BROCHURE

Enabling Lunar Navigation

Spirent™
Federal Systems

For the first time in over half a century, humans are going back to the moon. However, unlike the ground-breaking efforts of the 1960s and 1970s, modern missions such as ESA's Lunar Pathfinder will place greater demands on positioning, navigation, and timing (PNT) functions. This brings with it a set of challenges – some familiar to terrestrial PNT providers and users, and some unique to areas outside Earth's frame of reference. Understanding and addressing these challenges, and developing working solutions, will be critical to success.

Generic issues for lunar navigation

There are fundamental questions to answer that underpin the future of lunar navigation – whether that is in transit to the moon, in lunar orbit, or on the surface. These must be resolved before any consistent PVT solution can be delivered.

- *What reference will be used for time on the moon?* UTC is a likely candidate, but a Moon-based timing system will probably be defined. Relativity is an issue due to a different gravity field around the moon - clocks on the Moon would tick faster than clocks on Earth, gaining about 50 microseconds per day. If we stick to UTC to synchronise lunar assets, it's quite likely that a GNSS-like approach will be adopted: clocks embarked on lunar transmitters will be "slowed down" upon manufacturing on Earth to compensate for the mean value of this effect, and then finer correction could be applied by the user exploiting the knowledge of the transmitters' orbit.
- *What geometric reference frame will be used for positioning?* The X,Y,Z reference frame that we currently use, fixed on Earth's rotation, is problematic for lunar positioning. There will need to be both a lunar reference frame – based on the centre of the moon – and an established reference frame transformation (how the two reference frames relate to one another). This will be necessary for navigating to the moon (at what point does a mission switch reference frames?) and communications between equipment on Earth and the moon.
- *What systems will be used for lunar PNT?* There are many different options available for PNT, but few have the scalability and continuity needed for a perennial lunar presence. Initially, it is likely that GNSS will be utilised through specialist receivers. However, GNSS cannot provide the precision and coverage needed for extended, high-precision activities. Major space agencies - including ESA, NASA, and JAXA - are evaluating the possibility of establishing a lunar satellite constellation based on modernised GNSS architecture. If deemed viable, it is likely that this system (or systems) would take over many aspects of lunar PNT. Even if that is the case, it's likely GNSS will remain a critical resource for lunar missions and activities.

Test requirements

In order to establish and evaluate the performance of proposed lunar navigation technologies, a comprehensive, realistic testbed must be created. The devices that will require testing could include:

- GNSS receivers for use on LNS satellites
- GNSS/LNS receivers for lunar transfer use
- LNS receivers for use on the lunar surface
- LNS receivers for use in lunar orbit

In order to qualify functionality in each of these cases, a series of considerations must be addressed.

Simulating at the extremes of the GNSS Space Service Volume (SSV)

Designing, testing and qualifying receiver performance at the extremes of the SSV is no trivial task, and will rely heavily on high-end RF simulation tools. Among other key criteria, those tools must be able to accurately recreate and simulate - from multi-GNSS sources - the extremely low received RF signal strength, satellite vehicle backlobe and receiver antenna patterns, Earth and Moon obscuration, code/carrier delays, range/range rates, and signal arrival angles. Each of these is required to ensure realism in these extreme test use cases.

Lunar orbital dynamics modelling

Dynamics modelling for satellites orbiting the moon requires different mathematical formulations than for Earth-based systems. The factors influencing orbits – uneven gravitational pull from the Moon, perturbations from other celestial bodies, as well as solar radiation pressure and other forces – are different in lunar orbit, and using Earth-derived models would not be appropriate for high precision propagation. Failure to address this could lead to significant error in the satellites' trajectory, and consequently unrealistic test conditions.

Gain patterns

Newly designed satellites and antennas destined for lunar use cases will need to incorporate customised gain patterns. Using default transmitter gain patterns, for instance, would diminish the realism of any testing.

Atmospheric attenuation

As must be considered for LEO applications, thin shell ionospheric models are not appropriate for lunar testing. Similarly to LEO – where the ionosphere should be considered as a 3D object that can be partially or wholly traversed – lunar application testing will require further sophistication, as some signals may cross the ionosphere twice before reaching the Moon. Addressing this enables realistic signal propagation modelling.

LNS signal generation

The opportunity to explore and experiment with new signal structures, frequencies and content will be at the heart of defining the LNS SIS. That new LNS signal could well be closely aligned to existing modernised GNSS signals, but possibly not. Therefore the ability to quickly and easily model those new signals as per an arbitrary waveform generator, but also as a full LNS simulation, will be a vital tool for signal system and receiver designers alike.

Addressing test challenges for lunar applications with Spirent and SpacePNT

Spirent and SpacePNT have partnered to develop SimORBIT, a tool used to generate truly realistic LEO orbits in a simulation environment. This tool combines the expertise of SpacePNT in understanding and recreating space environments, and of Spirent as the established leader in GNSS and additional PNT simulation technology.

This tool, alongside the understanding and knowledge transfer between the two operations, places Spirent in a unique position to support lunar navigation projects. Relevant experience and technologies include:

Development of NaviMoon

NaviMoon is a GNSS receiver intended for lunar applications, developed under a NAVISP project that is approaching completion. It will be deployed on SSTL's Lunar Pathfinder mission, with strong involvement from ESA. In order for NaviMoon to acquire and track a sufficient number of GNSS satellites it has to rely on the sidelobes of the GNSS transmission patterns. Testing the receiver required modelling of the gain pattern not only in terms of elevation, but also in azimuth – as gain is not constant for a given elevation – utilising in-depth knowledge of satellite altitude and orbit models. NaviMoon can process signals down to C/N_0 = 12 dB/Hz and has been extensively tested using a Spirent GSS9000 GNSS simulator.

NaviMoon

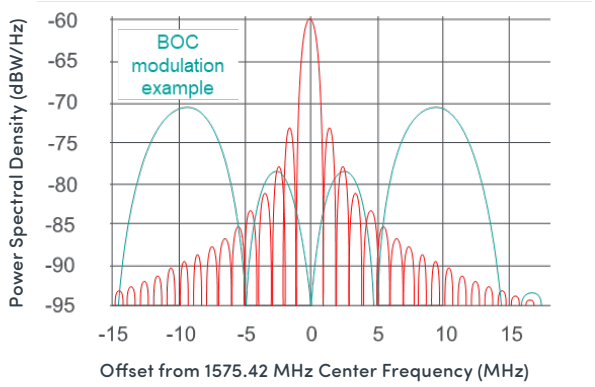
SimORBIT

Developed in partnership with SpacePNT, SimORBIT implements precise orbital models in order to test orbiting applications. This provides the framework to implement the precise Lunar ephemeris and reference frame transformations, dynamics modelling for lunar environment, and more. While some models from the Earth-based SimORBIT can be retained (e.g. solar gravity and radiation pressure), others can be enhanced for Lunar modelling (e.g. the gravity field of the Moon to be represented with spherical harmonics expansion, as opposed to the purely spherical model that is currently implemented). Other LEO-specific parameters, such as atmospheric drag, can be switched off.

Custom signal generation

The FLEX and SimIQ features available on Spirent GNSS simulators enable the creation of non-SIS ICD signals from the same hardware as standard GNSS. With FLEX, engineers are able to use an existing GNSS signal (NaVIC S-band, for instance) and alter chipping rate, BOC, navigation message, and more, in order to experiment with signal design. With SimIQ, engineers are able to use external IQ files containing newly defined signals and generate them through Spirent's unrivalled architecture. Whether for creating new signals, or for testing downstream lunar applications that will utilise these new signals, FLEX and SimIQ deliver ultimate test capability.

Flex signal example - BOC modulation



Signal generation architecture

Spirent signal generation architecture has been the trusted partner of major defence and space developers for over 35 years. Offering fine control over power levels, high simulation iteration rate, unmatched spectral purity, and the in-field upgrades and flexibility needed to move innovative projects forward quickly and reliably. Key features of the GSS9000 GNSS simulator include:

- 2 kHz update rate for simulating highly dynamic trajectories
- High 6-DOF dynamics with remote motion and ultra-low latency
- Mono, dual and multi RF output configurations enabling complex test definitions
- FLEX and SimIQ for non-SIS ICD signal generation
- Customisable antenna patterns for rear lobe of GNSS signals (Tx and Rx)
- Up to 65 day scenario duration
- Earth, Sun, and Moon gravitational effects modelled
- Modifiable atmospheric parameters
- Realistic multipath modelling
- INS emulation
- Ultra-low signal strength and low thermal noise
- Fine control over power levels (0.1 dB)

About Spirent Positioning Technology

Spirent enables innovation and development in the GNSS (global navigation satellite system) and additional PNT (positioning, navigation and timing) technologies that are increasingly influencing our lives.

Our clients promise superior performance to their customers. By providing comprehensive and tailored test and assurance solutions, Spirent assures that our clients fulfill that promise.

Why Spirent?

Over five decades Spirent has brought unrivaled power, control and precision to positioning, navigation and timing technology. Spirent is trusted by the leading developers across all segments to consult and deliver on innovative solutions, using the highest quality dedicated hardware and the most flexible and intuitive software on the market.

Spirent delivers

- Ground-breaking features proven to perform
- Flexible and customizable SDR technology for future-proofed test capabilities
- World-leading innovation, redefining industry expectations
- First-to-market with new signals and ICDs
- Signals built from first principles — giving the reliable and precise truth data you need
- Unrivaled investment in customer-focused R&D
- A global customer support network with established experts

INVESTORS IN PEOPLE
We invest in people Platinum

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About Spirent Communications
Spirent Communications (LSE: SPT) is a global leader with deep expertise and decades of experience in testing, assurance, analytics and security, serving developers, service providers, and enterprise networks. We help bring clarity to increasingly complex technological and business challenges. Spirent's customers have made a promise to their customers to deliver superior performance. Spirent assures that those promises are fulfilled. For more information visit: **www.spirentfederal.com**

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