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LEO constellations and tracking challenges

Krystal Dredge, Director of Marketing, Matthew von Arx, Senior Mechanical Controls Systems Engineer, and Ian Timmins, Principle RF Engineer at AvL Technologies explain the challenges of the new LEO constellations from a tracking point of view.

Satellite communications positively impacts nearly everything we do. As consumers, we unknowingly (and seamlessly) use it when we're on wireless calls, using apps requiring data transfer, and watching broadcasts from disaster sites and sporting events. As business professionals, we're maintaining contact with colleagues and customers in remote locations and accessing data that's been collected and transferred via satellite.

Because of the growing demand for satellite communications, many new satellites, new constellations and new applications are now in the works.

Many of the newer satellites will be quite small and constellations will be flying in low Earth orbit (LEO). And many of these constellations will have large quantities of satellites flying, adding significant complexity to the communications effort.

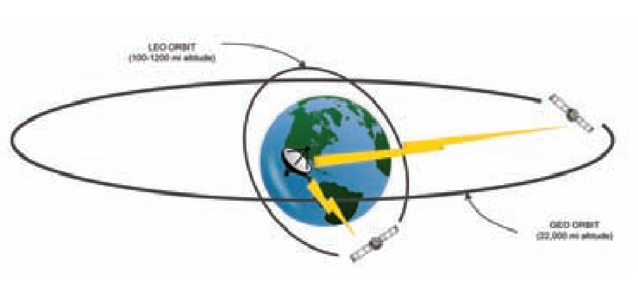
Most of the LEOs now being developed and/or produced are in highly inclined polar or near-polar orbits. Though their paths will vary, there's still some concern with collision due to the sheer volume of LEO satellites in development – more than 1,100 LEO satellites have been fully funded for development and/or launch during the next five years with many, many more in the works.

Why is LEO so popular?

Low Earth orbits, like medium Earth orbits (MEO), are dramatically closer to Earth than GEO orbits. Because of this, smaller satellites can be used and they require considerably less power. Satellites in LEO orbit are ideal for Earth imaging applications, too, because of their proximity to Earth. But the most significant benefits of using LEO and MEO satellites for communications applications are low latency and increased throughput.

Both LEO and MEO constellations experience little or no latency as compared to GEO satellites. And having little or no latency enables mission critical communications and applications that are more challenging with GEO.

Another reason for the popularity is cost. Smaller satellites cost less to design and build, and many can be launched together so launch costs are less, too. Cost alone has provided an 'in' for many universities and science-based businesses to join the space race and develop, launch,



GEO & LEO Orbits by Alan Ellis

operate and maintain a LEO small satellite.

Significant to military users is the low probability of intercept for LEO and MEO satellites. As these satellites are in constant motion, it is much, much more difficult for non-approved users to intercept, communicate with or jam them. The constellations also provide an innate redundancy, which we have become comfortable with in terrestrial based cable networks, whereby data can be routed through various paths through the network should a single satellite become disabled.

Why is LEO so challenging?

LEO satellites are in constant motion as they orbit Earth, so an individual satellite can only cover (or capture) small areas of the planet with each pass. So, many LEO constellations will be comprised of dozens, hundreds or thousands of small satellites. Some of the better known and now in-development constellations include SpaceX (4,000 satellites), Boeing (1,300+ satellites), OneWeb (600+ satellites), and LeoSat (100+ satellites).

Herein lies the complexity. Some constellations, such as LeoSat, will have optical laser inter-satellite communications. But most constellations will rely on intermittent communications between each satellite and a ground station, and the data collected by the ground station will need to be analyzed and correlated with data collected by partner satellites on a continual basis. However, the challenge that results from a moving constellation is that each singular satellite only has line of sight to an Earth station for a short period of time. Once the satellite moves beyond the field of view, the Earth station must seek link to a different satellite that has come into the field of view.

Tracking and communicating with LEO satellites is challenging for three reasons. First, LEOs move very quickly and most are only visible for 20 to 30 minutes during each pass. This requires an antenna that can acquire the signal, track the satellite's path, and upload or download as much data as possible in this short amount of time. Second, with so many satellites flying within each constellation, antennas must be able to communicate through handoffs from one satellite to the next to the next. Conventional antennas may require tens of seconds to locate and track a follow-on LEO satellite. This type of communications outage, though brief and predictable, is undesirable for data communications, and in many circumstances, such as voice or video communications, unacceptable. Third, the high duty cycle (constant movement and continual use) requires antennas that are rugged and high performing. The excessive wear and tear that comes from continual movement, as compared to a stationary GEO application, creates a different set of performance criteria for LEO and MEO ground stations.

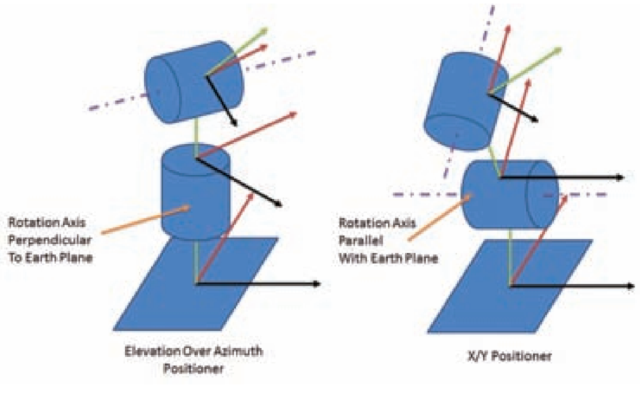
Types of LEO tracking antennas

Several types of antennas can be used to track and communicate with LEO satellites, and all must operate with high duty cycles. The continual motion of tracking one LEO satellite after another equates to significant mechanical performance requirements for traditional Earth stations. LEO tracking antennas also must move rapidly – both when tracking a LEO satellite from horizon to horizon and when returning (retracing) to a position to link to the next satellite as it rises.

X/Y antennas are the most widely used and most efficient mechanically steered antennas for tracking LEO satellites. X/Y antennas range in size from a small fixed or transportable 1.2m aperture to a much larger fixed 12m aperture. An X/Y design places the X or elevation positioner parallel to the ground. The Y positioner is placed in a vertical plane above and perpendicular to the X positioner, and its rotation ranges from horizontal to vertical depending on the rotation of the elevation positioner. This design, though simple, pushes keyholes (areas of data loss) out to the horizons and provides full hemispheric coverage. To track LEO satellites, X/Y antennas need to move quickly at a typical speed of three degrees per second, and even quicker to track a new satellite once the current satellite passes beyond the ground station's field of view.

Elevation over azimuth (El/Az) antennas with parabolic reflectors also work well, but will have a keyhole area when the antenna is positioned at zenith. These antennas are designed with the azimuth positioner perpendicular to the ground with the elevation positioner above. Both positioners can move independently or in a coordinated manner, and for LEO tracking a third positioner is required to dynamically change the base tilt of the antenna. El/Az antennas need to move at a typical speed of five to ten degrees per second to track LEO satellites.

One emerging technology is the use of phased array (flat panel) antennas. These low-profile form factors can be either electronically steered arrays or fixed beam antennas that utilize a mechanical positioner. Electronically steered array (ESA) flat panel antennas can be steered very quickly – perhaps instantaneously – which eliminates keyhole issues and minimizes losses, but they also offer less gain than other



El-Az and X-Y Positioner Diagrams by Matthew von Arx types of antennas. Furthermore, ESA antennas typically have a +/- 60-degree field of view, and though this may provide adequate steering for a constellation of large numbers, a mechanical positioner may be required for infrequent macro level movements in combination with the electronic steering that would occur continually. Mechanically steered flat panel antennas perform similarly to mechanically-steered parabolic antennas and will experience losses with a keyhole at zenith position.

Gateways

All new LEO constellations will require gateways for tracking the antennas, downloading data, and sending information back to each satellite. Depending on the frequency, gateway antennas vary in size and complexity. The higher the frequency, the harder it is to position the antenna to track and communicate with each satellite. Gateway antennas must have absolute pointing accuracy and no backlash. And the larger the constellation, the more terminals or gateways will be needed to maintain frequent communications with each satellite.

Many gateways are comprised of three antennas: An active antenna, a passive (ready) antenna, and a spare. Some gateways with quick retrace antennas may have one active antenna and a spare. Rarely is a gateway an individual antenna. Because of this, gateways can be a significant investment.

New LEO constellations will be heavily populated with satellites (i.e. have high orbit density), and most will require significantly more gateways than GEO constellations. As such, most new LEO constellations are working with Earth station antenna designers to provide smaller and moveable (or relocatable) gateway antennas. Instead of a large 10m antenna, a LEO constellation can easily communicate with a 2m class to 4m class antenna, such as the multi-band transportable antennas made by AvL Technologies, and thus drive down costs. These antennas can be permanently ‘fixed’ to a site, or temporarily anchored at a site as needed, then packed into cases, relocated and temporarily anchored to a new site. AvL’s experience with making military ruggedized antennas – and work in all frequencies – has made these transportable antennas a solid solution for LEO communications. AvL antennas also operate with precision and zero backlash, regardless of the operational environment.

Constellations with inter-satellite links will require fewer gateways. These constellations will be able to maintain private satellite-to-satellite links and minimize the need for continual communication from each satellite to a gateway.

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LEO satellite tracking

Because of the volume of LEO satellites that soon will be flying, the speed at which they’re travelling, and variations in frequencies, tracking LEO satellites is challenging. Any terminal or gateway communicating with a LEO satellite will need to receive satellite positions on a regular basis, and this information is pushed to terminals continually. Many types of tracking are employed, including TLE tracking and Parabolic Step Tracking. Though these tracking methods are complex, an antenna control system such as AvL’s AAQ controller has these capabilities and makes LEO tracking simple and manageable.

TLE tracking

TLE, an acronym for two-line element or two-line ephemeris, tracking is an ideal tracking method when memory is constrained. TLE uses two lines of ASCII text formatted into 80 columns, and must be paired with an appropriate algorithm containing Standard General Perturbation models, such as SGP, SGP4 or SGP8. These perturbation models serve as a propagator, or math engine, which translates the orbit of a satellite in terms of pointing angles. The beauty of TLE tracking is in its simplicity: An antenna control system for an Earth station reads the TLE through the SGP propagator to determine a satellite’s location and pointing angles at any point in time – but it does not require additional memory to ‘remember’ the satellite’s location.

Parabolic Step Tracking

Parabolic Step Tracking is a further refined peaking method, ideal for tracking satellites that have been in orbit for some time and have sub-optimal orbits due to gravitational pull and other external forces. This method starts with TLE tracking angles and adds offsets, which are intentional shifts along the satellite’s expected path. A satellite initially may be acquired by raster scanning over the propagated TLE angles to locate the peak of receive energy. A finer acquisition is then performed by spiral scanning at the satellite’s discovered location, and final peaking is performed whereby tracking offsets are determined with periodic re-peaking along the parabola of the primary lobe of the antenna’s signal. Re-peaking determines the positional offset angle against TLE propagated angles then follows the corrected path, which is often parallel to the TLE trajectory.

This system is complex due to the combining of Parabolic Step Tracking with TLE and SGP propagation, along with layers of course and fine scanning data, and failures are still possible. A typical failure occurs when an antenna is not able to locate a satellite’s location during a periodic re-peaking cycle. To avoid this type of failure, Earth station antennas are often programmed with instruction for frequent re-peaking; they follow open loop TLE data to find the satellite and re-peak on the signal, and the signal loss is often unnoticed.

Summary

Many new LEO constellations will be soaring above us soon, and they will enhance our daily communications, provide us with unending sources of new information, and enable many new applications. Operating and tracking these new antennas, however, is complex and requires high-duty, rugged, and smart Earth terminals and gateways.

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