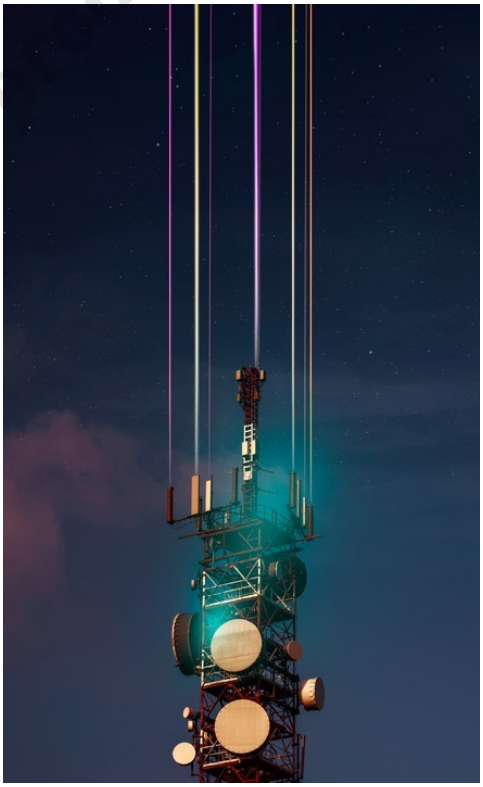


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Examining the LEO to GEO Scan Loss Challenge

By: Bob Potter



Given that LEO, MEO and GEO each have their own unique characteristics which offers distinct advantages, the ability to switch between orbits provides users in both commercial applications and the defence sector with much needed flexibility, resilience and security. LEO, for example, with its close proximity to Earth, offers low latency and high resolution, while MEO provides wider coverage, simpler network connectivity and higher data rates than LEO, and GEO, with a higher altitude compared to LEO and MEO, delivers a broad footprint but with higher latency, but with flexible network topology, simple operation and potentially lower cost per bit. Given these different characteristics and the advantages that each orbit brings, it's hardly surprising then that we're in the midst of an industry-wide shift towards a multi-orbit environment. A key component of this shift is phased array flat panel antennas (FPAs), which offer capabilities that traditional parabolic antennas cannot match.

FPAs contain tens, hundreds or even thousands of tiny antenna elements that can be controlled by precise amplitude and phase shifts. This design enables FPAs to track and switch between fast-moving satellites as they pass overhead, making them highly useful in LEO as well as in multi-orbit networks. Their compact form factor also makes them ideal for applications where space is limited or for COTM.

However, because of the inherent difference between LEO and GEO satellites' positions, moving from those different orbits without loss of signal strength remains a challenge. The amount of beam steering required to switch from one orbit to the other requires the antenna to steer away from its central position. This causes a number of technical difficulties.

Impact of scan angle on gain

Central to these challenges is antenna gain, the measurement of how effectively an antenna concentrates RF energy towards a satellite. Unlike a parabolic reflector antenna, FPA performance

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changes with pointing or beam steering, known as scan. An electronically steered array generally performs most favourably when operating at broadside, where the full aperture can contribute to the beam. As the beam moves away from broadside, the net result is a less effective aperture, as the combining of the individual elements can become less effective, resulting in scan loss.

This means that a satellite can remain clearly within the antenna's field of view while the quality of the RF link changes. A loss of several dB of useful gain at a particular scan angle can have a direct impact on link margin, with the consequences depending on factors including transmit power, receiver sensitivity and atmospheric conditions.

Scan-angle performance is particularly important for a multi-orbit FPA antenna. Users need to consider not just how much gain an antenna can achieve under ideal broadside conditions, but also how it performs across the range of angles required to operate between different orbits.

The challenge at the edge of scan

Alongside scan loss that comes from a reduction in gain as an antenna steers away from its central position, beam width, sidelobe behaviour and cross-polarisation also affect the antenna's performance as the beam moves towards the edge of the scan range.

As the beam moves further from broadside, maintaining control of the sidelobe pattern becomes more difficult. Increased sidelobe levels can make the antenna more susceptible to unwanted signals and can also increase the potential for interference with other spectrum users. This matters in an increasingly crowded orbital and spectrum environment, where neighbouring and overlapping allocations have to be carefully managed.

Cross-polarisation, which can become more pronounced as an array scans, is another potential issue that needs factoring in when considering how an FPA will perform. In this scenario, some of the transmitted or received energy essentially "leaks" into horizontal polarisation, reducing the quality of the wanted signal and increasing risk of interference. This consideration becomes particularly relevant when an antenna is expected to operate across different orbits and a wide range of look angles.

Need for more comprehensive testing and standardised specifications

Assessing an FPA for multi-orbit operation therefore requires a much broader view of performance than a single gain measurement. Ideally, specifications will show how the antenna performs across the actual operating range, including gain at relevant scan angles, cross-polar discrimination and sidelobe behaviour.

Testing is obviously a crucial requirement to verify how an antenna performs, yet while measurements taken at broadside or at a single pointing angle can provide useful information, they do not necessarily reveal how an array will behave across its full field of view. Testing across the required scan range provides a better indication of how performance changes as the beam moves away from its central position. This is particularly relevant for sidelobes, where behaviour at the edge of the scan range can differ from what simulations or central measurements suggest.

There is also a wider issue around how FPA performance is specified. Gain, G/T, EIRP and scan range are not always presented in a consistent way, making it difficult to compare antennas on a like-for-like basis. A more common approach to specifying performance across scan angle, temperature, polarisation and other relevant operating conditions would give operators a clearer picture of what an antenna can deliver in the environments where it will actually be used.

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Again, this is particularly important for multi-orbit systems. A wide electronic scan range may look attractive on paper, but if performance falls significantly as the antenna approaches the limits of that range, the specification can be misleading.

Designing for the entire window of operation

Given that more elements can provide greater control over the beam and help maintain sidelobe performance across a wider scan range, the obvious response to the scan loss challenge is to increase the number of elements in the array. However, this comes with its own trade-offs.

The more elements included, the more complex the RF architecture becomes, and additionally, in an active array, power and thermal requirements also then increase. Unsurprisingly, RF electronics generate heat, and managing that heat becomes increasingly important as antenna designs become more compact. For terminals intended for COTM or other applications where size and power are constrained, simply adding more elements is not necessarily the best option.

There can also be diminishing returns. Additional elements bring more RF components and control circuitry, along with the power and thermal overhead that comes with them. At some point, the extra complexity may not deliver a proportional improvement in useful link performance. Conversely, going too far the other way and limiting the design to a narrow electronic scan range may restrict its usefulness in a multi-orbit environment. The design challenge is therefore to find the right balance between aperture, gain, scan performance, sidelobe control, power consumption, thermal management, physical size, and cost.

When it comes to designing a network, the seemingly highest-performing array on paper may not be the most appropriate design for a specific network, particularly when achieving that performance requires a substantially larger aperture, significantly more power or results in unnecessary complexity.

Mechanical assistance provides another way of mitigating scan loss. Rather than requiring the phased array to perform at the extremes of its electronic scan range, a mechanical mechanism can physically reposition the antenna towards the satellite. This type of system can reposition the antenna over a wide range while the phased array provides the rapid beam steering needed to track the satellite. The result is an antenna in which the mechanical and electronic elements each perform the task they are best suited to, reducing the burden on the array itself, thereby also reducing scan loss.

This hybrid approach reduces the amount of electronic steering required and keeps the array closer to its broadside position, where its performance is strongest and most controlled. In a multi-orbit network, this method can be used to help the antenna move between LEO, MEO and GEO without requiring the phased array to operate continuously at extreme scan angles.

Final thoughts

As the ground segment adapts to support a multi-orbit landscape, the ability to maintain a reliable link while moving between very different geometries is set to become increasingly important. Antenna manufacturers are tasked with meeting users' evolving needs in terms of beam performance, while also balancing those needs with the practical constraints of size, power, thermal management and cost.

Seamless multi-orbit operation cannot be guaranteed on the basis of a single measurement such as maximum gain or scan range; what matters is how consistently the antenna maintains good

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performance across its entire operating range. Operators must therefore look beyond broadside measurements and consider how gain, cross-polarisation and sidelobes behave at every scan angle that is relevant for the intended application. Getting a complete picture of how an antenna performs is, however, easier said than done, particularly when measurements and specifications are often inadequate or inconsistent.

This makes comprehensive testing and clearer, standardised specifications all the more important, because it gives operators a better basis for comparing antennas and understanding what they can expect in real-world deployments. As FPA technology continues to develop, we'll likely see improved components and new concepts coming to market. Yet even with these advances, consistently delivering a strong, controlled beam across the required operating range will still require manufacturers to effectively balance the different factors that influence antenna performance.

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