlink data transmission. Downlink data rates are planned to be as high as 2.2 Gbps by mid 2020.

FIGURE: Astro Digital's 3rd Generation Ka-band Transmitter (AKAT-3) is in production now.



CHARACTERISTICS; 3RD GENERATION*:

- Pout = 0.6 watts RF
- Pin = 11.0 watts DC (ITA)
- Pin = 9.0 watts DC (Mod/Cod)
- f = 25.5 to 27.0 GHz
- Antenna Gain = 23.5 dBi
- Antenna BW = 10.2°
- Polarization = RHCP or LHCP
- EIRP = 20 dBW = 100 w
- Modulation: DVB-S2(X); 28 MODCOD Steps
- Bandwidth: 86.4 MHz
- Symbol Rate: 72.00 Msps
- Data Rate: Selectable from 34 to 320 Mbps
- Mass: 700 g
- Volume: 1 liter (1 U)

* *Current Production Units*

Innovative Satellites

The partnership between KSAT and Astro Digital has created unprecedented technical innovations that will benefit the satellite industry as a whole. First, Astro Digital's small-size Ka-band radios pair with KSAT Ka-band ground stations to enable high data rate services with very low bit error rates. Second, KSAT ground stations track Astro Digital satellites and schedule data downlinks. End-customers will benefit by getting the most accurate data at an optimal cost.

Ka-band and Pointing Accuracy

Antenna size, operations, and tracking technique are large drivers in the overall ground station service cost and performance. KSAT and Astro Digital, through proper sizing of the satellite and ground station antennas, have coordinated with the antenna vendor for an innovative design-to-cost solution that avoids auto-tracking and maintains a cost-optimal design. They have balanced a small antenna on the satellite with a small antenna on the ground station in order to produce a high speed downlink. On the ground station side, KSAT has maximized Figure of Merit (G/T) while keeping an optimal beamwidth[1]. Due to the physical properties at Ka-band, a smaller antenna meets the G/T requirements for the data downlink, allowing for high throughput at an ideal price point.

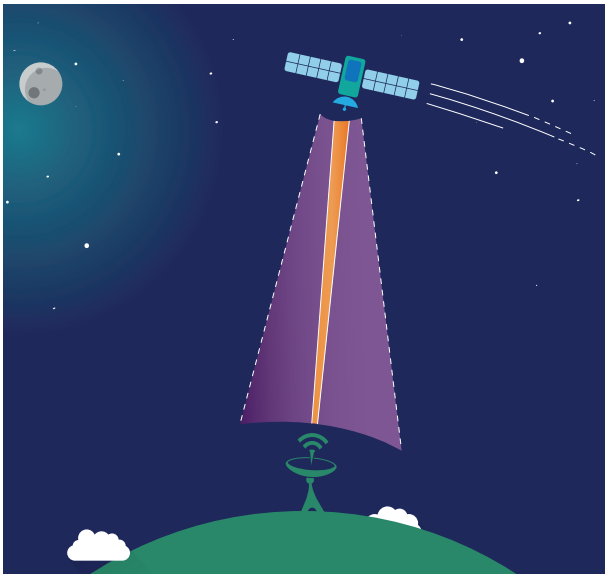


FIGURE: The image shows the ground station antenna and the satellite antenna tracking each other without the implementation of auto-tracking. The antenna on the satellite gives a larger beam (shown in purple) and the antenna on the ground station captures a narrow slice of this beam (shown in orange).

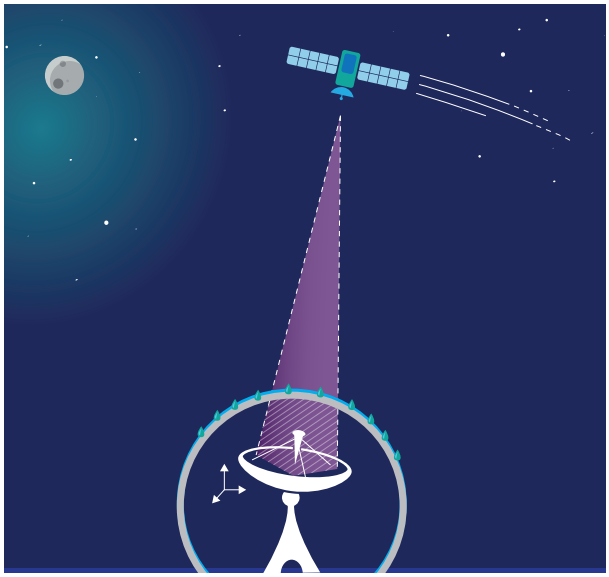


FIGURE: The KSAT systems are designed to defy typically Ka-band challenges – pointing accuracy, through precise alignment and tracking, and high precision mechanics and reflectors, and signal attenuation due to atmospheric moisture, through desert-like locations and advanced downlink handling.

[1] The satellite Ka-band antenna beamwidth is 10.2° while the KSAT 2.8 m aperture has a beamwidth of 0.25°, a gain of 55.9 dBi and a G/T of 30.7 dB/K.

Smaller Antennas in Drier Locations

Due to its smaller wavelength as compared with X-band and S-band, Ka-Band systems typically require smaller antennas on the satellite and on the ground for a given data rate, which in turn reduce the cost for smallsats. The dry conditions of the KSAT polar ground stations allow for smaller antennas on the ground than would be required of a system in more humid locations as shown in this ITU chart.

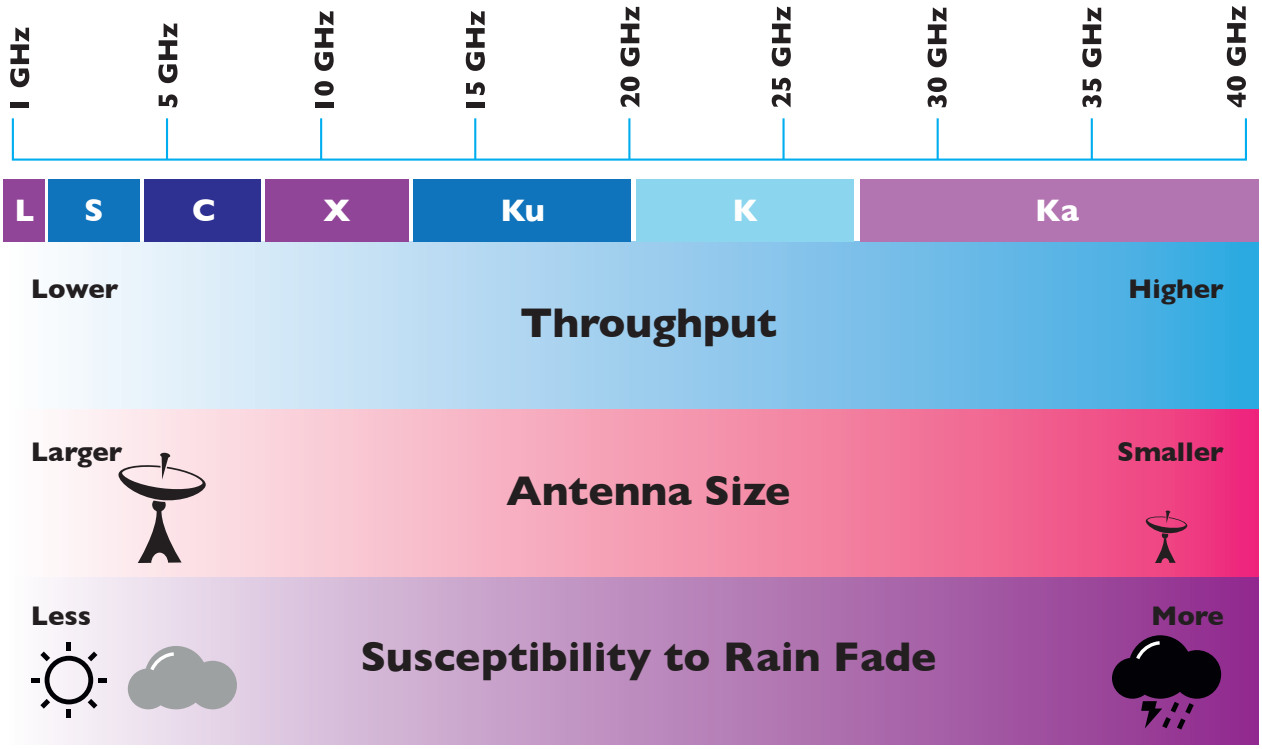


FIGURE: Ka-band is more susceptible to atmospheric moisture than other bands. However, KSAT ground stations, located in desert-like conditions in the polar regions, offset this inherent limitation, realizing the full benefits of operating in Ka-band frequencies.

An equatorial ground station has issues that do not arise with polar locations. First, the weather conditions at the equator mean a greater degradation of the overall bandwidth and require a larger and more expensive antenna. Second, these more humid weather conditions require an auto-track functionality, which further drives up the cost. The benefits offered by KSAT[LITE]'s polar ground stations – lower degradation of signal without expensive auto-tracking – make for an ideal solution.

Implementing DVB-S2(X) and Adaptive Coding Modulation (ACM)

Astro Digital has coordinated with KSAT to implement all three modes of DVB-S2: Constant Coding/Modulation (CCM), Variable Coding/Modulation Mode (VCM), and Adaptive Coding/Modulation Mode (ACM). In order to optimize high speed data throughput as the Landmapper constellation matures, Astro Digital's satellites are being designed to dynamically change the downlink data rate based on their position in orbit and their downlink signal strength as detected at KSAT. This results in a constant maximization of data delivery from space-to-earth depending on link conditions.

New Business Models

The barrier to entry into the satellite market is high. Start-up ventures have limited capital, and must prioritize investments across their satellites, platforms, ground segment, customer development, etc. They can save precious resources by partnering with KSAT and choosing to no longer invest capital in building ground stations and securing ground station licensing, or the operational time and expenses of station maintenance. KSAT hardware infrastructure and licenses provide turnkey capabilities for smallsat companies like Astro Digital so they can focus on core competencies and revenue generation.

KSAT has made it easy for smallsat companies to interface with its ground station network and offers a flexible subscription-based model; companies have an option to pay for system level capacity for each constellation annually, pay per pass, or work with KSAT on a spring-board option. KSAT works hand-in-hand with start-ups with lean models, enabling them to grow and implement a global ground network as their business develops and as their customers demand for big data escalates. Data backhaul can be sent back over the Internet to customers in any form, including multiple cloud platforms or to a customer's own data center.

KSAT^{LITE} combines an industry track-record and ideal ground station sites with flexibility in pricing models and a commitment to meet the changing needs of its smallsat customers.

PART VI.

Parting Words

KSAT's in-depth expertise and specialized knowledge of infrastructure projects is unmatched. KSAT^{LITE} Ka-band provides a flexible and low-cost standardized solution for smallsat companies to enter the satellite market. Astro Digital's market-ready Ka-band solution is proving this concept. By pairing Astro Digital's Ka-band transmitter with KSAT^{LITE} Ka-band, new customer missions can be realized without significant investments in technology development and ground infrastructure: "Big data" on every orbit with low latency is attainable today.

FOR FURTHER DETAILS, PLEASE CONTACT:

PATRICK SHANNON
PATRICK.SHANNON@ASTRODIGITAL.COM
+1 978 973 6564

ASTRO DIGITAL

CAROLYN BELLE
CAROLYN.BELLE@KSAT.NO
+1 650 237 9805

KSAT KONGSBERG
KONGSBERG SATELLITE SERVICES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