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Optical Free Space Communications
Status of the First Commercial Operational System

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ABSTRACT

The Space Data Highway (SDH) will become operational in summer 2015 with the launch of EDRS-A. The SDH connects geostationary relay satellites with low Earth orbiting (LEO) observation satellites using a bi-directional 1.8 Gbps data link to geostationary (GEO) relay satellites. In addition to LEO satellites, terrestrial links links and to high-flying remotely piloted aircraft (RPA) are possible. This instantiation of Lasercomm will provide a number of unique features to include, high data-rates, secure communications and a phenomenal increase in available spectrum.

Airbus Defence and Space (Airbus DS) is developing the SDH to address several shortcomings of today's satellite communication systems. Firstly the GEO satellite "sees" over the earth's horizon to provide connectivity to low earth orbiting (LEO) satellites for more than half of its orbit (See Figure 1). This allows the LEO satellite to transmit data in real time, or using a Time Division Multiple Access (TDMA) scheme, in near real time. This obviates the need of expensive, widely disbursed ground stations across the globe, that provides very limited connectivity (only a few minutes during per pass) and provides coverage in inaccessible areas (limited by geographical, or political constraints). Additionally, after complete deployment of the SDH system (3-4 satellites), the data latency is reduced to near real time with 100% orbital coverage. Secondly 1.8 Gbps would allow many modern "big data" airborne sensors such as Gorgon Stare to downlink significant data sets, real time, via the SDH versus storing it on board for post-mission processing. Third, the low divergence of the laser channel leads to a number of advantages to include anti-jam, very low probability of interception / detection (LPI/LPD), and much more efficient use of spectrum.

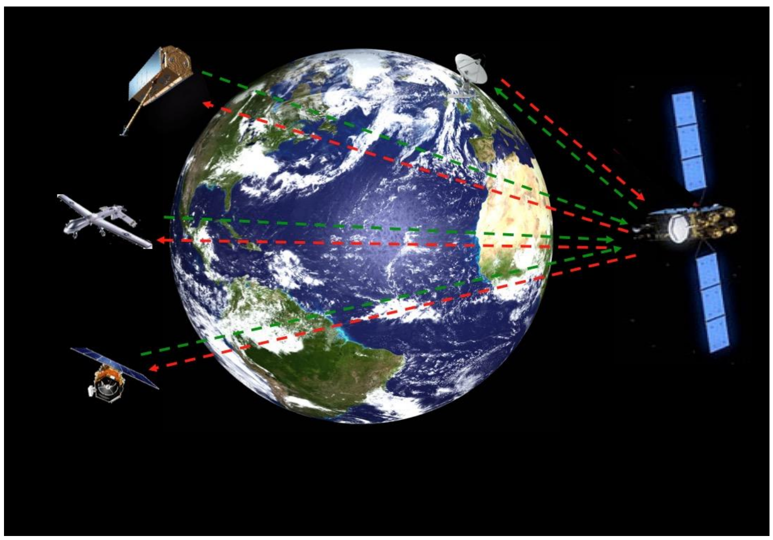

Figure 1: The SDH GEOSAT Lasercomm terminal can provide over the horizon connectivity to other satellites, airborne terminals and terrestrial stations.

Conversely, the technology is nascent and possibly more complex than current Ku/Ka band terminals. However, many technical risks have been mitigated and demonstrated with great results. For example, since 2008 an Inter Satellite Link (ISL) has been operated between the US NFIRE satellite and the German TerraSARX satellite with a data rate of 5.6 Gbps. Additionally, a 1.8 Gbps Inter Orbit Link (IOL) has been established between Alphasat (2013 launch) and the Sentinel 1A earth observation satellite (2014 launch). Finally, in August this year the first operational GEO SDH Node will be launched with a second node to follow soon.

The launch customer for the SDH will be the European Union's Copernicus system with 4 earth observation satellites dubbed Sentinels. All four Sentinels will carry LCTs; however, even while servicing the Sentinels, the SDH will have the capacity to support many more customers with the high data rate and the low latency essentially providing "virtual" ground stations everywhere on the globe. Finally, work is in progress at General Atomics to demonstrate an airborne LCT in the 2016/2017 timeframe.

THE SPACE DATA HIGHWAY

The SDH is European Data Relay System is a public-private partnership between the European Space Agency and Airbus Defense and Space (Airbus DS). Airbus DS offers commercial service to customers requiring high data rates, low information latency and independency of ground stations in all areas of our globe. Airbus DS affiliate TESAT is a highly experience space operator and has developed the LCT for the ISL at 5.6 Gbps between NFire and TerraSARX and also the LCT for the links between the LEO and GEO relay satellites. Also, in an industrial partnership with an airborne LCT (ALCT) is under development to link also highflying RPAs to the GEO nodes and provide near real time high-speed data transfer. The TESAT LCT (See Figure 2) provides symmetrical data rate performance of 1.8 Gbps and can also serve as feeder link to remote communication nodes, or task Satellites and RPAs in near real time. There are two principal operation modes – real time for a certain extended time slot, or near real time using a TDMA scheme (i.e. serving several remote terminals one after the other for a short time slot). The coherent homodyne technology allows transmission in low signal to noise ratio conditions such as the sun passing through the field of view of the receiver. Additionally, the integral design and the low size, weight and power (SWAP) requirements of the TESAT LCS allows other satellite operators to host a TESAT terminal with minimal impact on their primary mission.

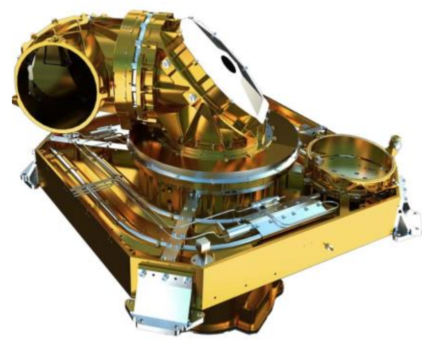

Figure 2: TESAT Lasercomm Terminal

WHY FREE SPACE LASER COMMUNICATION

Currently spectrum is one of the most valuable commodities on earth[1] and Lasercomm operates in a huge unused spectrum. The SDH free space laser communication system uses a carrier frequency of about 300 THz corresponding to 1 µm wavelength. With this carrier frequency, modulation bandwidth is not constrained and provides for very high data rates. These frequencies also allow for small apertures (in the range of 10 cm) and low transmit power (in the single Watt range); however, this drives very precise pointing and tracking requirements (10's of urad) but this has been demonstrated. Additionally, the low divergence and precise pointing makes it very difficult to intercept or interfere with the transmission, make the system anti-jam and LPI/LPD.

The small communication cone achieved by the short wave infrared (SWIR) wavelength makes it practically impossible to detect, intercept or disrupts the laser beam. The diameter from a GEO downlink towards a Reaper orbit is about 500m, while the diameter of a uplink at 60,000 feet above the Reaper is about 30 cm. An adversary would have to be in the beam divergence cone to detect or intercept the link (See Figure 3).

[1] Bengt Nordstrom, *Spectrum Auctions Hurt Mobile Consumers*, Bloomberg Business, August 17, 2010, http://www.businessweek.com/globalbiz/content/aug2010/gb20100817_915227.htm

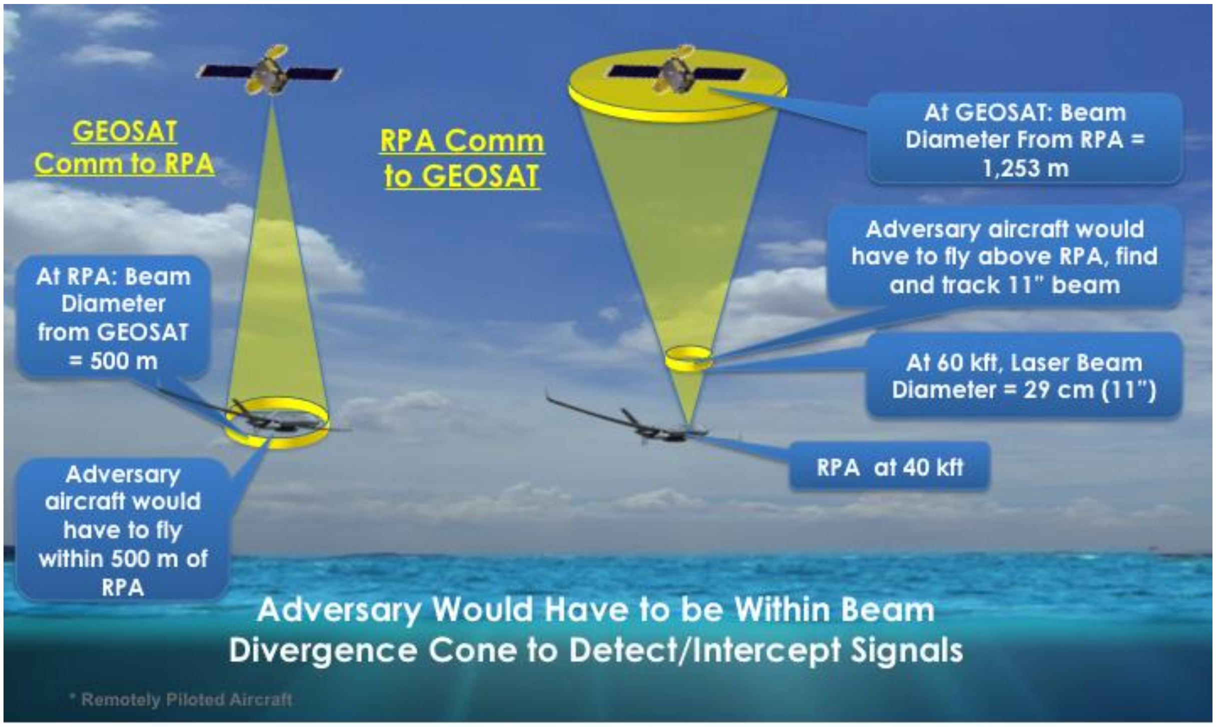

Figure 3: The low divergence and small beam diameter provide very secure lasercomm communications.

Modern sensors - space borne or airborne - generate “big data”. Gorgon Stare, for example, is 1600 Mpixel at 12 or 30 frames per second and generates more than 100 Gbps uncompressed data. Being able to download this quantity of data via RF links is prohibitively expensive while in contrast, a compress version of this data could be encapsulate on a single optical channel. Additionally, while the current space borne laser links are limited to 1.8 Gbps, the growth potential is almost unlimited. For example, the Foenex program demonstrated a 10 Gbps airborne link and the current record in a single fiber is 69 Tbps using 432 bands of wavelength division multiplexing[2].

An operational concern the GEO relay system solves is the information latency inherent in the current store and forward operations of LEO satellites. The data rate offered by free space laser communication allows for a much more efficient and faster link data for the user. Depending on the geometry more than 50% of a LEO orbit can be seen from one GEO node and with a constellation of three to four GEO nodes all possible orbits are covered 100% of the times. This is especially important, when direct downlink station are restricted by geography such as the Pacific Ocean.

Another operational consideration is the connectivity of long range, long endurance Unmanned Air Vehicles (UAVs). For example, based on a 10 hour mission in place, the MQ-9 Reaper has a 2500 nmi mission radius. To ensure timely recovery of ISR data, an airborne Lasercomm terminal (ALCT) can uplink the gathered ISR information to the SDH at high speed and downlink anywhere in the world.

[2] "World Record 69-Terabit Capacity for Optical Transmission over a Single Optical Fiber" (Press release). NTT. 2010-03-25. Retrieved 2010-04-03.

MATURITY OF THE SDH

The technology used for the SDH was first demonstrated in 2008. During this test, the U.S. MDA NFIRE satellite connected with the German TerraSAR X satellite at a data rate of 5.6 Gbps. The experiments were very successful and eliminated the most challenging technical risk: the pointing and acquisition of the corresponding LCT. During the demonstration, the acquisition time could be as low as ten seconds – impressive when one considers the two terminals must first conduct a spatial acquisition through a spiral search over a distance of 8,000 km, acquire the other LCT and then conduct a frequency acquisition using a coherent homodyne BPSK modulation scheme. This is especially challenging for an ISL link, where the satellites have a relative velocity of 25,000 km/h and a corresponding Doppler shift of their Laser frequencies. Also all development of the IOL laser terminals will include ISL capabilities. Using a 135mm telescope the LCT will allow bridging 45,000 km with the 1.8 Gbps data rate. Finally, General Atomics is concurrently developing an airborne LCT terminal for use with RPA's and other airborne command and control nodes. As those aircraft fly above most of the atmospheric perturbations the probability of blocking clouds is low and the use of adaptive optics is not necessary.

EVOLUTION OF THE SDH AND COMLEMENTARY SYSTEMS

The SDH will be operational in 2015 using one GEO relay node (EDRS-A) and four Sentinel satellites in LEO. The GEO LCT on Alphasat is currently used for measurements for downlinks through the atmosphere to the ground. A second GEO LCT (EDRS-C) will be launched in the first quarter 2017. Continued expansion of the SDH in the coming years will include deployment two additional GEO nodes (i.e. EDRS-D, EDRS-E).

Complementing the space borne links, General Atomics is developing an airborne LCT that will be compatible with MQ-9 Reapers and other airborne Command and Control platforms (e.g. AWACS, JSTARS, etc). Currently General Atomics has completed initial design reviews and plans for a ground test in 2016 and a flight test in 2017.

NASA is also experimenting with Lasercomm[3]. In 2013, during the Lunar Laser communication demonstration, NASA established a laser link from earth to a spacecraft circling the moon at 622 Mbps. Further plans include the Laser Communication Relay Demonstration planed for 2018. Internationally, Japan has completed several experiments to include ETS-VI in 1994 using intensity modulation and direct detection at 1 Mbps and later in 2006 OICETS at 50 Mbps.

Interestingly a large variety of laser wavelength have been used. Diode lasers have been employed at 0.6 and 0.8 µm wavelength, the terrestrial fiber communication lasers are 1.5µm and the solid-state lasers on SDH are 1.06µm. In the Lasercomm community a debate continues. A significant advantage of the 1.06 µm solid-state laser source is its availability of high output power (100s of watt), prolific use in military laser designators and its established space heritage (since 2008). Other laser sources and amplifiers are available from the telecom industry; however, most will need to undergo space qualification to guarantee survivability and reliability in this harsh environment.

Laser eye safety is always a consideration. In space, these systems can be fairly low power (few watts) and will be far from any human optical receivers (i.e. eyes); however, ground based uplink terminals require significantly more power. For example, the system being designed by General Atomics will have an uplink using approximately 100W average power. Although, safety systems are well understood and have multiple redundancies, at these powers, most laser systems will not be eye safe at short distances (100's of meters) and appropriate precautions must be taken.

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[3] NASA, Goddard Space Flight Center, *Lunar Laser Communication Demonstration*, Oct 2, 2014, http://esc.gsfc.nasa.gov/267/271/335.html

SUMMARY

At this time, SDH LCT represents the only space proven and qualified system terminal. With the launch of the EDRS-A, in mid 2015, the SDH will be operational. It will offer all the advantages of a free space Laser communications relay system including a high bi-directional data rate (1.8 Gbps), real time, or near real time TDMA data transmission, secure (anti-jam, LPI/LPD), requires no on-board data storage and allows the user to use his own end-to-end encryption. Additionally, it is flight proven with seven year of reliable operation. Finally, the coherent homodyne technology will provide robust operations and reliability even with the sun in the field of view of the receiver. Overall, this system offers an amazing step forward in managed commercial service for the SATCOM customers.