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NewSpace INTERNATIONAL

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Dr Amy Saunders
Editor

Edging back to business as usual

"The world is far from back to normal, but life can only be stalled for so long. With much of the world cautiously edging its way back to a new normal, this is also translating to the space sector.

Virgin Orbit achieved a historic first in May with its first attempted launch of LauncherOne; although the launcher achieved clean separation from its carrier plane, it failed to continue to its intended orbit for reasons as of yet unknown. Meanwhile, after a last minute cancellation on 27 May, SpaceX has made history with the launch of two NASA astronauts to the ISS via its Crew Dragon capsule – the first launch of American astronauts from the USA since 2011, and the first time this feat has been achieved by a privately-owned company.

It's great news that the world is getting back on track somewhat, not least for the sake of economy, business owners and employees everywhere. Mental health difficulties have sky-rocketed during the COVID-19 pandemic, with many suffering severely with such a grave impact on their daily lives, as well as fear of what the future holds. With many countries edging back to work in some form or another, populations the world over will feel some relief to return to normal. We've heard of a significant number of redundancies and company closures in the space sector, and we wish all those affected the best for the future.

This latest issue of NewSpace International features exclusive in-depth interviews with two exciting launch entities; Scotland's commercial launch company Skyrora and USA-based smallsat launch logistics company Orbital Transports. Lacuna Space has contributed an intriguing piece on using the Internet of Things (IoT) in space, while NanoAvionics opines on new developments in propulsion technologies. Printech Circuit Laboratories provides an overview of flat panel antenna technology, while we report detailed reviews of deep space communications and space-based cryptocurrencies.

We hope you enjoy the issue!

Qtum satellite

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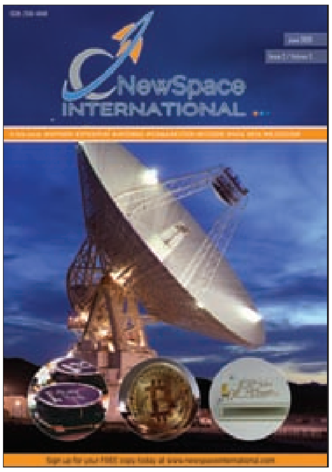

Front cover: Photo courtesy of NASA

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Intelcomm to develop new technology to support human robot interaction in space

Intelcomm has signed up to the national SPRINT business support programme to collaborate with the University of Surrey on the development of new autonomous decision support system (ADSS) technology for space applications.

Intelcomm will integrate a unique fault detection algorithm from the University of Surrey to its space robotic system. This will provide safer space exploration by enabling the crew to remain fully aware of the health of an identified spacecraft system at all times, making data-enabled decisions in real-time and increasing the level of autonomy of the robotic platform.

The University of Surrey will deliver a Connected and Autonomous Vehicles (CAV)-designed Predictive Maintenance algorithm. Intelcomm will utilise the expertise and facilities at the University of Surrey to prove the concept for an enhanced Human-Machine (Autonomous/remote Rover) interface.

Using ADSS will greatly reduce the astronaut's dependency on Earth-based mission control and will return control to the astronaut to enable a full oversight of the robotic operating systems. This will help astronauts to manage difficult or potentially dangerous failure scenarios in a timely manner and avoid escalation, ensuring their safety and the safety of the robotic or autonomous system at the same time.

The project will be funded by a grant from the £4.8 million SPRINT (SPace Research and Innovation Network for Technology) programme that provides unprecedented access to university space expertise and facilities.

SPRINT helps businesses through the commercial exploitation of space data and technologies.

Bob Buckle, Director of Intelcomm UK said: "This new piece of Internet of Things technology will allow us to import and convey large amounts of information in an intuitive way. Although some of this technology is already in place, the integration of real-time information is relatively new. Astronauts can use the technology and although we're using space as a primary target for this particular development, we've also had interest from other industries.

"Intelcomm and the University of Surrey have worked together on other programmes including autonomous vehicles and through the Surrey Space Centre, they will bring extremely useful experience in deep space communications."

Dr Saber Fallah, Senior Lecturer in Vehicle and Mechanotronic Systems at the University of Surrey added: "We've worked with Intelcomm in the past on a feasibility study into a purpose built, complete, communication system for remote deployed CAV operation, and have already developed a successful working relationship.

"For the SPRINT project, we will leverage this research expertise to integrate a patent-pending algorithm for predictive maintenance. This will enable Intelcomm to develop an ADSS for space situational awareness in a human robot interaction scenario."

The project will also be supported by the FAIR-SPACE Hub, a SPRINT partner, located at the Surrey Space Centre and a national centre of research excellence in space robotics and AI.

Ann Swift, Innovation & Partnership Manager at the Hub said: "The Hub is pleased to actively support new R&D being led by UK SMEs. Intelcomm has ambitions to prototype a new Augmented Reality enabled solution that will make operating in space safer for all, including those humans working alongside robots and we are confident that this project will stimulate significant interest from within the UK space sector as well as globally."


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Blockchain reaches for the stars

Cryptocurrencies and their enabling technology, blockchain, are more than 10 years old now, having achieved considerable success and infamy during that time. The space sector, always racing ahead, is keen to get in on the action, with several innovative new projects taking advantage of blockchain technology or cryptocurrency hosting on board satellites.

Amy Saunders, Editor, NewSpace International

Only two decades ago, at the turn of the century, the vast majority of the population would think you quite mad if you claimed you had invented a new currency, with no physical basis or government backing whatsoever (side note; check out Terry Pratchett's *'Making Money'* for a more whimsical view around inventing currencies from thin air).

To paraphrase an old saying - 'If you can imagine it, it exists' - this has certainly been proven true as far as cryptocurrencies are concerned. Nevertheless, here we are a mere twenty years later, and more than 2,000 cryptocurrencies have been imagined up out of nowhere (well, not quite, but that must be how it appears to some *author waves hi to parents*).

Cryptocurrency/blockchain 101

For those not fully in the know, we'll take a brief look at cryptocurrency/blockchain as an ecosystem.

Bitcoin was the first decentralised cryptocurrency available on the market, designed in 2008 and launched in 2009. It remains the most widely known and the most valuable, although many other such cryptocurrencies have arisen off the back of its success; Litecoin (launched in 2011, designed with similar technology as Bitcoin, but processes blocks – we'll come on to these later – 2.5 times faster); Ripple (launched in 2012, designed as a real-time gross settlement system, currency exchange and remittance network); and Ethereum (launched in 2015, designed with a very different technology, namely a decentralised Turing-complete virtual machine platform runs smart contracts, namely applications that run exactly as programmed with no possibly of downtime, censorship, fraud or third-party interference) are the biggest names in cryptocurrency besides Bitcoin. Countries and cities, too, are getting in on the action with their own cryptocurrencies; Dubai launched emCash in October 2017, with which consumers can achieve anything from buying their daily coffee to paying utility bills and money transfers.

The majority of cryptocurrencies are based on blockchain technology. The first blockchain, conceptualised in 2008 and implemented in 2009 by Satoshi Nakamoto (an unidentified person or group), was the core component of Bitcoin, where it acts as the public ledger for every transaction. Since then, other entities have come on board with their own blockchain technologies for use in other cryptocurrencies or related systems. A blockchain is a continuously-growing list of records or 'blocks' which are linked and secured using cryptography. Each block usually contains a hash pointer as a link to a previous block, a timestamp, and transaction

Bitcoin was the first decentralised cryptocurrency available on the market. Photo courtesy of Pexels data. That means that, by design, blockchains are resistant to data modification. In the words of the *Harvard Business Review,* "…blockchain is an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way." For use as a distributed ledger - such as for cryptocurrency applications - a blockchain is managed by a peer-to-peer network collectively adhering to a protocol for validating new blocks. Blockchains are, in effect, a distributed computing system delivering a decentralised consensus, making them suitable for recording events, transaction processing, food traceability, voting, and general record management.

While blockchain technology is absolutely critical for cryptocurrencies, we can expect to see many more applications emerging in the near and medium futures on the basis of blockchain. Many believe that it is the blockchain technology itself, and not the cryptocurrencies, which will deliver truly world-changing innovations in the years to come.

Cryptocurrencies in action

The widespread proliferation of high-speed Internet combined with a general distrust of financial institutions and governments have been key in fuelling the rise in cryptocurrencies. Many digital natives believe that cryptocurrencies are the key to the future and find immense value in a digital currency that is beyond the control of governments, banks, and companies. A world where each user directly owns their money, instead of the banks, is extremely attractive for much of the population, who mistrust the banks and/or fear for the future. In addition to providing what many see as a fairer and safer financial system, it's said that cryptocurrencies will solve the problem of weak and failing currencies, such as Venezuela's Bolívar.

Since its inception, Bitcoin has had its fair share of ups and downs as investors rushed into the market, only to dump their stock at the first sign of a wobble. Back in March 2010, each Bitcoin was worth US$0.003, while in May 2010, the first real-world transaction took place when Laszlo Hanyecz bought two pizzas for 10,000 Bitcoin. The first Bitcoin bubble saw prices peak at US$31 in July 2011, followed by a crash down to US$2 in December 2011. Prices hit their all-time high of US$19,783, plummeted in the months to follow, and have never recovered (prices are at US$9,145 at the time of going to print), but have stabilised.

We're now ten years on since the launch of the first cryptocurrency and it's hard to say whether it can be considered a success. Despite so many investments in the technology, and so many people and companies owning some of these intangible coins, cryptocurrencies have yet to break into the mainstream. Very few merchants and financial institutions accept payment in anything under than fiat currencies.

Back in our 2018 article *'Satellite – Making cryptocurrencies truly global,'* Bitcoin and the other cryptocurrencies were big news – daily, there would be new stories, new updates, new prices, and technologies to be discussed. Today, however, we're reading a lot less about cryptocurrencies and blockchain. Looking back, it's possible that 2018 was something of a slow-news year, and we mustn't forget that we're now living in a post-Greta Thunberg, post-Brexit and post-Megxit world, and all the news pages those are bringing us. The supporters of cryptocurrency and blockchain technology believe that this loss of speculative interest is actually good news for the future, with the pricing stability allowing more natural demand to be created, and companies to further explore their application without hyped up risk levels. Indeed, for Bitcoin or other cryptocurrencies to truly be used a real currency in everyday life, several changes are required:

- A stable price that does not fluctuate;
- To be widely accepted as legal tender, for both public and private debts; and
- Easy and frictionless trading between people and entities.

To date, only one of these changes is approaching, namely the stabilisation of prices. This is an absolute must; if a company moves all its holdings from Dollars to Bitcoin, the value of those holdings could fall by a half in minutes, should the market swing in that direction. Moreover, currently, it is not possible for entities to operate in Bitcoin alone. Even safe storage is a problem; all are held in a private digital wallet or exchange, so they are only as secure as your computer. Hundreds of millions of Dollars of cryptocurrencies have famously already been stolen from both large corporations and individuals to date.

Blockstream Satellite enables more inclusive Bitcoin trading

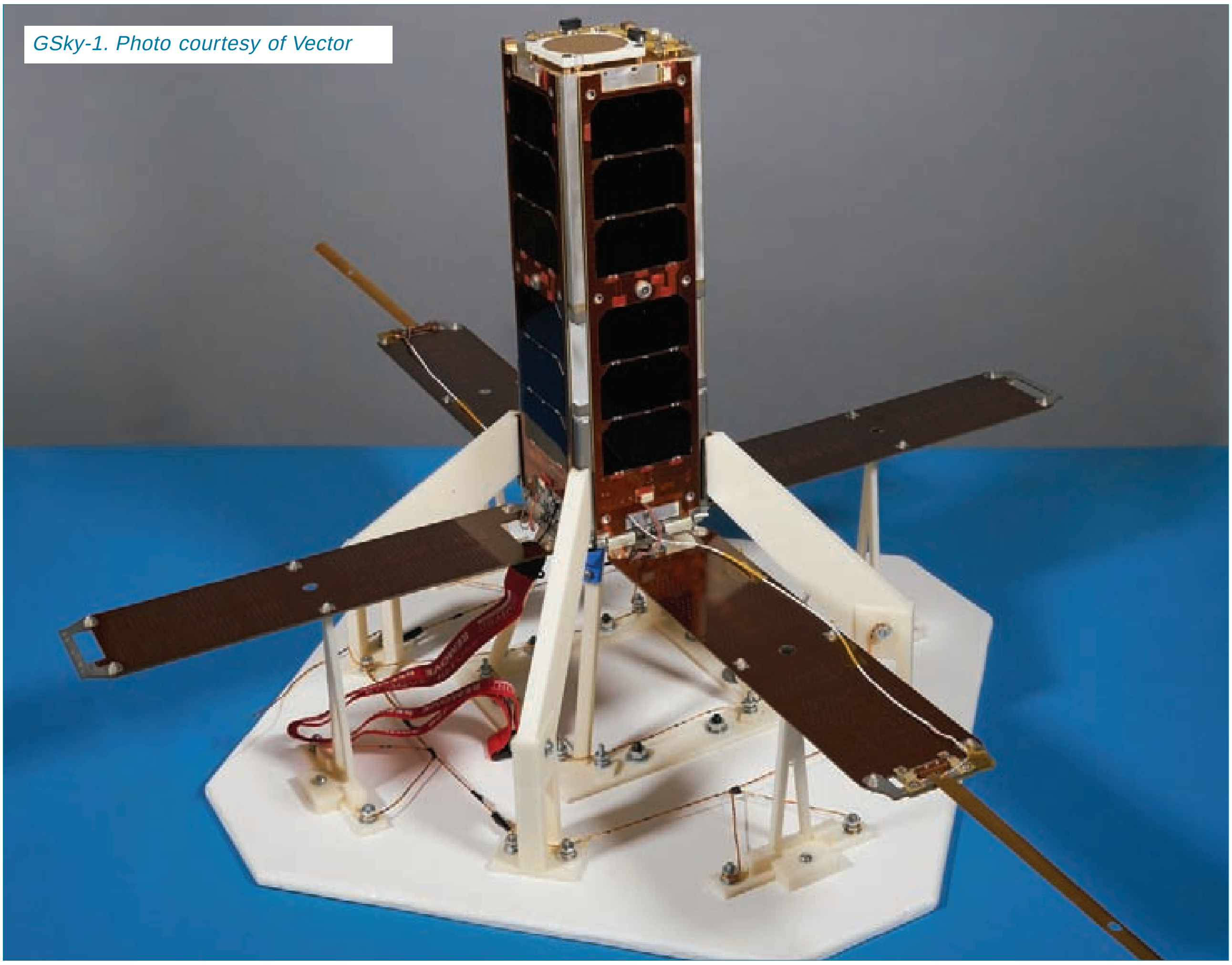
Blockstream launched Blockstream Satellite back in August 2017, a new service which broadcasts real-time Bitcoin blockchain data from a network of satellites - Galaxy 18, Eutelsat 113, Telstar 11N and Telstar 18V - to most of the Earth's population. Teleports uplink the public Bitcoin blockchain data to the satellites in the network, which then broadcast the data to large areas across the globe. The service enables further participation in Bitcoin, namely the billions of people in the world without Internet access, as well as people in places where bandwidth costs make participating price prohibitive.

According to CEO Adam Black, Blockstream Satellite will put Bitcoin into the hands of those who need it most. He told *CoinDesk*: "There is some coincidence between countries with poor Internet infrastructure and unstable currencies. The people who are in direct need of Bitcoin are those who currently have unstable access to Bitcoin. This project will address that problem, and, we hope, will allow many more people to use bitcoin."

Blockstream Satellite is the world's first public satellite service that allows anyone to operate and maintain Bitcoin nodes, without the constraints of traditional network connectivity. Blockstream Satellite sends blocks in real-time, as well as recirculates older blocks, providing free access to the Bitcoin blockchain for both long-time and new users. In addition, Blockstream Satellite provides an additional layer of reliability for blockchain data in the event of a network partition.

"Bitcoin is a powerful and transformative Internet native digital money that has blazed a trail of disruption, with its full potential yet to unfold. Because it's permission less, Bitcoin enables anyone to freely create new financial applications and other innovations that use the blockchain that haven't been possible before," said Adam Back, Co-Founder and CEO at Blockstream. "Today's launch of Blockstream Satellite gives even more people on the planet the choice to participate in Bitcoin. With more users accessing the Bitcoin blockchain with the free broadcast from Blockstream Satellite, we expect the global reach to drive more adoption and use cases for Bitcoin, while strengthening the overall robustness of the network."

Blockstream Satellite makes extensive use of open source software. GNU Radio, an open source software development toolkit, enables the cross-platform implementation of software-defined radios (SDRs). The use of SDRs eliminates the need for specialized hardware, which greatly reduces cost and makes the technology widely available. To further ensure performance and reliability, Blockstream Satellite utilizes the Fast Internet Bitcoin Relay Engine (FIBRE), an open source protocol. Together, these open source technologies power the Blockstream Satellite network, enabling Blockstream to provide this free service reliably and cost effectively. Consumers require around US$100



GSky-1. Photo courtesy of Vector

of equipment, including a USB SDR interface and a small satellite antenna.

Blockstream Satellite remains successfully operational today. The latest news came in 2019, when Blockstream launched its satellite message application programming interface (API), which allows clients to pay a very small fee in Bitcoin to transmit a message - any message - into space over the Blockstream Satellite network. Any user with access to an antenna can receive the messages, opening up a new way for clients to send and receive encrypted messages anywhere on Earth, which cannot be blocked via mainstream media outlet, Internet Service Provider (ISP), or even government. Indeed, back in December 2018, Blockstream's Chief Strategy Officer Samson Mow, told Forbes: "Bitcoin has always been about uncensorable money, and now we have uncensorable communications as well."

Nexus to launch first space-based cryptocurrency

In December 2017, nanosatellite launch company Vector partnered with Nexus to host its decentralised cryptocurrency in space using Vector's GalacticSky software-defined satellite platform. This would make Nexus the first company to deploy a cryptocurrency, NXS, on a satellite.

"With Bitcoin's valuation at an all-time high, people are beginning to accept cryptocurrency as a real form of payment, but there are still problems with storage and ownership," said Colin Cantrell, Founder and Lead Core Developer of Nexus. "The capabilities provided by the GalacticSky platform, combined with the flexibility of Vector's launch model, bring us one step closer to accomplishing our mission of providing the world with a decentralized currency that can be accessed virtually anywhere, anytime."

By hosting NXS in space via GalacticSky, Nexus will no longer be tied to a nation-state and can create the backbone for a more decentralised financial ecosystem. By utilising a satellite virtualisation platform through GalacticSky, Nexus can distribute its blockchain across multiple satellites, providing it enhanced reliability and performance. Nexus' secure cryptocurrency and decentralised peer-to-peer network will grant greater freedom and transactional transparency for global access to financial services. By hosting Nexus' cryptocurrency on Vector's software-defined satellite, Nexus can further demonstrate the wide range of disruptive innovations that can be hosted on the GalacticSky platform. GalacticSky's mission is to provide unprecedented accessibility to entrepreneurs and space innovators, and the platform's additional level of reliability and scalability makes it a natural fit for cryptocurrency applications.

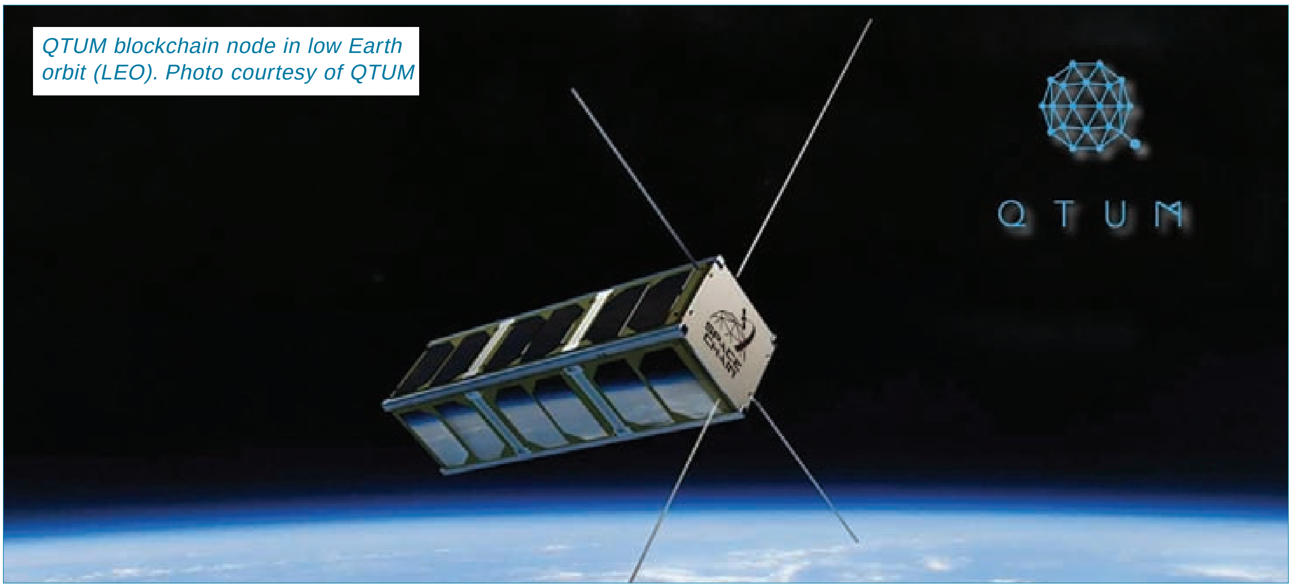
According to the developers, Nexus provides improvements over existing blockchain systems like Bitcoin and Ethereum. It features SHA-3 cryptography with 571-bit keys, which reportedly provides 'quantum security' against next-generation quantum computers and hackers. Nexus is also working on a 3D Chain to address today's challenges of speed and scalability.

Although NXS hasn't reached space just yet, significant progress has been made. In July 2019, Nexus announced that GalacticSky had closed its Series B financing round and is due to deploy its first 6U satellites late in 2020. According to Nexus, its current plans for exploring the Galactic Sky platform include: Hosting Nexus on the constellation to provide greater access to Nexus, while adding additional redundancy to the network; utilizing Nexus as a means to tokenize the ownership of Galactic Sky to manage split revenue payments from fees earned; and using Nexus to improve the process of authorizing access to the constellation.

The future for the GalacticSky platform remains uncertain; Vector filed for bankruptcy back in December 2019, and as of February this year, Lockheed Martin looks set to acquire all assets by default. Only time will tell whether we'll see NXS hosted on a GalacticSky or alternative platform in the years to come...

SpaceChain achieves first Qtum transaction in space

Another interesting project founded in 2017 is SpaceChain, a community-based space platform that combines space and blockchain technologies to build the world's first open-source blockchain-based satellite network, allowing users to develop and run decentralized applications in space. The SpaceChain operating system will be available to anyone, anywhere in the world, all while remaining secure and immutable through proven blockchain cryptography. SpaceChain's vision is to remove barriers and allow a global



QTUM blockchain node in low Earth orbit (LEO). Photo courtesy of QTUM community to access and collaborate in space.

The company launched its first two Qtum satellites into space in 2018. The first came in February, a blockchain node equipped with a Raspberry Pi hardware board and blockchain software. It ran a full-node program on the Qtum blockchain and could process existing blockchain data. The node was offline and had limited functionality, but it was the first successful deployment of a Qtum blockchain node in low Earth orbit (LEO). The second came in October, embedded with SpaceChain's smart operating system, SpaceChain OS, and capable of performing blockchain-related functions on the Qtum blockchain such as running smart contracts and multi-signature transactions.

SpaceChain made history in January 2019 with the successful test of its second blockchain node in space. Since the launch in October 2018, the SpaceChain team had run a number of connectivity tests to ensure the node's full operational capability. During these tests, the node's signal was detected, and transaction data was uploaded to the node to complete the signature and then downloaded via the ground station, finally verified on the blockchain network.

"This multi-signature cold wallet service – an application developed by SpaceChain engineers to test the space node – shows proof of technology of being a potential cybersecurity solution for the blockchain industry," said SpaceChain Co-Founder and CTO Jeff Garzik. "SpaceChain deployed and tested the space-based multi signature transaction which opens up brand new possibilities in space security models."

SpaceChain's success has been well noted throughout the satellite and space sector, with the company winning funding via the European Space agency's (ESA) Business Applications and Space Solutions Kick-start Activity programme, for the further development and identification of commercial use-cases of satellite blockchain technology.

Meanwhile, in December 2019, SpaceChain's blockchain hardware wallet technology was launched to the International Space Station (ISS) as part of a SpaceX CRS-19 commercial resupply service mission. This is the first technology demonstration of blockchain hardware on the ISS, and it will be installed in Nanoracks' commercial platform on the ISS. SpaceChain expects the testing of this payload to be completed in the first half of this year.

The payload is expected to demonstrate the receipt, authorization, and retransmission of blockchain transactions, creating 'multisig' transactions which require multiple signatures (approvals) to complete, increasing the security of the operation. All data will be both uplinked and downlinked directly through Nanoracks' commercial platform.

"Blockchain is the next major disruptor in space," said Jeff Garzik, SpaceChain Co-Founder and CTO. "SpaceChain addresses security vulnerabilities for financial systems and digital assets in the growing digital economy. Through integrating technologies, new paradigms that were once beyond reach can now be created and add exciting elements in the NewSpace economy."

SpaceChain's progress to date brings it one step closer to its ultimate goal of a satellite constellation that is distributed, decentralised, and rests on a heterogenous mesh network of interoperating LEO and MEO spacecraft managed by multiple owners across multiple jurisdictions. ■

Are you getting more for less?

Reducing the footprint of space antennas has been an ongoing challenge for equipment manufacturers for decades. With so many smallsat and deep space projects well underway, the requirement for more efficient antennas is now greater than ever. Such antennas require the highest quality of circuitry, as outlined in this technology update.

Nick Howland and Dr Chunwei Min, Printech Circuit Laboratories

Planar antennas are widely used in high-performance aircraft, missile, spacecraft, and satellite systems, where size, weight, cost, performance, ease of installation and aerodynamic profile are constraints. For smallsat platforms, antenna designs that do not require deployment are relatively preferable with low profile and direct interconnection to the rest of the system. They have been extensively adopted and built to generate broad half-power beam width (HPBW) with acceptable gain and circular polarisation (CP) for coverage of the systems operating typically from ultra-high frequency (UHF) to X-bands. Recent enquiries for deployment-free antenna solutions require high gain with good CP performance at Ka-band and higher frequencies. Typically, these are for deep space missions and inter-satellite links requiring high data rates, whilst being compatible to the often-small footprint available on the spacecraft.

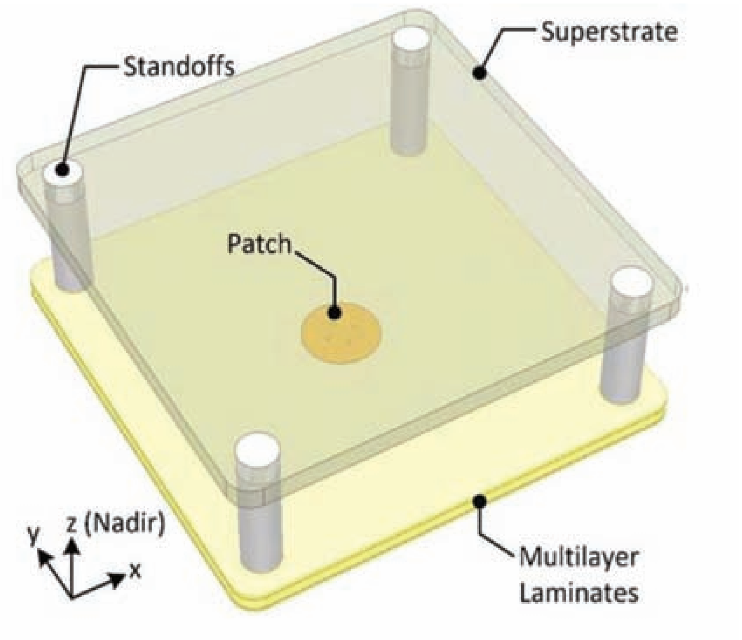
Horn antennas and microstrip patch antenna arrays are typically considered for systems where intermediate to high gain (≥20dBiC) is required. Horn antennas are inherently linearly polarised, and polarisers are needed to generate CP waves.

A relatively small footprint is required on the platform for attachment, but they must be physically long enough to focus the beam, which often makes them unsuitable for small satellites.

Enhancing flexibility

More flexibility can be achieved from microstrip patch antenna arrays, on which radiating elements can be configured to generate CP waves and produce the required gain. More patches in an array form a larger aperture size and can produce beams of higher directivity, however, its associated feeding network becomes more complicated and results in more ohmic losses, particularly at mm-wave frequencies. This ohmic loss issue has led to a design of low-profile antennas to achieve all the requirements, whilst still being small enough for the limited space and not suffering the losses from an extended feed network.

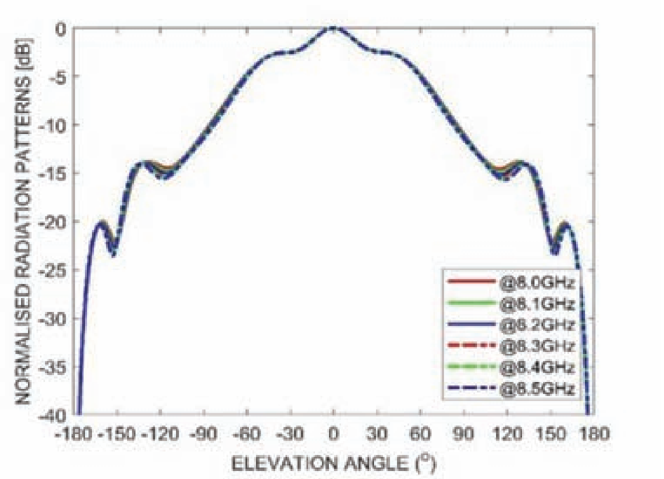
Several designs have been manufactured with the use of single driven element incorporated with engineered superstrates on top which will produce narrow beams with high gain. The driven patch is fabricated on space-qualified printed circuit boards (PCBs), energised by two orthogonal differential feeding pairs of planar transmission lines separated by a shared ground plane in the middle to produce CP waves with low axial ratio and symmetrical radiation patterns across the operating frequency band. The relative dielectric constant and thickness of the loaded superstrate are selected so that the resonant condition can be generated, which co-interacts with the driven patch to focus the beam.



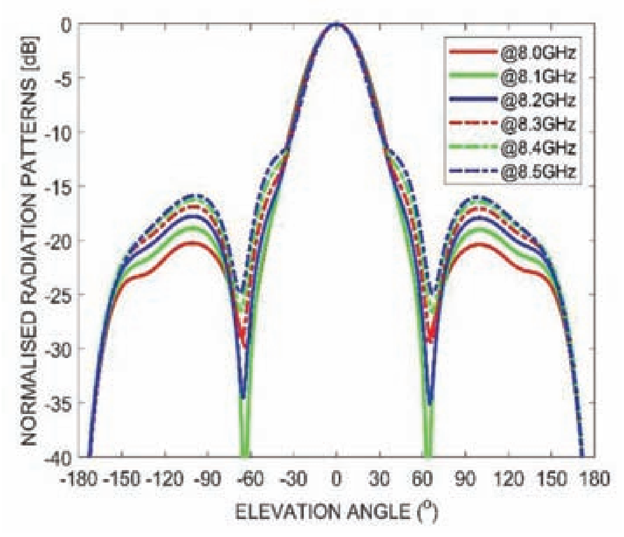
Design model with Superstrate

It is seen that the integration of the superstrate broadens the impedance bandwidth of the antenna in comparison with the patch without the superstrate, which is effectively the combination of two types of resonances; one is from the resonance of the patch and the other is that established by longitudinal electric fields oscillated between the superstrate and the ground plane of the antenna.

Radiation patterns of the antenna are shown which are generated by the excitation of the patch in RHCP mode to demonstrate that use of the superstrate effectively focuses the fields radiated from the patch to



Single patch no superstrate 100mm square



Superstrate integrated 50mm square

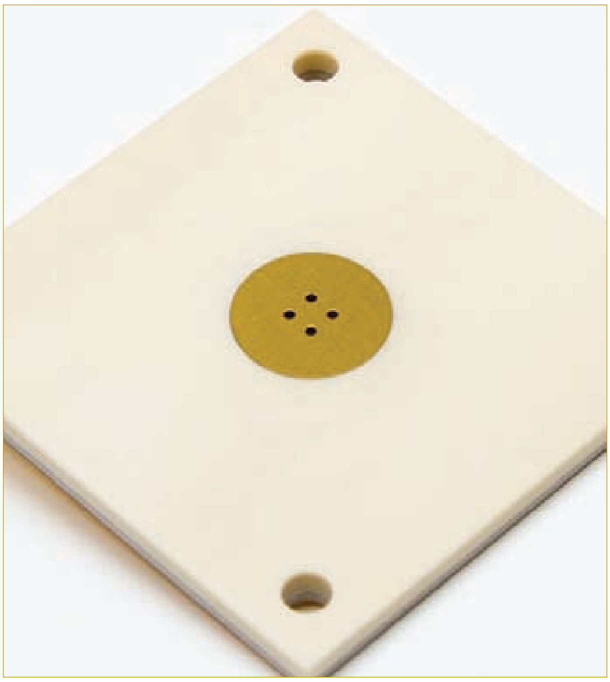
generate sidelobe-free beams with consistency of HPBW.

The antenna can generate high gain and narrow beams without the use of large arrays that need complex feeding networks which introduce additional ohmic losses. Impedance bandwidth can be further broadened by capacitively coupling a patch on top of the driven patch. It was also found that the driven patch can be expanded into a 2x2 array to increase the peak gain by up to 6dB.

Delivering communications

As the challenges of greater and faster data rates continue to drive the satellite industry, the requirements of new ways to deliver this communication either to the Earth or the satellite becomes even more important. Coupled with the small size of the satellite and the space available on the outside of the spacecraft makes these requirements even more challenging.

Today there are many ways to approach these issues with different antennas and communication systems, but each will have its own limitation or risk. The design and manufacture work carried out so far, planar antennas using an additional superstrate can deliver much more data whilst maintaining a very small footprint, with no deployable parts and easy operation can be considered a great advantage. ■



Small X. Photo courtesy of Printech Circuit Laboratories

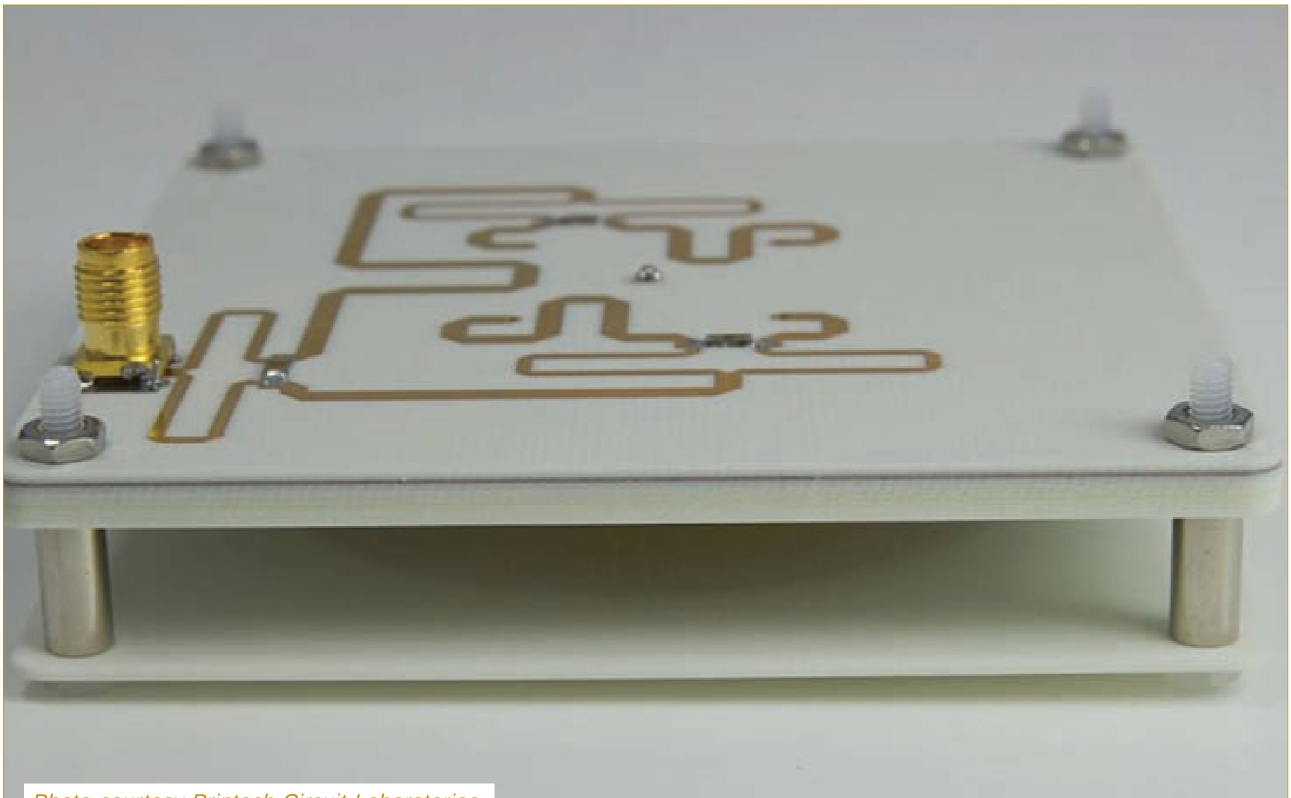


Photo courtesy Printech Circuit Laboratories

Beyond Earth orbits - the future for smallsat propulsion systems

Propulsion systems are an essential element in any off-world voyage, delivering effective, reliable maneuverability to spacecraft on their journey. With so many options available, and a slowly turning tide towards environmentally friendly propulsion systems, there's a lot to consider.

Vytenis J. Buzas, Co-Founder and CEO, NanoAvionics


Vytenis J. Buzas, Co-Founder and CEO, NanoAvionics

On 8 December 2010, the Japanese spacecraft IKAROS passed by Venus at a distance of 80,800km (50,200 mi). Of course, it wasn't the first time that a satellite visited Earth closest neighbouring planet. What was really remarkable about this achievement is how it got there. At the time it was the world's first spacecraft to use solar sailing as the main propulsion, a technology that only a few decades ago still ranked among science fiction.

Seven years later, on 5 July 2017, in a polar sun-synchronous orbit at an altitude of 508km a successful in-orbit test of the first ever high-performance chemical propulsion system on-board a nanosatellite (3U LituanicaSat 2) developed by NanoAvionics was performed. And only a year earlier the first microsatellite with a high-performance green propulsion (HPGP) system, the SkySat-3 by Swedish Space Corporation subsidiary ECAPS, was launched into a 500km sun-synchronous orbit.

What do these separate events have in common and what makes them so significant in addition to the individual achievements? First of all, they show the considerable advancements of in-space propulsion technology for spaceflight. IKAROS also demonstrates the usability and capability of smallsats for future deep space missions. Since 2015, NASA has been planning a number of lunar and LEO CubeSat missions as testbeds for deep space missions.

Challenges for smallsat propulsion for missions beyond Earth orbits

All space exploration is about getting somewhere safely, quickly, cheaply and with enough payload to fulfill the mission. The revolution of the space industry and the success of the NewSpace industry were due to the miniaturization of existing technologies and the resulting lowered cost, which in turn allowed missions in low Earth orbit, services, and revenues previously not possible.

The question is can small satellites replicate the same success with more sophisticated missions, such as lunar, interplanetary, or deep space missions? And if the answer is yes, how would this be achievable? Part of the solution to that and the success of future space exploration via smallsats is coupled with new propulsion systems for small buses, allowing more complex mission architectures that previously had been the exclusive realm of large spacecraft. There's no doubt that the rise of small satellites for commercial applications has supported and is further supporting the growth of the satellite propulsion system market. Valued at US$9 billion in 2017, a recent MarketWatch report estimates the global satellite propulsion system market to reach over US$29.9 billion by 2026.

For Earth-orbital missions, satellites need to overcome gravitational pulls and keep themselves in their allocated orbits and to maintain their orientation as required by their missions. This can only be achieved through micro-propulsion systems to perform functions like orbit change and raising, formation flying, precise attitude control, station keeping, avoiding space debris and de-orbiting.

The last two are a real problem for smallsat manufacturers because controlled satellite decommissioning and collision avoidance are becoming more restrictive and regulated. Many propulsion systems are not optimized for these manoeuvres demanding high thrust.

For missions beyond Earth-orbits, they also need to provide enough thrust to complete manoeuvres such as trans-orbit injection and planetary intercept, while keeping a minimum of transit time. The difficulty lies in designing new and efficient light-weight propulsion systems for these missions meeting the high-performance requirements and overcoming constraints such as mass, volume, and power.

Chemical vs electrical - the pros and cons

So, what is the best propulsion system for future missions? The answer to that is: There is no single propulsion technology that will benefit all missions. They all have their own advantages and limitations. The better question then to ask is what technology is the most suitable for the mission at hand, and what are the trade-offs?

With the exception of test missions like IKAROS, essentially all existing viable smallsat propulsion technologies fall into one of two categories: Electrical or chemical like the Enabling Propulsion System for Small Satellites (EPSS) onboard NanoAvionics' nanosatellite. Both chemical and electrical systems have different performance and scalability properties. The physics battles they each have to fight are structural-mechanical limits in the case of chemical propulsion, or too stringent power limitations for many types of electric propulsion. A second problem is that the vast majority of existing propellants are hazardous and expensive. This has started to change though, and the field of suitable small satellite propulsion systems is growing. Both electric and chemical systems have seen significant developments as a closer look at the pros and cons as well as available options reveals.

When in space, the purpose of a propulsion system is to change the velocity of a spacecraft. They must deliver very precise 'impulse bits' in order to accurately control their position or attitude. Reliability is of utmost importance since there is no real opportunity to service them over their lifetime. High performance is also a must. Engineers generally discuss spacecraft performance in the amount of change in momentum per unit of propellant consumed, also called specific impulse. The higher the specific impulse, the more efficient these systems are. Ion propulsion engines for example have high specific impulse and low thrust whereas chemical propulsion systems have a low specific impulse (LSP) but high thrust. Any increase of LSP systems provides additional on-orbit lifetime or the capability to increase the 'payload' portion of the spacecraft.

Nanosatellite testing in thermal vacuum chamber. Photo courtesy of NanoAvionics

Over the last few years, a number of companies have made significant efforts to develop and test miniaturized thrusters. Electric propulsion systems have evolved by a series of continuous tests for a wide range of technologies comprising electrosprays, Hall-effect thrusters, pulsed plasma thrusters and ion engines. For many small spacecraft concepts higher specific impulse of advanced electric propulsion technologies makes them an ideal option for attitude control applications on commercial communications satellites and for prime propulsion on some scientific long duration space missions.

But the lower thrust of electric propulsion systems also results in longer manoeuvre times and limits the suitability for more ambitious manoeuvres such as large orbital transfers, collision avoidance, constellation deployment and de-orbiting. Traditionally, chemical propulsion systems have been employed for these applications. A chemical propulsion system's higher thrust, though bigger in size and heavier, is quicker to perform these manoeuvres. Where using electric propulsion might take about one-month, chemical propulsion merely takes a week. And while electric propulsion is lightweight, reducing mass, they require lots of power, which means more solar cells, causing thermal issues and increasing satellite mass and size after all.

This is why chemical propulsion systems were the powerhouses of the space age. Even today, the chemical propulsion segment dominates the global market, in terms of revenue. Electrical systems have been catching up though with companies such as Enpulsion, using field-emission electric propulsion (FEEP) for electric propulsion, Exotrail's Hall-Effect ion thruster or ThrustMe's microwave thruster, using radio-frequency gridded Ion Technology (RF GIT).

Developing chemical propulsion systems for small satellites has its own challenges, starting with higher cost, requiring many tests, a high number of sealing units to prevent leakage and international logistics of delivering dangerous propellants to launch sites, to name just a few.

The cause for the last two challenges is the current standard propellant for satellites based on chemical propulsion technology: Hydrazine-based fuel. Hydrazine is highly toxic to living organisms, and its derivatives are also highly carcinogenic. Being exposed to high levels of it can cause all kinds of health problems, ranging from liver and kidney damage to harming the central nervous system. Hydrazine is also violent and explosive when it meets air and the satellite is still on the ground creating safety issues and cost to prevent them.

Pressure and efforts to make chemical propulsion environmentally friendly

It is hardly a surprise that there are efforts underway to limit the risk and move away from hydrazine. Back in 2011, the European Commission added hydrazine to the list of substances of very high concern. And there are speculations that the European Union might ban the use of the toxic propellant as early as 2021. With the EU space industry using about 20 tons of hydrazine annually, mostly for satellite propulsion, banning the fuel would impact the European space industry with estimates going into billions of euros per year. Consequently, ESA has been encouraging companies to seek for solutions how propulsion system hardware could be changed to work with a less toxic alternative. And not just in Europe, the search for 'greener' fuel and propulsion technology is part of both ESA's and NASA's clean space initiatives.

To become economically viable for satellites and satellite constellation projects, and enabling the provision of new satellite services, any green propulsion system for small satellites has to be cost effective, high-performing and permitting significant levels of thrust to be stored within a relatively small storage volume.

The first complete module of a High-Performance Green Propellant (HPGP) system was developed by Swedish company ECAPS in September 2014 for integration into SkySat-3 and launched in 2016. Through further deployments of SkySat microsatellites it also became the first large-scale use of an environmentally friendly propulsion system. HPGP uses Ammonium DiNitrimide (ADN) instead of hydrazine.

The first CubeSat in the world with high-performance and environment-friendly chemical propulsion system was developed by NanoAvionics. Its EPSS is a low-cost plug and play designed for satellites weighing less than 150 kg. It is also fuelled with an ADN monopropellant, which has higher specific impulse and higher energy density as compared to the hydrazine employed systems. After a successful in-orbit demonstration in 2017, the company launched the product to the market and since then has been working on expanding the range of fuel tanks and scaling total impulse to suit various mission needs and satellite sizes.

Also, among those developing and using non-toxic propellants is Dawn Aerospace. Their thrusters for CubeSats and smallsats provide responsive, non-toxic propulsion based on bi-propellant nitrous oxide and propene instead of hydrazine. So far, the company, founded in 2017, has built three flight-ready propulsion systems for CubeSats and eight larger thrusters for microsatellites.

Using a different 'green' propellant for its high-performance system is Aerojet Rocketdyne. Their propulsion system is running on a hydroxyl ammonium nitrate fuel/oxidizer blend called AF-M315E. Developed by the Air Force Research Laboratory (AFRL) it's also a high-performance and non-toxic spacecraft fuel. Last year in June their system was launched to low Earth orbit as part of NASA's Green Propellant Infusion Mission (GPIM). Their modular propulsion systems cover a range of propulsion module sizes from 1U to 8U.

Despite all these new developments for both chemical and electrical systems for small satellites it is also true that the ecosystem of components necessary to assemble these propulsion systems is very immature and very small still. And given the multitude of different mission, in particular for deep space, it seems unlikely that a single technology will emerge as the winner.

Planned planetary and interplanetary missions

The first planetary nanosatellite mission to use 'green' propulsion will be NASA's Lunar Flashlight as a secondary payload of the 2021 Artemis 1 mission. Artemis also carries a 6U nanosatellite (IceCube) destined for the moon with miniaturized electric thrusters powered with an iodine propellant, and a 6U nanosatellite (CuSP) to orbit around the sun with a cold gas thruster system for propulsion, attitude control and orbital manoeuvring.

The trajectory of the IceCube satellite is somewhat different to other nanosatellites that are also heading for the moon. Rather than being deployed closer the moon, the spacecraft will take advantage of the gravitational acceleration of the sun, Earth, and moon, looping around Earth a couple of times before reaching its destination. The low-thrust system also prevents it from taking Artemis' outbound path because it cannot accommodate the rapid change in the orbit's velocity.

For low-cost deep-space and science missions it's likely that a combination of different propulsion systems is required. For example, combining the advantages of long-distance travel via propellant-less systems such as solar sails with chemical technology for manoeuvres while in orbit to the target.

NASA 's upcoming in-orbit demonstration of its Advanced Composite Solar Sail System (ACS3) on-board a 12U nanosatellite bus by NanoAvionics being a case in point. The aim of the ACS3 mission is to replace conventional rocket propellants by developing and testing solar sails for future small interplanetary spacecrafts destined requiring long-duration, low-thrust propulsion.

The future for science and commercial missions on nanosatellites certainly looks bright, due to their immense versatility and the possibilities of what we can do with them seem endless.

Assembling propulsion system EPSS. Photo courtesy of NanoAvionics

Reducing the economic and environmental costs of spaceflight

Skyrora is a UK space launch vehicle developer based in Edinburgh aiming to reduce the economic and environmental costs of spaceflight. The company recently performed a rocket engine test using Ecosene, a high-grade eco fuel which Skyrora develops from unrecyclable plastic waste. Skyrora hopes to complete the inaugural launch of its Skyrora XL vehicle from a British spaceport by 2022. Volodymyr Levykin, CEO at Skyrora, discusses all the company has achieved in the last two years.

Laurence Russell, News and Social Media Editor, NewSpace International

Volodymyr Levykin, CEO at Skyrora

Question: Could you tell us a bit about the Ecosene engine test you performed at Fife, and the development cycle that led you to it?

Volodymyr Levykin: Ecosene was test-fired in Skyrora's 3.5kN upper-stage engine, LEO, at Skyrora's testing facility in Fife, Scotland, the largest site of its kind in the UK. Several 30-second firings revealed remarkable likeness to RP-1, a standardised, highly refined form of kerosene. Manufactured using plastic waste, Ecosene became the first ever eco-aviation fuel to be test-fired in Scotland.

Crucially, the tests also confirmed that Ecosene contains two orders of magnitude less sulphur content than RP-1. High concentrations of sulphur in emissions are detrimental to air quality, contributing to respiratory problems, acid rain and crop damage. Sulphur rich emissions are also effective absorbers of the sun's energy, contributing to global warming.

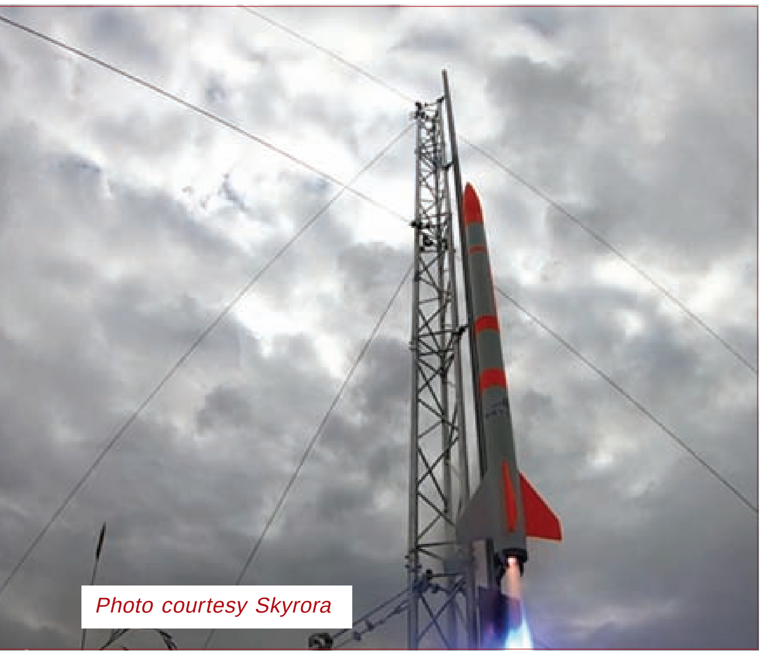


Photo courtesy Skyrora

Ecosene has been subject to rigorous testing for the past six months and will now undergo final adjustments to its chemical makeup to make sure it is optimised for Skyrora's launch vehicles. This will be followed by further development of a full-scale manufacturing process, ensuring that production is as cost effective as possible.

Skyrora's Ecosene can also be sold to the wider aviation industry once it's been commercialised. Ecosene can be used on jet aviation fuels and our vision is to set up manufacturing sites in remote locations to decrease the transportation of Jet-A1 fuel. This decrease in transportation would also add to reducing the carbon footprint.

Question: Aviation has always been a big industry for pollution, but it's nothing compared to rocketry on a per-flight basis. The notion of green space launch seems like the stuff of science fiction. How have you managed to have the best of both worlds?

Volodymyr Levykin: Skyrora believes that combining rocketry and environmental responsibility is a question of willingness to invest in green solutions, rather than a technological impracticality. It's an investment Skyrora has made with Ecosene and a decision that, at least so far, has reaped great results.

Skyrora's environmental focus traces back to its foundations. From the beginning, Skyrora has been working towards environmentally optimised orbital launch vehicles. This emphasis on protecting the climate and minimising impact is reflected in the design and manufacturing decisions of the company.

The Ecosene project demanded great innovation of our engineers. Other companies have attempted to develop eco-fuels in the past, but most have found it difficult to extract the excess paraffin waxes created in the manufacturing process. Skyrora developed a solution incorporating low-temperature catalytic pyrolysis to extract the paraffin wax. We then applied our own process, dubbed hydro-treating, to upgrade the plastic after the pyrolysis stage. These innovative processes will allow the once-distant dream of eco-fuel to become reality.

Question: You quote the ability to turn a tonne of waste plastic into 600kg of usable kerosene fuel in a 24-hour span, which will emit 45 percent less greenhouse gas than a conventional rocket. With such practicality, do you predict you will see Ecosene becoming a household name of the NewSpace market?

Volodymyr Levykin: Subsequent to further testing, the fuel will be made available to the wider industry for the benefit of the environment as a whole. It would be fantastic to see the fuel used by other launch providers. It is Skyrora's hope that Ecosene will eventually make an appearance in the aviation industry also, especially in remote locations where transporting fuel is costly and, in itself, damaging to the environment. It is perhaps worthy of note however, that Ecosene is not a permanent solution to plastic pollution. To truly solve the climate crisis, change needs to come from the source of the problem.

Question: With massive spaceflight pioneers such as ESA and NASA on our international doorstep, the UK's space programme has always seemed modest by comparison. Skyrora has shown that we still have a lot to contribute. Do you think Britain will continue to act as a disruptive innovator in the field, or do you anticipate our industries achieving a more definitive competitive edge?

Volodymyr Levykin: Skyrora sees the brilliance in the UK regaining leadership in advanced technology and manufacturing. The rise of NewSpace has reignited the UK's relationship with space. With world-class thinkers and numerous top scientific and engineering institutions based in the UK, the emergence of private companies in space brings with it much-welcomed investment in the sector. The oncoming wave of private companies has given way to a host of adventurous new ideas, such as Ecosene, driven by commercial competition and private funding. Restrictive budgets for government-run space programs are no longer the limit to innovation and British engineering excellence in space. The industry now employees 42,000 and generates £14.8 billion per year.

Given the incubation time for such advanced technological projects, the UK will witness a wealth of exciting innovations emerge over the next decade, no doubt taking the global space market by surprise.

Question: You mention your achievements have attracted 'major interest' in the space race sector. It's becoming fairly common for small UK innovative developers to be acquired by conglomerates oversees. Is Skyrora open to that possibility?

Volodymyr Levykin: Skyrora Ltd is only two years old and the milestones we have achieved since are remarkable. The potential customer interest is global, and all of this was achieved with Scotland as our home. Skyrora is open to international collaboration but will always remain a UK company.

Question: Does Skyrora have a position on the environmental sustainability of the NewSpace market, both in terms of greenhouse gas and the mounting fears of space debris clogging the low Earth orbit domain through rushed satellite and spacecraft development?

Volodymyr Levykin: The emergence of new space is a blessing in disguise to the climate crisis. Tackling climate change begins with scientific research and the collection of meaningful data. Without the increase in Earth observation satellites and data over the past decade, our understanding of changes in sea-level, air quality, deforestation and melting at the ice caps, would be severely handicapped.

Space junk is an unavoidable issue that has already become a market in its own right. Our very own LEO engine could play a key role. Its unique ability to reignite several times makes it suitable as an orbital manoeuvring unit or 'space tug.' As stated by the European Space Agency, "strong compliance with post-mission disposal guidelines is the most effective long-term means of stabilising the space debris environment at a safe level." As such, Skyrora will always follow best practise in post-mission disposal.

Question: Could you tell us a bit more about your preparations around the Skyrora XL launch you're planning in 2022?

Volodymyr Levykin: Skyrora takes an incremental approach in developing its technology, minimising the risk by allowing thorough testing of complex systems on a small scale first. Skylark L, our sub-orbital vehicle, is ready for launch and we are aiming to apply for a license to be able to launch it this year. The timescale for the launch of Skyrora XL is very much dependent on the success of Skylark L, however various other factors, such as the launch site, must also be taken into consideration. ■

Ecosene Testing. Photo courtesy Skyrora

What the COVID-19 health crisis has taught us about satellite IoT

The Internet of Things (IoT) has been hot news for several years now, with innovators coming up with fantastic new world-changing applications. The COVID-19 pandemic has highlighted just how excellent a tool for remote operations the IoT can be, with far-reaching implications for a number of industries, including NewSpace.

Maria Kalama, Business Development Director, Lacuna Space

Maria Kalama, Business Development Director, Lacuna Space

Everyone will agree that we are living in unprecedented times, the full human and economic impact of which we still haven't seen. Across the whole spectrum of businesses, we have witnessed the tendency to reduce CAPEX, pause projects that were not a priority or related to Covid-19, and a decline in consumer demand.

Despite these generic downward trends, the IoT sector seems to be dealing with the crisis pretty well! If anything, the crisis has laid bare the importance and need for digitalization, automating processes as well as tracking and tracing.

If we were to summarize what we see now as the biggest fall outs and events within the wider satellite industry, we would have to start with the suspension or delay of many launch operations and the news about the OneWeb bankruptcy. At the same time, SpaceX continued sending their Starlink satellites into orbit and even managed the first crewed rocket launch from the USA in nine years. On the applications front, together with an increase in mission critical communications, there has been a decline in leisure, maritime and airborne traffic.

But what about satellite IoT? Several players have announced positive news. Myriota has raised AU$28 million in Series B funding, and Omnispace has also announced the launch of a test constellation. Let's take a more detailed look at some trends.

Remote operations and controlling remote assets

The business case for remotely controlling assets through IoT solutions has been evident for a long time, leading enterprises to spend significant amounts in traditional satellite IoT solutions. But new small satellite IoT constellations offer lower prices and more flexible pricing schemes.

Whether in energy, water, or agriculture - saving costs in predicting faults and reducing manpower for routine inspections continues to be a no-brainer. However, changing long established business processes is difficult and not always a priority. What we have noticed though, is that the recent crisis has expanded the need for remote monitoring to more sectors, with more people seeing the benefit of connecting with their assets or machinery. They also clearly noticed the benefit of doing so and realised that this would continue being the case even for times with no travel restrictions in place. So, we're expecting to see many such deployments in the next 6-12 months.

Track and trace solutions get used more extensively

Supply chains have seen disruption never encountered before, highlighting the need for accurately tracking and tracing goods, even as they travel through remote areas with no terrestrial coverage. So, a spark in the demand of these solutions is no surprise. But are there enough options in the market to satisfy this increased demand?

Cost, size, and battery life have always been factors that limited the expansion of satellite IoT in this sector. On the terrestrial network front, LPWAN (low power wide area network) solutions and LoRa® (short for long range) dominate the market for tracking. LoRa® is a wireless radio frequency technology which is also low power, and mainly for these two reasons has become the de-facto technology for Internet of Things (IoT) networks worldwide. LoRa® based trackers retail currently at about $40, which is a low price point, way off the scale for the satellite IoT products we see on the market.

Need for security

It has been widely reported that security attacks on businesses and networks have increased during this period, reminding us again how important security is for the IoT. Networks usually employ cryptographic keys that are AES128 encrypted. Although this mechanism is highly secure, it is only as secure as the protection afforded to the keys themselves. Hardware Secure Elements are probably the most secure way of storing cryptographic keys.

These are low-cost and small chips, which are located on the IoT device and make it virtually impossible for an external third party to extract them. The manufacturer can then share the keys held within the hardware security module (HSM) with a Join server. Technically it does not share the actual keys, but another root key from which the joint server can derive the root key. Lacuna Space together with The Things Industries has demonstrated the use of secure elements over satellite for the first time ever in January this year. Providing an efficient mechanism to distribute security keys to IoT devices and their nominated Join server, without the need to physically reveal the keys to the device manufacturer or the network provider.

Photo courtesy of Lacuna Space

Flexibility in supply chains

Most businesses have experienced a disruption in their supply chain and delays in product launches or technology roadmaps. While having alternative sources for suppliers has always been good practice, the space sector has a real bottleneck in the form of available launches, now further delayed by the pandemic. Satellite launches sites around the world went into reduced operation or have been temporarily shut down. It is probably the only part of the supply chain where there is very limited flexibility once a launch provider has been contracted. So, it's not surprising that the most reported impact on the supply chain for the satellite sector has been launch. But there's good news because at the time of writing this article, these restrictions have started to be lifted!

Photo courtesy of Lacuna Space

What has the crisis taught us at Lacuna Space?

At Lacuna Space we are providing secure, satellite connectivity for Internet of Things (IoT) devices that use open source reference designs and LoRa® technology. The open LoRaWAN® protocol has enabled a vibrant ecosystem of technology developers, device manufacturers, network service providers and software platform providers – in which Lacuna Space as a satellite operator and connectivity provider is a central part of; extending market reach for the whole ecosystem and filling gaps in network coverage.

While it has been a challenge to keep to some schedules due to the Covid-19 crisis, we have expanded user trials faster than any other time of the year! This is because our LoRa® based devices are really small, just shipped by regular mail and work straight out of the box – like any standard IoT device. And there is no need to physically travel anywhere, install, point, power and maintain a dish or a gateway.

We have actually weathered the current crisis pretty nicely; in fact, we are seeing an increase in demand and pace in developing ground operations. Resembling rather like a standard IoT business rather than a standard space business. ■

Building a partner network for space

Orbital Transports is a space logistics provider building orbital infrastructure to nurture the NewSpace economy. The company develops tools, technologies, and services needed to support business enterprise operations in space. David Hurst, CEO of Orbital Transports, talks through the company's recent accomplishments, including its introduction of the Space Catalog, chronicling all the important players in the smallsat industry.

Laurence Russell, News & Social Editor, NewSpace International

David Hurst, CEO, Orbital Transports

Question: What are some of Orbital Transports' recent achievements?

David Hurst: Our most recent achievement is putting together our Space Catalog, a showcase for our partners' products and services. As a provider of logistics for small satellite missions, we've built a network of partner companies that help us deliver small satellite technology, which we're really capitalising on now.

The Space Catalog is the go-to place for the smallsat sector. We want to help develop that entire ecosystem to grow the market by supporting every inch of the supply chain.

First of all, the catalogue is not an e-commerce site. Perhaps it could grow into something closer to that down the road, but right now it's a place to bring customers and suppliers together, to encourage a healthy ecosystem.

We want to facilitate the realisation of a culture that uses more affordable off-the-shelf technology and services, which is a trend that's already happening, so it's in the interests of the sector to benefit from the investments and efforts it has generated.

Question: Earlier this year you partnered with Dawn Aerospace to accelerate Dawn's green bi-propellant satellite propulsion systems in the US market. Could you tell us a bit about that?

David Hurst: We were very happy to partner with Dawn Aerospace and add their green bi-propellant propulsion modules to the Propulsion Systems section in the Space Catalog. We also carry propulsion modules from Benchmark Space Systems, NanoAvionics and Tesseract. These partnerships are part of our larger strategy to bring together the smallsat sector, to create common spaces where companies can interact more seamlessly. We were very happy to add Dawn Aerospace to that environment. And you can look for announcements in the upcoming months of new partners being added to the Space Catalog.

Question: Orbital Transports boasts a hands-on relationship with all its partners and customers. What's the nature of your working relationships with them?

David Hurst: We work very closely with our customers to understand their precise engineering and business needs. We operate as a general contractor for missions, coordinating partnerships and sourcing technologies together. We're the glue that holds the ship together, so to speak.

One of our priorities, is helping customers with an interest in space data, but limited prior experience in organising launch missions. Unfortunately, these customers are rather underserved at the moment. These are companies looking to find business value in orbit, despite it not being their primary business model.

Examples of that would be university researchers, biotech, agriculture companies, and so on. Groups who need a leg-up to establish themselves and create new opportunities, which could really grow the smallsat market with the right amount of expertise, so we're passionate about making sure they're taking all the right steps.

Question: What do you think are the primary challenges that the smallsat industry faces?

David Hurst: The smallsat industry is growing very rapidly. Growth is being spurred by the development of massive constellations, which will drive the development of manufacturing capability, which can crank out more and more small satellites. I see that plateauing as a commodity-type market, where you'll end up with a wide array of commercial off the shelf (COTS) products ready for missions.

The challenge lies in shifting away from requirements-driven mission planning in which technology is built around explicit applications driven by specific missions toward a more de-scoped model where budgets and timings are far greater factors. This leads to an approach where mission requirements are adjusted to accommodate the capabilities of COTS components, because it's faster and more cost-effective than custom designing to spec. I think that's a trend that'll be felt across the entire space industry, but because the smallsat industry happens to be so fast-moving, this shift in mission planning culture is happening there first.

Orbital Transports built the Space Catalog to help facilitate and streamline that transition.

Question: Do you have any predictions for the NGSO market given the challenges of the current climate?

David Hurst: Orbital debris.

With the development of the mega-constellations, low Earth orbit (LEO) is going to become extremely crowded, so one of our challenges as a responsible, sustainable corporate entity is to ensure that our missions have a plan for termination once the satellite reaches the end of its operational life, in order to avoid exacerbating the problem of orbital debris.

There are a couple of different approaches to solving this issue, depending on the orbit. Small satellites are often the easiest to de-orbit because there's less mass to break up during re-entry.

It's been suggested that a 25-year lifespan could become the industry standard for how long a satellite can perform before these concerns need to be addressed, however, I believe that's too long. We can't afford to sit around for 25 years as the NewSpace era booms and launches grow exponentially, or the problem will get ahead of us as some amount of debris from rushed models inevitably falls from the sky.

It's only getting more important that groups can bring their platforms back down again and collect data at the end of their missions, and there is an increasing portfolio of products and services to assist with that goal. Deployable tethers, emergency propulsion systems, docking plates, and so on can be part of the solution. These are exactly the kinds of things that you're going to find in our catalogue.

The other challenge comes from tracking the dead satellites and pieces of identifiable debris in orbit. Although that's not something that we can address at the moment, it's work that the Joint Space Operations Centre (JSpOC) has historically undertaken, which has been extremely valuable to everyone in the space industry.

Question: In the wake of an uncertain economy, how does Orbital Transports plan to proceed?

David Hurst: Our timeframe for space missions is longitudinal, so while I expect that we're going to see a historic dip in the economy in the coming months, it'll be just as temporary as the crash ten years prior. In fact, during the last few months our workload has increased as we have connected with more companies around the globe that are proceeding with smallsat technology development that needs in-space testing, and with other companies launching their first generation of LEO smallsats.

The demand for space services is still an emergent and exciting prospect across the globe, particularly in the realm of small satellites, so I'm doubtful that the optimistic growth vectors we were seeing in 2019 have been lost just because of this setback.

We and many space entities like us are playing out a much longer-term plan than the industries worst hit by the pandemic. You can rely on Orbital Transports to weather the storm and we'll see you on the other side. ■

Photo courtesy of Orbital Transports

ESA's Cebreros antenna. Photo courtesy of ESA

Communicating in the void

Communicating through the depths of space is one of the biggest challenges faced by today's would-be space tourists and exploration companies alike. Large-scale radiofrequency communications have proven adequate until now, but in a time of booming demand, we need to pick up the pace.

Amy Saunders, Editor, NewSpace International

Deep space communications are something the vast majority of us don't ever really think about. However, every mission beyond geostationary orbit, such as probes sent to the Moon, Mars, Jupiter and beyond, require all exploration data and findings to be transmitted back to Earth, since most exploration spacecraft are on a one-way mission with no return. Moreover, effective deep space communications with such vehicles enables many issues with the spacecraft to be diagnosed and repaired remotely; the absence of this technology would result in the loss of millions of invested dollars for every slight malfunction. Quite simply, deep space communications are essential for successful deep space exploration missions.

While today's deep space exploration programmes are limited to a small number of entities like NASA, ESA, JAXA, etc. running a very small number of projects, the number of exploratory programmes is set to rise significantly in the coming years, prompting a boom in demand for deep space communications. As of March 2016, the Mars Reconnaissance Orbiter (MRO) had returned more than 298Tb of data, and NASA expects that, over the next three decades, communications capacity will need to grow tenfold for each decade. More sensitive instruments and larger mission numbers result in increasingly huge amounts of data production, and all that data must be transmitted safely, securely, and reliably back to Earth for analysis.

Deep space communications are, naturally, much more complex than terrestrial or even satellite communications systems due to the vast distances involved. NASA's Voyager 1 and 2 spacecraft, for example, are both more than 15 billion kilometres away from Earth, or 100 AU (1AU equals the average distance between the Sun and the Earth). Deep space exploratory spacecraft like these have long lifetimes (the Voyager spacecraft were launched in 1977 and remain operational today) and require reliable onboard communications systems with minimal weight and power requirements.

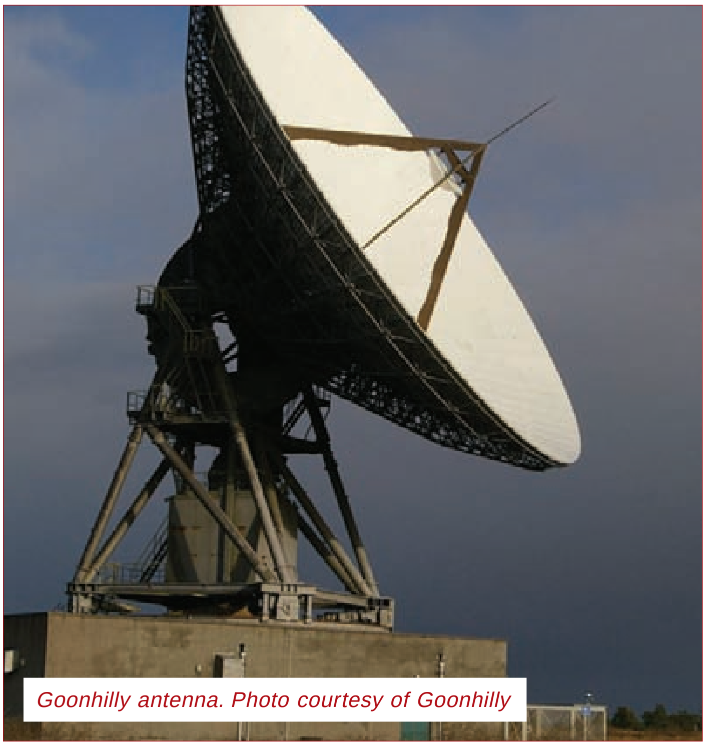
These vast distances create problems for traditional radiofrequency communications. Radio waves are ideal for terrestrial communications because they travel readily through our atmosphere and over relatively short distances, however, when we move into space, radio waves diffuse over long distances, requiring greater power and massive antennas for successful transmission and receipt. Such facilities with this level of technology are extremely limited, and with (literally) skyrocketing demand, change is needed.

Deep space networks

Deep space networks have been the answer to deep space communications challenges for some time now, with the first (NASA's) having been established in 1963 and playing a key role in the Apollo programme. Featuring massive antennas capable of transmitting and receiving radiofrequency signals over vast distances, these deep space networks have been vital in all space travel to date.

NASA's Deep Space Network (DSN) is the largest and most sensitive scientific telecommunications system in the world. The network consists of three massive complexes, each comprising one giant 70m antenna and several 34m antennas which can be used individually or in combination. The complexes are located in California, Spain, and Australia, spread equidistant from each other around the globe to allow constant communication with spacecraft as the Earth rotates. Operated by NASA's Jet Propulsion Laboratory (JPL), the DSN supports interplanetary spacecraft missions, plus several Earth-orbiting missions, and also provides radar and radio astronomy observations that improve our understanding of the solar system and the larger universe. According to the JPL, the antennas are an indispensable link to explorers venturing beyond Earth, providing the crucial connection for commanding our spacecraft and receiving their never before seen images and scientific information on Earth, propelling our understanding of the universe, our solar system and ultimately, our place within it.

The European Space Agency (ESA) operates a similar network, with three 35m antennas in Australia, Spain and Argentina, primarily operating in X-band, in addition to its global system of ground stations, Estrack, which provides links between satellites in orbit and the European Space Operations Centre (ESOC) in Germany, comprising seven stations in seven countries.


Goonhilly antenna. Photo courtesy of Goonhilly

In February, ESA's DSA made history when it successfully sent two commands simultaneously to the Mars Express and the ExoMars Trace Gas Orbiter (TGO) from a single antenna in New Norcia, Australia. The successful test is an important step in increasing the flexibility of ESA's Estrack network of antennas across the globe, to find, control, or receive data from missions across space.

Typical interactions feature a signal being transmitted between one spacecraft and one terrestrial antenna, however, since the ESA ground stations have four receivers each, they can in principle receive data from up to four spacecraft simultaneously. This Multiple Spacecraft Per Aperture (MSPA) technique is used routinely by ESA's Estrack and NASA's Deep Space networks, but it only works one way, with the ground station receiving data from multiple spacecraft. Ground stations are built with two transmitters, however, which ESA used to simultaneously transmit two signals at the same time, and in two different frequencies (X-band and S-band). This first Multiple Uplink per Aperture (MUPA) is the first step in allowing ESA's Estrack network, which is already operating at full capacity, to serve the ever-growing number of interplanetary missions.

Lunar Pathfinder mission

The provision of deep space networks isn't limited to massive entities like NASA and ESA. Cornwall's Goonhilly Earth Station is developing the world's first private deep space communications network in order to support lunar and deep space missions. The company is modifying its 30m Goonhilly-3 and 32m Goonhilly-6 antennas to be compatible with NASA and ESA's deep space communications networks to enable cost-effective access to beyond GEO communications. The almost £10 million investment also included the opening of a new data centre to help process the huge amounts of data expected to be generated on lunar missions.

In parallel with its deep space antenna upgrades, Goonhilly has partnered with SSTL and ESA in the development of Lunar Mission Support Services (LMSS). The LMSS partnership aims to develop communications, navigation, and operations services for use at the Moon, to support both orbiting and landed lunar assets. As part of the build-up of this infrastructure, there will also be opportunities for transportation of user payloads to lunar space to both public and private sector users at a price of £1 million per kg.

Accordingly, February saw SSTL announce the kick-off for the implementation phase of its lunar data-relay spacecraft, Lunar Pathfinder, which is designed to provide affordable communications services to lunar missions via S-band and UHF links to lunar assets on the surface and in orbit around the Moon, and an X-band link to Earth via Goonhilly's upgraded deep space antennas. As early as the fourth quarter of 2022, the 280kg Lunar Pathfinder will be a mission enabler for polar and far-side missions, which, without direct line of sight of the Earth, would otherwise have to procure their own communications relay spacecraft. Lunar Pathfinder is a more cost-effective alternative to Direct-to-Earth solutions and a credible alternative to institutional deep-space ground stations, offering orbiters and near-side missions a better availability, enhanced safety, and improved data-rate.

"Lunar Pathfinder will be the first commercial service to address the need for data relay around the Moon, and will not only demonstrate an innovative business idea, but we fully expect it to also stimulate the emerging lunar market," said Phil Brownnett, SSTL's Managing Director. "By pioneering a commercial solution and service delivery model in lunar orbit, SSTL and ESA are opening the door to providing services to the solar system and contributing to the scientific progress of deep space exploration."

To support booming demand from Lunar missions and a clear goal in the scientific community to undertake detailed study and analysis of the Aitken Basin, Lunar Pathfinder intends to operate in a stable elliptical orbit to provide long duration visibility of the Southern Lunar Hemisphere each day, with maximum opportunities for the transmission and reception of data between Earth and the lunar surface. NASA's Artemis programme also calls for 'landing the first American woman and next American man at the South Pole of the Moon by 2024, followed by a sustained presence on and around the Moon by 2028' and Lunar Pathfinder is accordingly working towards a 2022 launch to support early NASA missions.

Acting both as technology and service demonstrator, Lunar Pathfinder is expected to be a great opportunity for scientific and commercial mission developers to support the development, test and standardisation of lunar communication infrastructure, and for emerging off-planet telecommunication companies to acquire experience of lunar asset operations and off-planet service delivery. According to SSTL, Lunar Pathfinder is laying the foundation to support sustainable science and exploration for the next twenty years and beyond.

SSTL has also been working on plans for a constellation of spacecraft around the Moon, capable of providing enhanced communications and navigation services as the Lunar market grows from exploration to commercial exploitation and even tourism. As part of this, SSTL is designing a low-cost 35kg lunar communications satellite mission which will provide a communications relay back to Earth using Goonhilly's Deep Space Network. The DoT-4 satellite, expected for launch next year, will link up with a rover on the surface of the moon, and is envisaged as a precursor to the roll-out of a full constellation in 2023.

Laser communications

Another area under exploration for deep space communications is laser technologies. Congestion in the radiofrequency spectrum is expected to motivate deep space missions (as well as other communications applications) to move towards laser communications in the future, since they enable orders-of-magnitude performance increases for the same power and mass.

NASA is seeking to improve communications performance 10-100 times over without incurring increases in mass, volume, or power, and one potential answer is lasers. NASA's JPL is accordingly researching long-haul optical communications, optical proximity link system development, and in-situ optical transceivers. Laser communications technology remains in its infancy, particularly for space-based applications, and challenges include atmospheric noise, which can reduce the potency of a laser.

JPL's Deep Space Optical Communications (DSOC) project is well underway, with a specific objective of implementing a deep-space optical transceiver and ground receiver that will enable data rates greater than 10 times the current state-of-the-art deep space Ka-band system for a spacecraft with similar mass and power. Four key technologies need to be advanced to meet this performance goal while minimizing the spacecraft's mass and power burden:

- A low-mass Isolation Pointing Assembly (IPA)
- A flight-qualified Photon Counting Camera (PCC)
- A high peak-to-average power flight Laser Transmitter Assembly (LTA)
- A high photo-detection efficiency ground Photon Counting Detector array

The project's goal is to integrate a Flight Laser Transceiver (FLT) using key space technologies with an optical transceiver and state of the art electronics, software, and firmware to support a risk-retiring technology demonstration for future NASA missions. The demonstration will require ground laser transmitters and single photon-counting sensitivity ground receivers. Lasers and detectors can be integrated with existing ground telescopes for cost-effective ground transmitters and receivers. The DSOC payload is expected to undergo ground validation testing leading up to launch in 2022 aboard NASA's Psyche mission. Set to study the giant metal asteroid 16 Psyche in our solar system's main asteroid belt, the investigation will help scientists understand how planets and other bodies separated into layers – cores, mantles, and crusts – early in their formative histories. Aided by a Mars gravity assist, Psyche will reach its destination in 2026, enabling DSOC to begin its in-space investigation. ■

NASA's DSN. Photo courtesy of NASA

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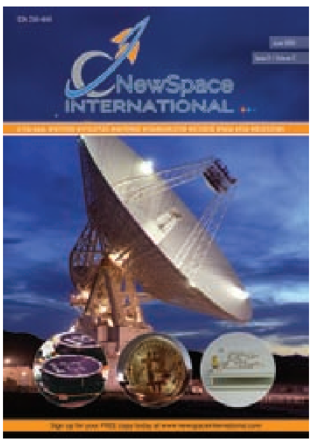

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