Why an Optical Modem?

A modem occupies a central part in all telecommunication systems. Short for *modulator-demodulator*, the modem converts the numerical data a user or a system would like to send into a suitable format for analogue transmission. On the receiving end, the modem converts the analogue data back into a digital format and provides it to the user. Over the years data rates have gone up, the modulation techniques have multiplied and the shear amount of information to be sent wirelessly has skyrocketed.

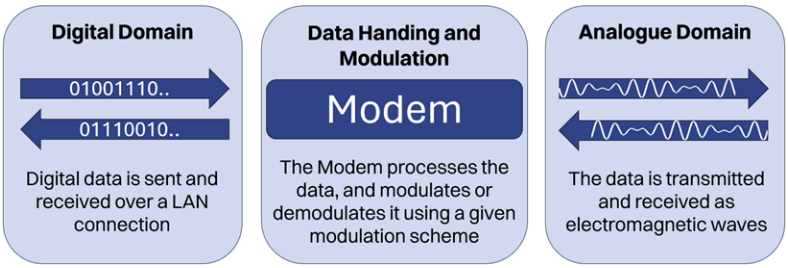

Figure 1: Purpose of a Modem

Telecommunications in space relies heavily on radio transmissions for all sorts of things such as controlling spacecraft, distributing satellite TV, GPS, transfer vast quantities of science data, and more. In recent years, constellations comprising hundreds/ thousands of satellites have been launched and more are planned. The need for resilient communication and high-speed data transmission capabilities is paramount to their success.

The radio spectrum is becoming increasingly congested as a result of terrestrial users (5G, WiFi, etc.), the increased number of satellites and the amount of data that is generated. In addition to this, there is a market need to support both higher data rates and to increase the level of data security. Operators are faced with challenges both in terms of frequency licencing and hardware to handle the data. To cope with these challenges, operators are switching to Free Space Optical (FSO) communications.

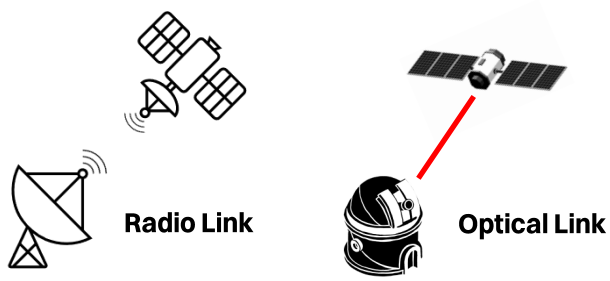

Figure 2: Radio Link vs Optical Link

There are several advantages to this over classical radio frequency transmission, including data security, absence of licensing restrictions, and the achievable data rates. The combination of these factors make FSO communication a potent supplement to classical radio communication. Although currently most standards target optical communications of up to 10Gbit/s, new standards are being created for data rates of 100Gbit/s and beyond.

Much like in classical radio telecommunications, the optical modem plays an important role in the communication chain. The most commonly used modulation scheme for FSO communication today, for Space to Ground (S2G) and Inter Satellite Links (ISL) is On-Off Keying. An optical modem wraps the user data into the format required by the standard, before transmitting it via an optical link to the end terminal (i.e. a satellite).

Optical data that has been received through a telescope is transmitted to the modem for handling. In order to minimise either data loss or erroneous data transfers the modem capabilities typically include automatic repeat requests (ARQ), comprehensive error correction, and other data handling mechanisms as defined in the different standards. Ideally 100% of the data should be transmitted to/from the user, error free.

The quality of the optical data transmission depends on many conditions that are outside the control of the modem, which emphasises the importance of a high-quality modem to have the ability to correct and reconstruct erroneous or missing data, as well as maintaining the throughput required for high-speed free space optical links.

The Celestia Optical Communications

Celestia-STS has provided the European and international space industry with modems and electrical ground support equipment for over three decades. Celestia systems are used everywhere from the Galileo ground stations to the testing facilities for the various ESA Copernicus satellites. Having contributed to over 80% of ESA missions, Celestia has earned an outstanding reputation in the space sector, delivering flexible and high-quality engineering, and products.

As data communication evolves, so does C-STS. With the onset of optical communications for S2G and ISL, a whole new range of products is needed, both for testing and for use in optical ground stations (OGS).

The Modem

The Celestia Optical Modem is designed to support multiple standards such as the SDA trance 0, SDA tranche 1, and CCSDS O3K standards. With this flexibility in mind the modem supports in-field upgrades and boasts the flexibility to implement different communication standards on the same product. Celestia has a long history of adapting its systems to the needs of its customers. The optical modem can be tailored to accommodate custom data handling, processing/ configurations. With a simple high-speed LAN connection, the modem receives user data, processes it and passes it to our Optical Transmitter Unit that contains the lasers and modulators.

Every telescope is different, and every OGS operator has different needs. The Celestia Optical Modem's Optical Transmitter is designed to support multiple optical outputs with tuneable frequencies, and with variable output power. By providing the ability to tune the output power, booster integration is made easier and OGS operators can chose from a larger array of suppliers which is a compelling advantage in today's competitive market.

The modem also integrates a powerful receiver unit capable of detecting very low incoming optical powers at high data rates. This has a direct impact on mission design where the link budget is a critical element. Thanks to the large dynamic range of our optical receiver unit, mission designers gain flexibility and can thus optimize both their design and cost.

Figure 3 Celestia Optical Modem

The Celestia modem products are completely agnostic to the meaning and contents of the user's data that is handled. Our systems don't interpret the information being transferred through the devices, and the modems themselves cannot make use of the information being transmitted. This renders our products completely data transparent within any optical transmission chain.

Raw Data to Disk

Celestia has designed and delivered systems capable of ingesting raw high-rate data directly to disk, prior to decoding. This is an extremely powerful feature that enables our customers to analyse system performances by correlating potential data corruption with phenomena such as fades, spacecraft pointing error, system events, and more.

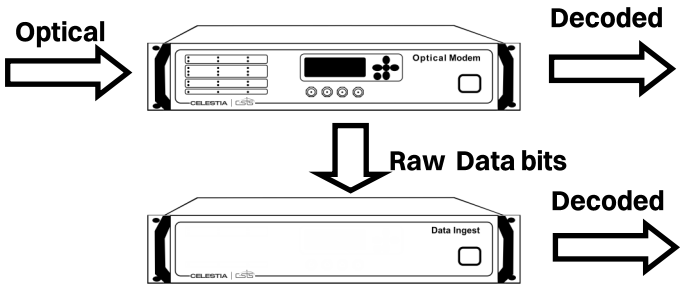

Figure 4: Data Ingest Illustration

Downlink Data Processing

In the Raw-Ingest configuration, data processing can be performed real-time within the hardware platform, or using software decoding of the raw bits acquired on the ingest server. The configuration enables standard-specific processing directly out of the box and, more importantly, it allows the user to develop and use custom decoding algorithms. This gives the user enhanced visibility of the entire transmission chain, and a cutting-edge advantage when testing their systems.

High Throughput Feeder Links

Celestia has been working on optical free space communication together with the Dutch research institute TNO (Netherlands Organisation for Applied Scientific Research) since 2018. A specific Optical Digital Processor (TOmCAT) was designed within this collaboration framework for optical data transfers of up to 100Gbit/s. The system was successfully tested at 28Gbit/s – the maximum allowed data rate permitted by the overall test setup - over a 10km distance underground atmospheric conditions. This demonstration of optical feeder links was highly successful and paved the way for other Celestia innovations.

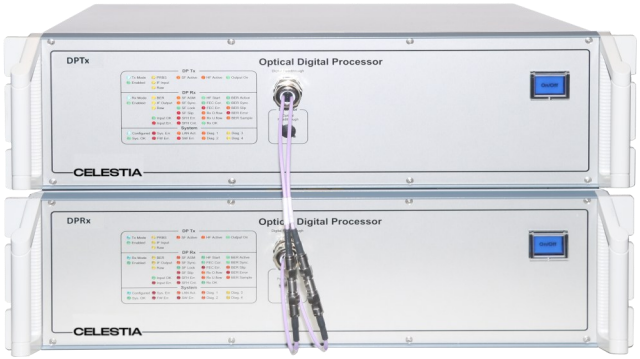

Figure 5: TOmCAT Optical Digital Processor

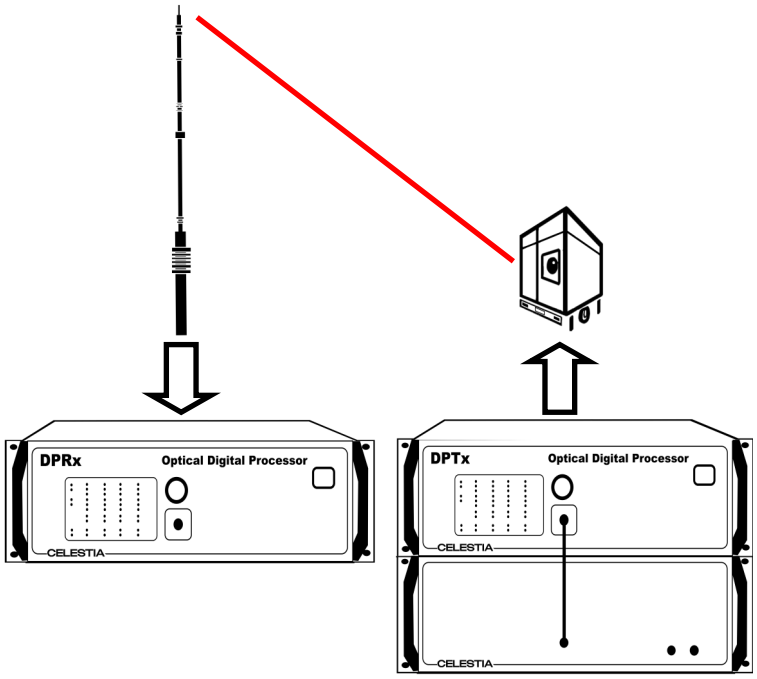

Figure 6: TOmCAT Field Test

In the frame of the TOmCAT project, Celestia developed a new and highly innovative data handling concept called Hyperframing. This mechanism uses deep interleaving of the data before transmission which renders the link incredibly robust against long duration fades. Using this process, the modem was tolerant to complete link severance of up to 20ms while transferring data at 28 Gbit/s. The fade represented a potential loss of over 5.5 Mbit of data, but thanks to the error correction provided by our algorithm, all the data was reconstructed.

Summary & Next Steps

Catering to the space industry for over three decades has fostered our ability to innovate and to find solutions to the complex challenges in this market. As communication standards evolve, so do our products. Our optical developments and solutions are a direct response to the market evolution where we both respond to our customer's needs and continue to align our product roadmaps with the various international standards for FSO data transmission.

In this article we have explored what a modem is and where it is used in a data communication chain. We saw that a modem converts digital user data into the analogue domain and vice versa. With the ever-increasing need for more data, higher data rates and increased data security, free space optical communication is being targeted as a solution which can address all of these aspects.

Celestia provides several solutions for free space optical communication. Our modems are multi-standard compatible, in field upgradeable and boast a high degree of flexibility. Also, terminal and operators can greatly benefit from our data ingestion capability where raw, as received data is streamed directly to disk. This powerful function enables users to perform in depth analysis of their optical link performance.

In the TOmCAT project we demonstrated high throughput feeder link capabilities, with hardware designed for a bit rates of up to 100Gbit/s. Our advanced Hyperframing mechanism enabled the link to successfully resist deep fades up to 20ms, representing a reconstruction of over 5.5 Mbit.

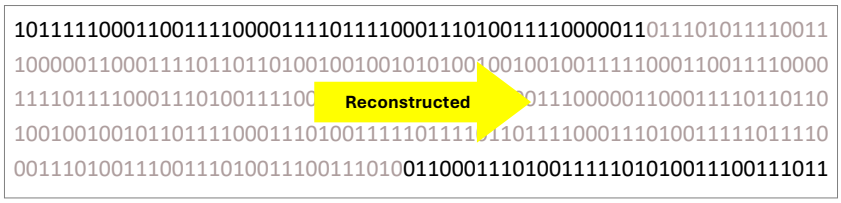

Figure 7: Reconstructing data using Hyperframing

In the upcoming period Celestia will continue to work on the optical communication products of tomorrow. Our optical modems are built with hardware supporting over 10Gbit/s data communication, and as standards evolve, we are ready to implement them.

Celestia are now targeting future constellation operators carrying on-board laser terminals. Operators will need ground stations and we are ready to help by supplying our optical modem products in parallel to our longstanding classical modem equipment.

In the scope of these developments, we are open to research and co-development projects to continue to evolve and to deliver a wider range of high-quality products to a competitive market. We have collaborated with many institutional and commercial partners over the years and will continue to do so in the future; innovating and creating solutions for the challenges associated in establishing highly reliable Free Space Optical communications.