Extra-Terrestrial Connections: Enabling Optical Mesh Networks In Orbit

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As the realm above Earth's atmosphere shifts from the domain of national space agencies to private corporations, the challenges associated with designing and deploying robust, space-based optical networks are evolving as well. In addition to meeting the rigorous technical demands of optical intersatellite links (OISL), organizations operating in space must contend with impactful commercial and supply chain considerations.

Key among the optical components that enable laser-based OISL and ground-to-satellite links are optical filters. Wavelength-selective dichroic beam combiners/splitters and bandpass filters are necessary to manage multiple signal bands, to provide beam steering, and to empower "more signal, with less background" at satellites' optical receivers.[1] However, optical filter implementation into orbital mesh networks must take place holistically: considering how price, performance, and delivery timeline are interdependent and can be optimized together to align with specific customer needs.

Optimal System Design Requires Balance

Consider a farmer who puts Formula 1 racing slicks on their tractor. Those tires undoubtedly are “high performance,” but they are ill-suited to traversing fields of crops. Similarly, satellite component specifications are limited by system design. Trade-offs must be considered: when one spec is improved, another may suffer. Maximizing performance in one area may “design out” overall system capability.

For example, tightening the steepness of a filter might negatively impact the filter’s wavefront error (WFE) and, as the angle of incidence (AOI) increases, polarization effects might get worse. When discussing spec trade-offs, a component supplier needs feedback from the customer clarifying system “need to haves” versus “nice to haves” to establish priorities. The component supplier also must be open to negotiating, because filter specifications do not exist in a vacuum inside the customer’s system.

Filter specifications are part of a budget, with interplay between all different parts of the instrument. The customer must accept that some specs may need to change to maximize overall system performance or to optimize design for manufacture (DFM). Designing a solution that can be scaled for commercial production is as important as establishing its feasibility/functionality. Likewise, the filter supplier must recognize how specification or tolerance change requests may burden the customer, necessitating changes to system design, plus additional simulations and analysis to understand the impact of each change.

Ultimately, a system will not work as expected if it is not properly characterized. So, it is critical that satellite system designers work with the filter supplier when determining specifications, leading to what is essentially a co-designed filter solution.

Common OISL Technical Challenges

Enabling OISL communication requires overcoming many of the same challenges that impact terrestrial signals, as well as some specific to the harsh environment of space. These include, but are not limited to:

- **Isolating the signal from background/ambient light source —** Solar rejection windows (SRW) allow the transmission of the OISL communication band between satellites while blocking the background solar radiation.[2] Typical SRW optical filter performance requirements include: high transmittance in signal band (typically 1550nm; wavelength is customizable), broad deep blocking of solar spectrum, typically large (up to 150mm diameter) windows, and low transmitted wavefront error (TWE).

- **Preserving signal quality with minimum wavefront distortion —** TWE often is specified and characterized by satellite system designers at 633nm, the industry standard in photonics. However, signals in space predominantly comprise 1550nm, so what happens at 633 nm does not have a direct relationship with their system performance. Moreover, system designers must be assured component and supply chain partners have taken that into consideration.

Additionally, in some cases, quantum key distribution (QKD) preservation of signal polarization states is critical. These requirements subtly differ from polarization dependent loss (PDL – a common spec for telecom filters).[3]

'Spec Creep' Can Propel Costs Into Orbit

In addition to different functional requirements, satellite-based optical filters must be designed and manufactured to survive the rigors of launch and operating in space. Iridian Spectral Technologies' filters adhere to numerous space environment testing and qualification standards related to survivability and reliable operation in conditions of heavy vibration, extreme temperature shock, and radiation exposure.

With thousands of filters operating across multiple applications, including in space,[4] Iridian can predict exactly how our filters will perform under any conditions. This space heritage is invaluable because it is often challenging to specify when a spec is "good enough." Specifications that are too loose can lead to suboptimal system performance; overly tight specifications can lead to supply chain reliability issues and reduced operational performance.

IDEX GS&D provides numerous solutions beyond high-performance optical filters (e.g., thin films), giving us exceptional visibility into the entirety of the optical chain serving complex space systems.[5, 6] Thoroughly understanding each component within a system enables Iridian to provide superior filtration solutions, at a minimal cost, while bolstering overall system performance.

If a customer procures individual components from different suppliers, each component must be specified under the assumption that all the other components will operate at the lowest end of their specification. So, margining for the worst case in all cases, a system designer ends up with tighter specifications on every component to allow for each to operate at its worst extreme and still have the system perform as expected. As Iridian provides more components in addition to optical filters, we can trade their performance off against one another.

Improperly Engineered Solutions Are Just Space Junk Waiting To Deorbit

"Off the shelf" solutions are not feasible for space-based systems because, although the wavelengths used are often similar, the specification budgets rarely are. Those differences, especially when coupled to commercial needs, are different enough that they don't translate across multiple filters.

Satellite constellations comprise different numbers of assets with different distances between them, which affects TWE budget, AOI, pointing and tracking, and how each system locks onto the signal. That variability does not allow for standardization because the lowest common denominator that would work across multiple systems would not be a very high-performing filter.

Iridian is purpose-built to provide custom solutions: our site is set up to handle everything from prototype design to commercial fabrication – a right-first-time approach, every time. Because of our space heritage and experience, we can accomplish this process quickly and without significant non-recurring engineering (NRE).

Moreover, based on our experience designing and fabricating small volumes of critical components for legacy space programs (i.e., for NASA and ESA) as well as large volumes of components for "new" space endeavors (e.g., private satellite constellations), Iridian can quickly respond to customer concerns and questions with information substantiated by real-world data.

Demonstrable heritage is easier to show with legacy space products since the use of public funds renders those valuable anchor points transparent.[7] Most commercial multi-launch, reusable, replaceable, replenishable space systems are private but we still can have a more general discussion with customers about what we have created and how it has performed in space. These conversations are critical to helping customers avoid unnecessary risks, costly missteps, and delays.

Onward And Upward

Operating satellite constellations in low earth orbit (LEO) will only become more complex as more organizations find increasing value in placing assets in orbit; hundreds of satellites already have been launched in 2025 alone.[8] More satellites in orbit means increased line-of-sight pathing challenges between the tens of thousands of objects in orbit.

Meanwhile, space-bound customers consistently demand greater signal resolution and access to more spectral bands. While the optical spectrum in space currently is unregulated, space law is an emerging field attempting to bring order to the "Wild West" of orbit, assigning entities responsibility for what they put up there, preventing piracy, and more.

Opportunities abound above the Earth's atmosphere, but so do actionable risks (e.g., the risk of component failure in space) and unactionable risks (e.g., space debris destroying satellites). Space heritage and experience in a component partner are critical in understanding and mitigating the actionable risks.

Finally, cost-effectiveness has emerged as a key consideration: many organizations investing in satellite constellations are selling services dependent on those units. They want to access different parts of the world that have varying disposable incomes available for buying those services. So, the need for component suppliers that provide the greatest value, even if it is not objectively the lowest cost, is vital. To learn more, contact the authors and watch our webinar, "Optical Filters In Space."

About IDEX MSS/GS&D and Iridian Spectral Technologies

Iridian Spectral Technologies is a world leader in the design and manufacture of custom optical filter solutions and is one of the sites that make up IDEX Materials Science Solutions, with commercial and engineering activities for space managed under the Global Space & Defense business. Using advanced, proprietary thin-film design deposition and manufacturing technology, Iridian delivers durable, high-performance optical filters for use in applications including telecommunications and datacenters, Raman spectroscopy, mid IR gas sensing, satellite-based imaging and communications, and many more. For more information, visit www.iridian.ca.

References

1. *"Messages from above - Optical Satcom Lights the Way." Messages From Above - Optical Satcom Lights The Way, Iridian Spectral Technologies, 22 Oct. 2019,* *www.photonicsonline.com/doc/messages-from-above-optical-satcom-lights-the-way-0001.*

2. *Iridian Spectral Technologies. "SatCom and Optical Filters" education page.* *https://www.iridian.ca/applications-satcom/*

3. *Bedington, R., Arrazola, J.M. & Ling, A. "Progress in satellite quantum key distribution." npj Quantum Inf 3, 30 (2017).* *https://doi.org/10.1038/s41534-017-0031-5*

4. *Palidwar, J., et al. "Fire Detectives in Orbit: Using Remote Sensing to Detect Wildfires." Fire Detectives In Orbit Using Remote Sensing To Detect Wildfires, Iridian Spectral Technologies, 11 Mar. 2025,* *www.photonicsonline.com/doc/fire-detectives-in-orbit-using-remote-sensing-to-detect-wildfires-0001.*

5. *https://www.idexcorp.com/news/news-item/idex-corporation-completes-acquisition-of-iridian-spectral-technologies/*

6. *Home - IDEX GLOBAL SERVICES*

7. *"MTG (Meteosat Third Generation)." eoPortal, European Space Agency, Last Updated 7 July 2025,* *www.eoportal.org/satellite-missions/meteosat-third-generation#eop-quick-facts-section.*

8. *https://spaceflightnow.com/launch-log/*

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