High Data Rate Interface Solutions for Earth Observation Payload Data Handling

Dr. Jens Haala

DOC-CLASS: O-K2

TESAT Product Overview

Downlink Solutions for Earth Observation

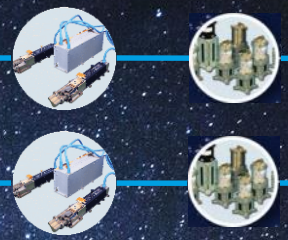
Mass Memory
Camera
etc

High Datarate I/F

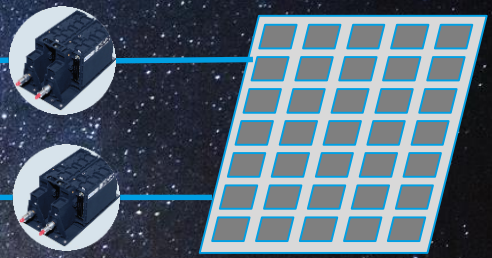
High Datarate Modulators

RF I/F
OUT

RF Dig.
I/F



Beamforming
Network



Active Antenna

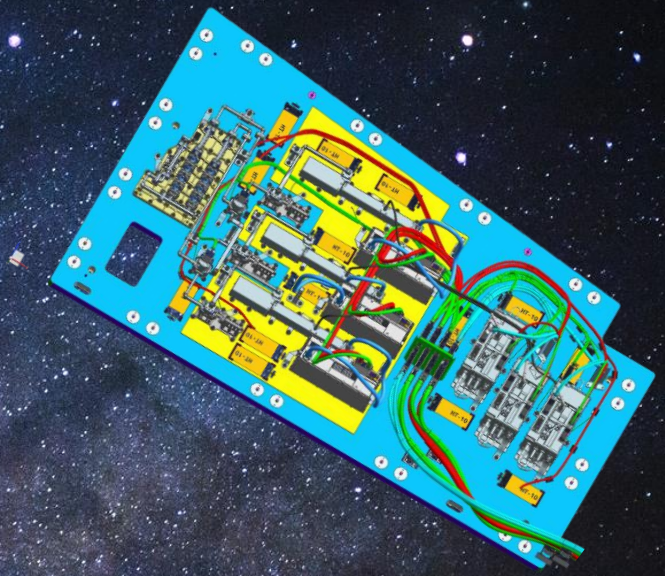
Laser Terminals

Transfer of high data vloume:

- RF Link
- Optical Link

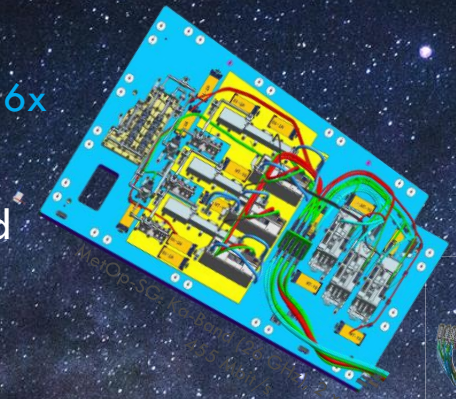
TESAT's Key Competencies for Data Downlink Subsytems

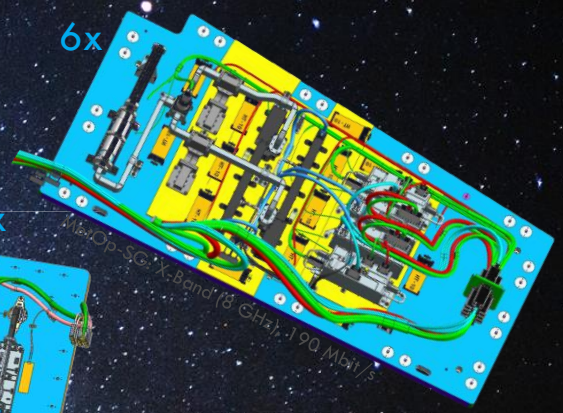
- Complete chain from input of mass memory up to transmitting antenna
- Modulators, TWTAs/SSPAs, Filters and WG Switches are all products of Tesat
- RF Harness Design (incl. antenna WG)
- Specification and Procurement of antennas
- Integration on Flight or Dummy panels
- Performance tests of complete subsystems using EGSE developed at TESAT

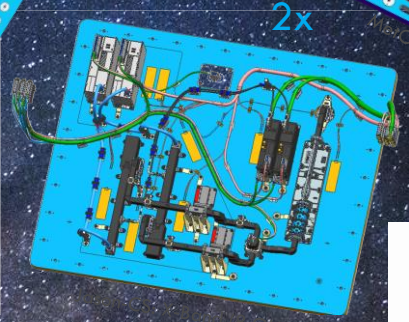


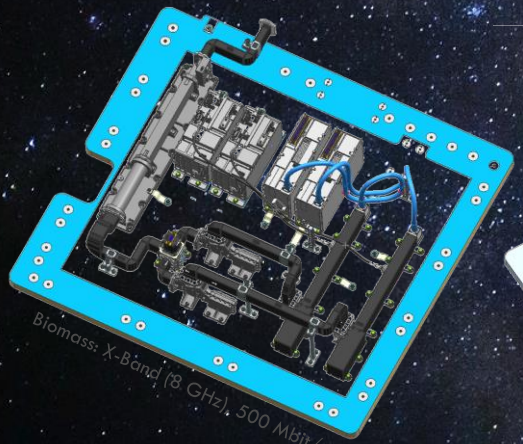
TESAT's Key Competencies for Data Downlink Subsytems

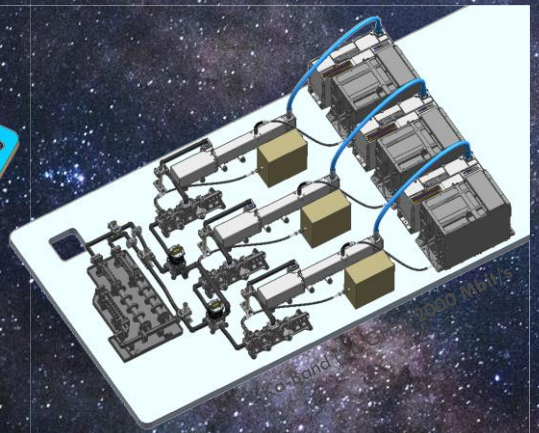
- ~100 Units in Orbit
- X- and Ka- Band
- Realizing 7 Gbps Download Capacity

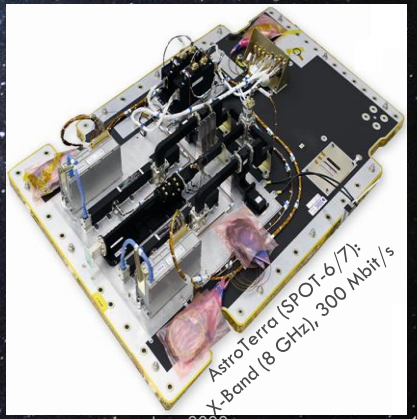


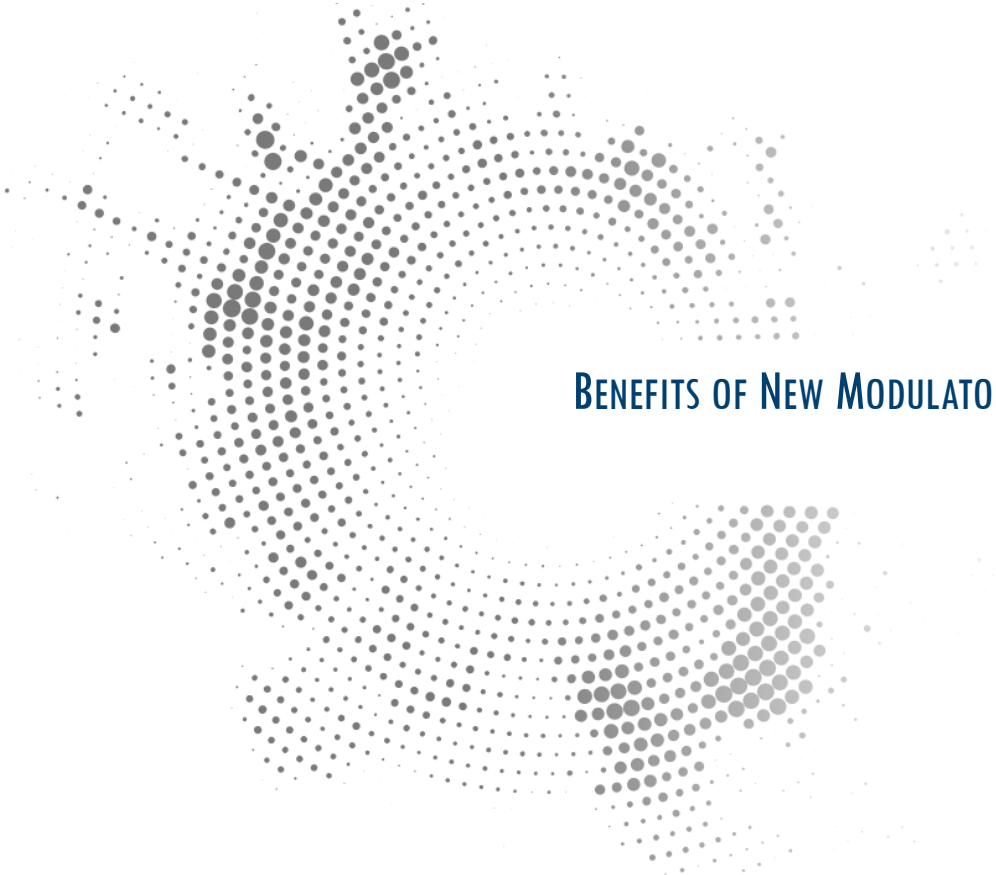








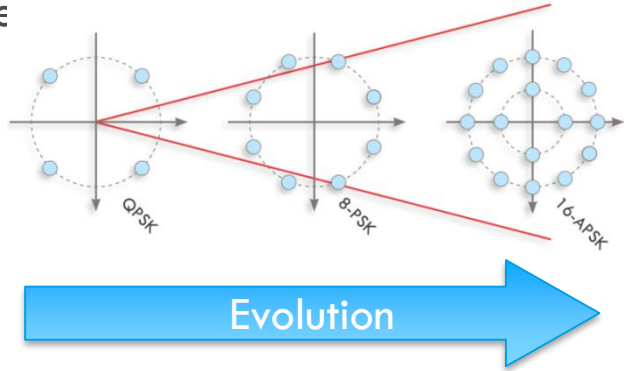




Benefits of New Modulator Concept

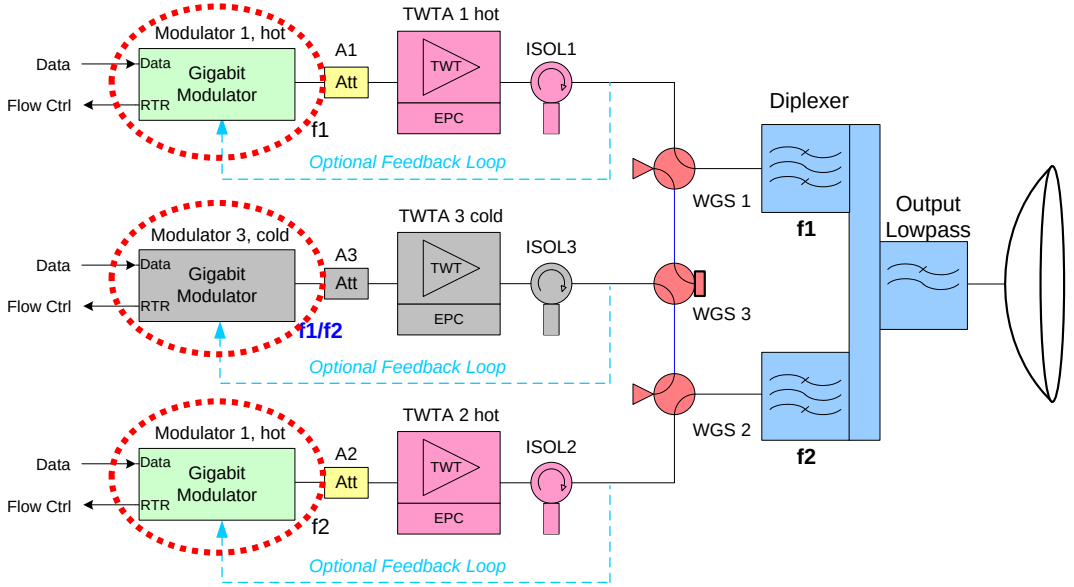
Challenges in High Downlink Data Rate Design

- High Spectral Efficiency required to reach high data rate
  - Implementation of APSK (16/32/64)
- High bandwidth required to use available bandwidth in EO Ka-Band (25.5 … 27 GHz)
  - Implementation of 500 Mbaud Symbol Rate
- High Efficiency in RF Power Amplifier on board satellites required: Operation near saturation induces nonlinearity distortion
  - Mitigation by digital predistortion
- High flexibility in order to cope with changing link conditions
  - Realised by adaptive/variable coding and modulation schemes (ACM/VCM)



Gigabit Ka-Band Modulator as Key for Next Generation Downlink Solutions

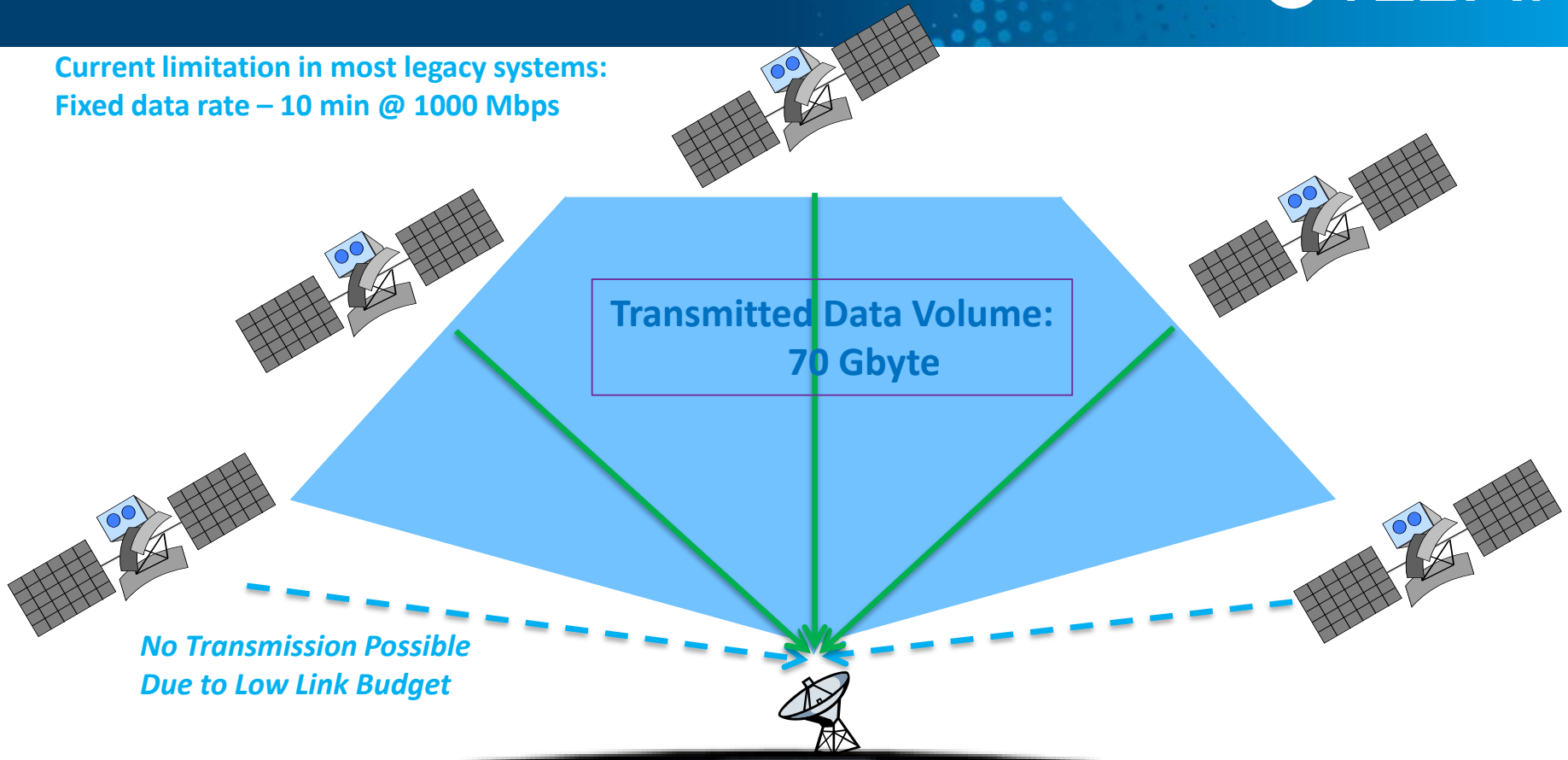
- Modulation: QPSK/8PSK 16/32/64-APSK
- Powerful SCCC coding
- Useful Data Rate Capability per channel:
  - **Ka-Band: 2000 Mbps** (Symbol Rate: 500 Mbaud)
  - X-Band: 1200 Mbps (Symbol Rate: 230 Mbaud)



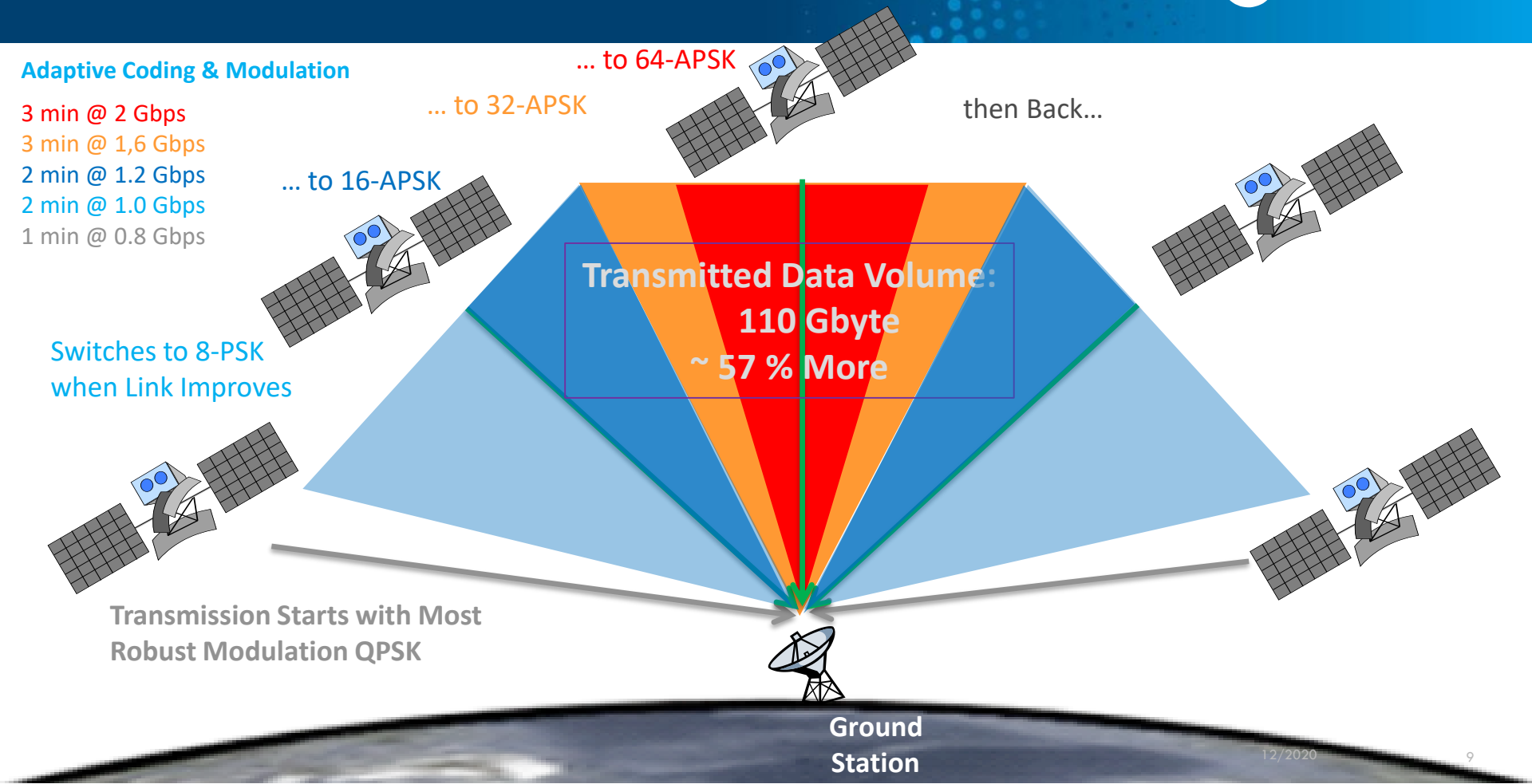
- Data Rate Capabilities:
  - 2-Channel System (full Ka-Band 25.5 – 27 GHz) allows for 4000 Mbps useful data rate
  - Doubling the architecture to 4 active channels allows to reach **8000 Mbps using dual polarisation**
    → cross polar cancellation algorithm required in the receiver!

Data Transmission from EO Satellite to GS with Constant Coding & MOdulation

Current limitation in most legacy systems:
Fixed data rate – 10 min @ 1000 Mbps



Data Transmission from EO Satellite to GS with Variable Coding & Modulation



NEXT GEN MULTI-GIGABIT MODULATOR

up to 6 Gbit/s per channel

Major Features and Goals

- Operation in the Ka-band frequency (25.5 to 27 GHz) and X-Band.
- SCCC encoding and APSK modulation schemes as defined in CCSDS 131.2-B-1.
- Exploitation of the full bandwidth of 1.5 GHz available in Ka-band with a single carrier

- Targeted symbol rate of 1.2 Gbaud
  - More than a doubling of the symbol rate

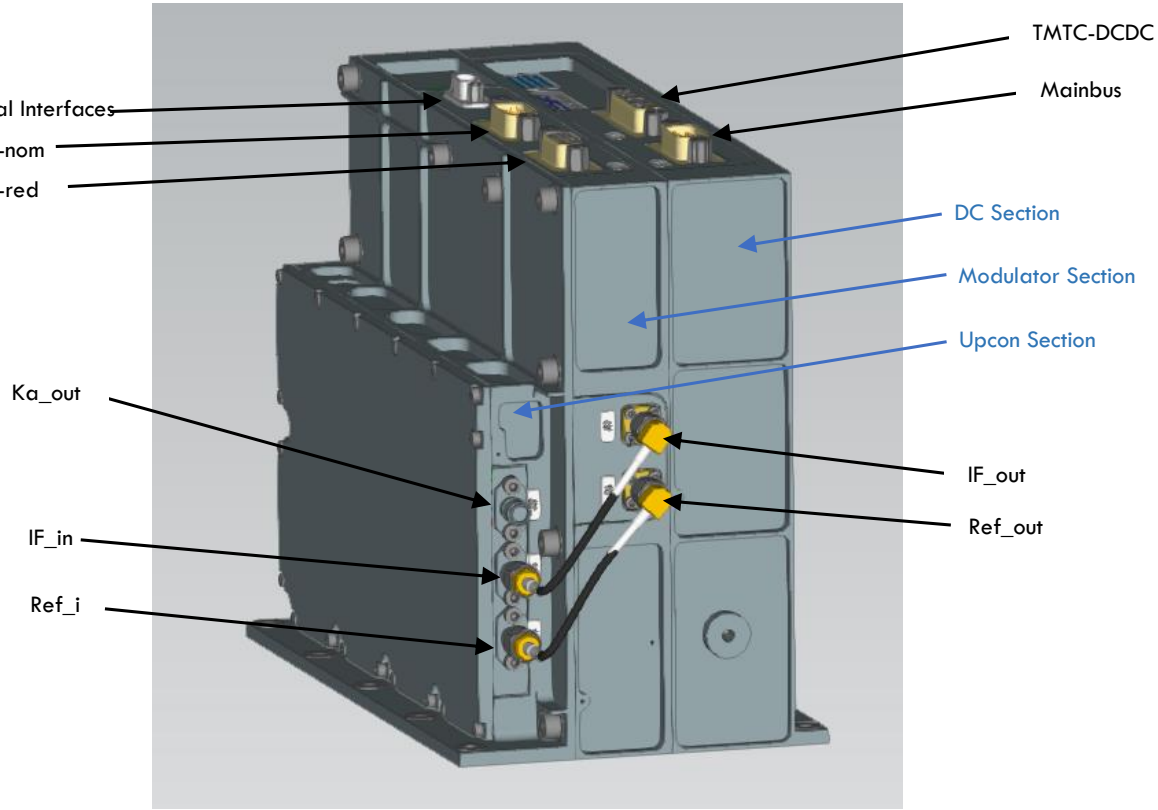
- In order to overcome the bottleneck of the currently available data interfaces (limit at 2 Gbps), it is proposed to implement an **optical interface** with a data rate capability of 6.3 Gbps.

Next Gen Multi-Gigabit Modulator - Characteristics

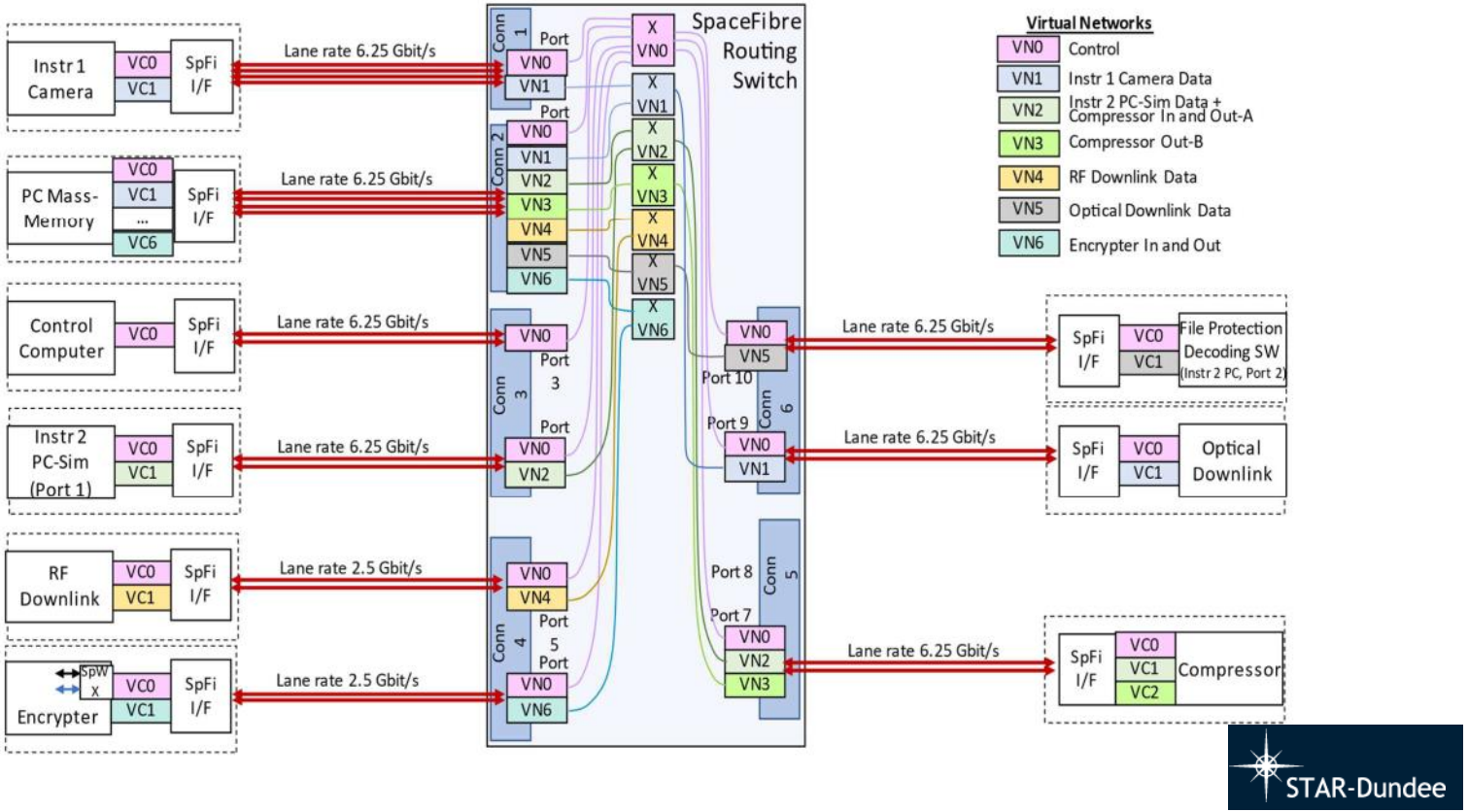
Parameter	Value
Frequency Range	25500 – 27000 MHz (Bandwidth 1.5 GHz) 8025 – 8400 MHz (Bandwidth 375 MHz)
Output power range	0 dBm … +6 dBm
Modulation Schemes	27 different schemes with various code rates: QPSK, 8PSK, 16-APSK, 32-APSK, 64-APSK
Coding Schemes	SCCC/CCSDS 131.2-B-1
Pre-Distortion	digital
Input Data Rate	Max. 6 Gbps
Output Symbol Rate	Max. 1200 Mbaud (on single carrier)
Supply Voltage	21 V - 42 V
Power Consumption	35 W
Mass	~ 2.5 kg
Quality/Lifetime	Class1/15 years – Option: High Quality NewSpace variant with lower grade components
Development Status	TRL 4 (Breadboard), EQM Qualification planned until Q2/2024

Next Gen Multi-Gigabit Modulator – Mechanical Design

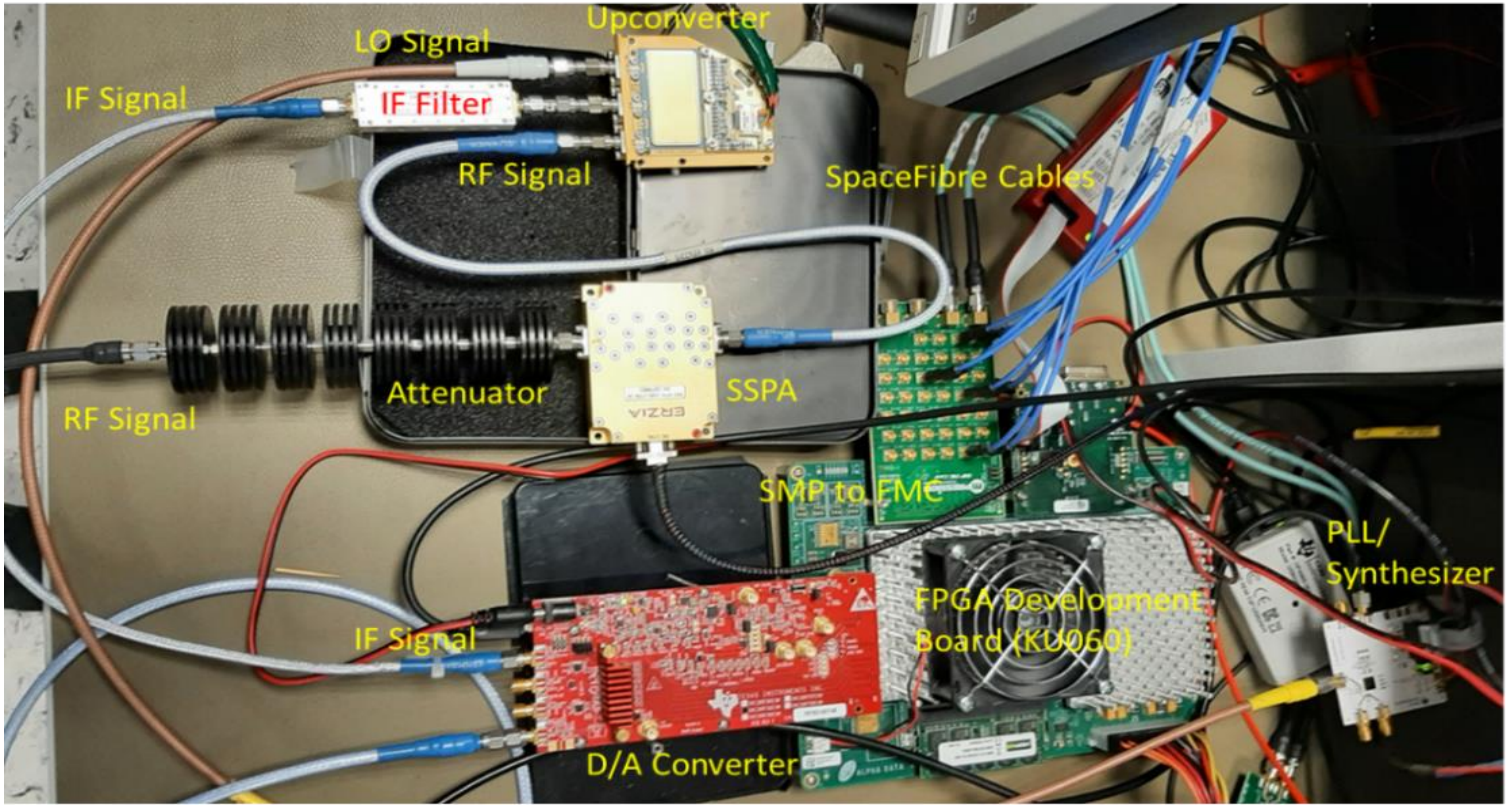
- **Based on new technologies** available at Tesat:
  - CDD: Compact Digital Design
    - Direct RF DAC
    - Slim design with FPGA and DAC in organic packages
  - HDI: High Density Integration
    - Allowing for very compact RF design
- **Very Compact Design with small footprint**
- **Qualification according to Generic Vibration & Shock Requirements**



HI-SIDE
Configuration Space-Fibre



HI-SIDE
Lab-Setup RF-Downlink



Data Interface: Baseline
Removing a bottleneck

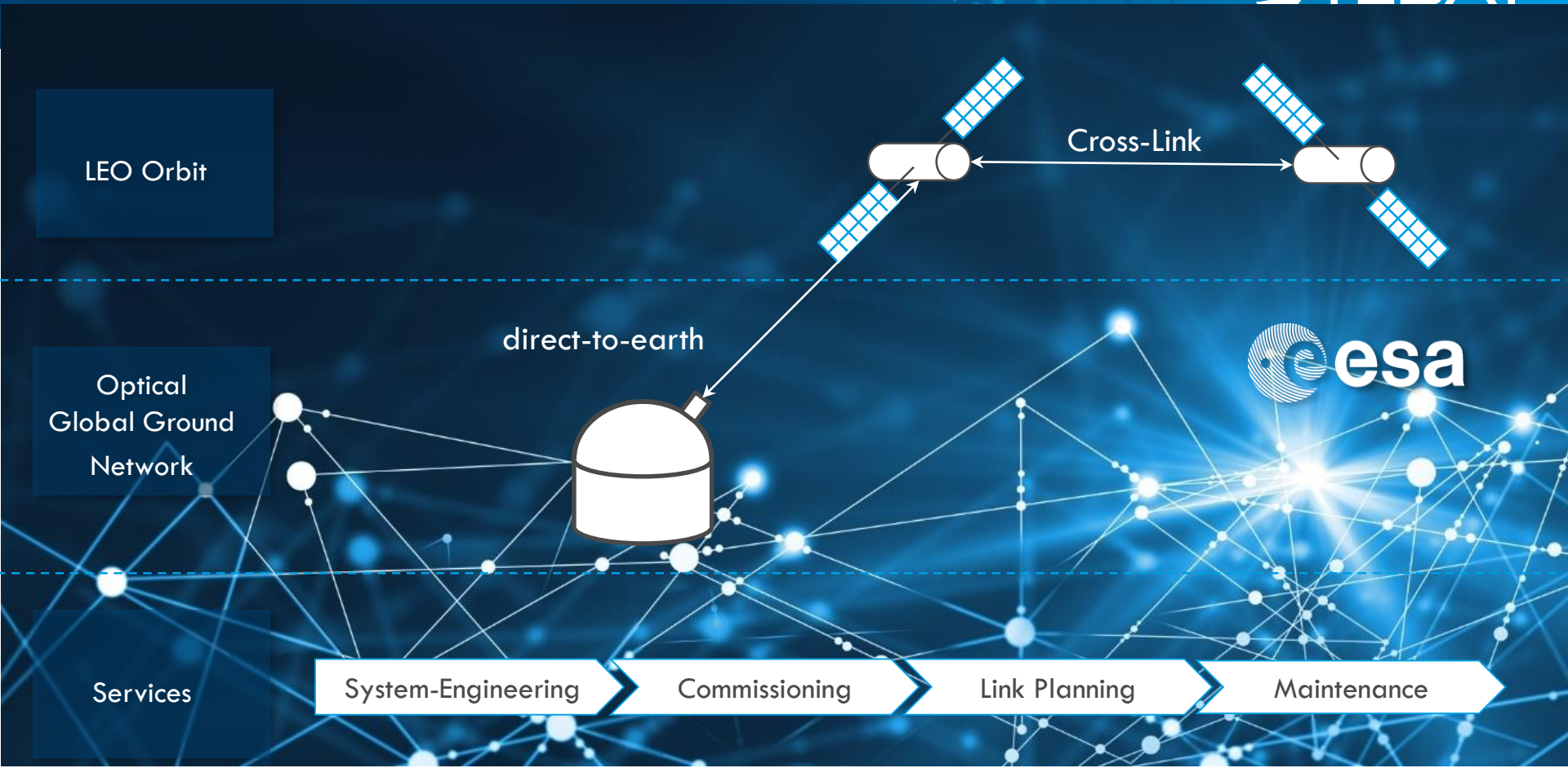
- Reception of input data up to a data rate of 6.3 Gbps
- Flow control necessary → need for return channel → TX signal needed
- “smart” interface in terms of harness complexity, weight, EMC and costs preferred

- **Optical transceivers** seem the best solution for the data interface
  - Advantages: Compact harness, EMC advantage

- Could 10G Ethernet be an alternative (e.g. new space)?
  (Feedback welcome ☺)

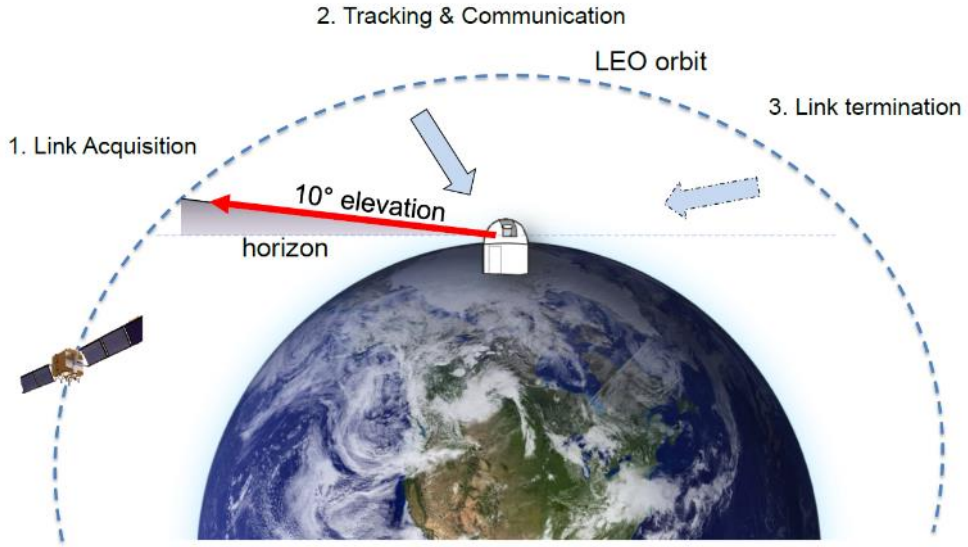
DIRECT-TO-EARTH OPTICAL LINKS

Applications



Direct-to-Earth Links from LEO Orbit

Direct-to-earth (DTE) laser links from the LEO orbit (**up to** 600km)



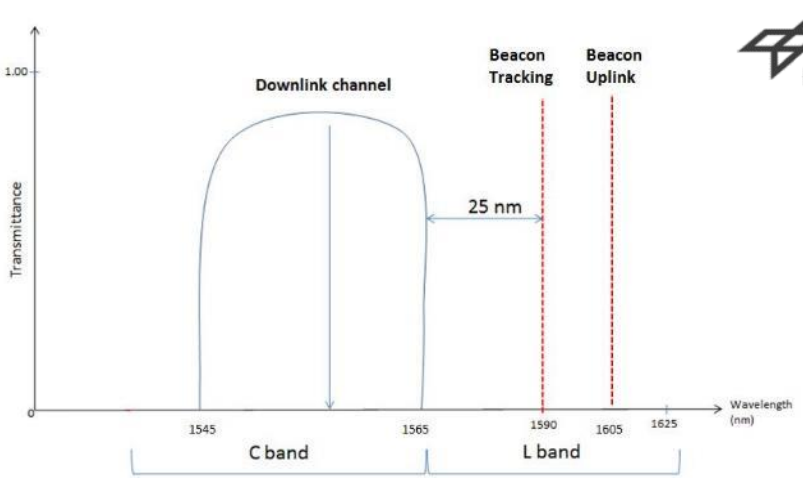
Source: DLR-IKN

High Service Performance by:

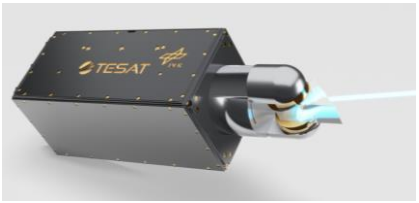
1. Robust modulation (IM/DD)
2. Channel coding (FEC)
3. Intelligent storage management (ARQ & reactive planning)
4. Distributed downlinks (site-diversity)
5. Unsusceptible network architecture (DTN)

TECHNOLOGY

- Based on DLR-IKN OSIRIS technology with >10 years experience and in-orbit heritage
- Use and qualification of COTS components
- Optical C-band and L-band wavelength
- Amplitude modulation with robust coding
- Forward error correction coding (FEC) to mitigate effects of atmosphere on the communication channel
- Reference implementation of CCSDS O3K standard for optical downlinks (Physical + Coding&Sync Layer)

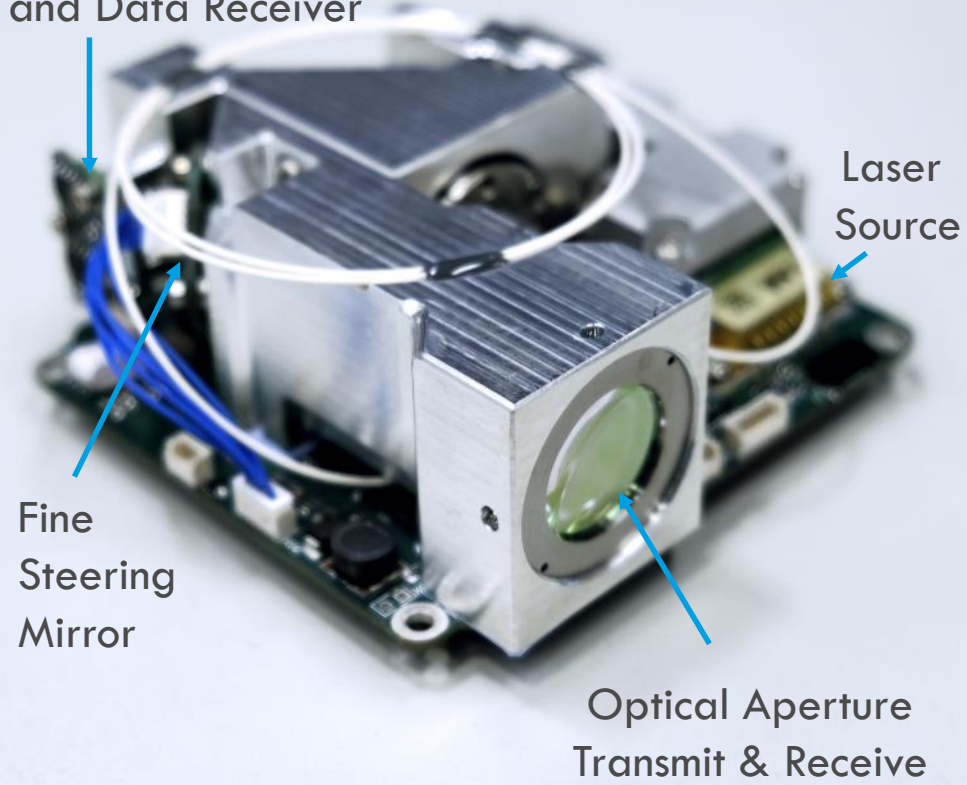


Bandplan for optical up- and downlink, according to CCSDS, indicating potential downlink wavelengths in C-band and Beacon in L-band
(Image DLR)



CubeSat Solution

CUBELCT MECHANICAL LAYOUT



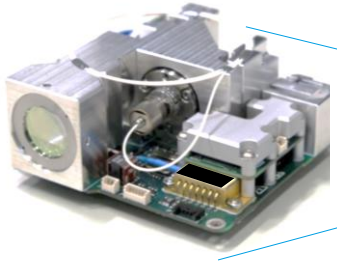
- Downlink Channel Rate 100Mbps (75Mbps user)
- Uplink several kbps

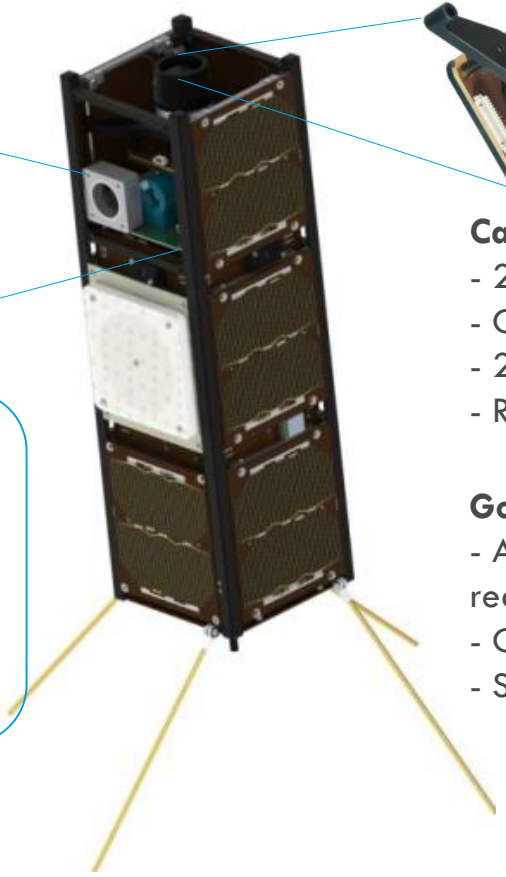
- Link Distance 1800km
- internal fine steering capability +/- 1°
- Use of S/C OBC and S/C body pointing
- Data interface LVDS

- 9x9,5x3,5 cm^3
- 0,4 kg
- 10 W (peak)

- Available within 6 month
- First models delivered to customer
- First mission flight January 2021

First Mission Flying the CubeLCT: PIXL





PIXL

First operational Lasercom Demo from a CubeSat

- **Launched on 24 Jan 2021**
- First Links to OGS performed in Summer 2021
- OGS Check-Out Service from 2022 on

Camera Payload:

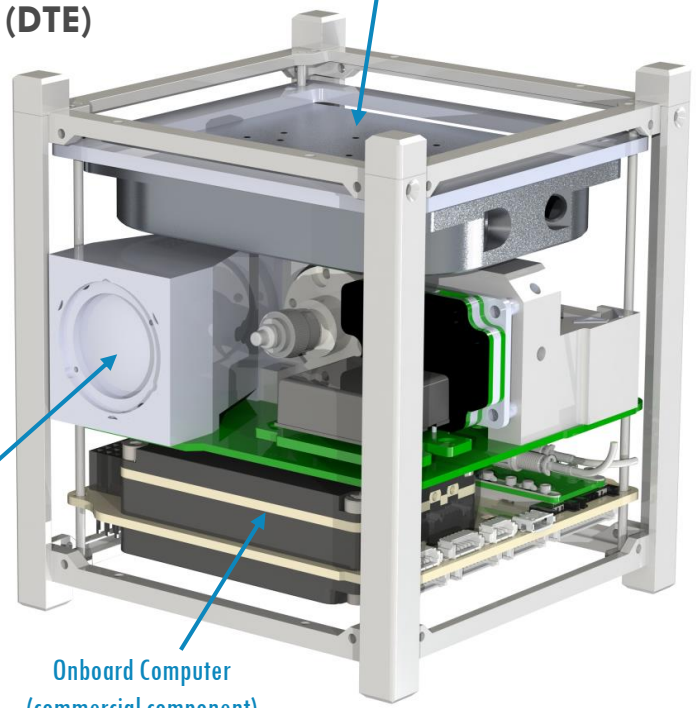
- 2048 x 1536 pixels (3MP)
- GSD: < 30m from 650 km
- 2 GB image storage
- RAW, BMP and JPEG output format

GomSpace Satellite Bus:

- AOCS with star camera and reaction wheels
- OBC for data handling
- S-Band downlink for commanding

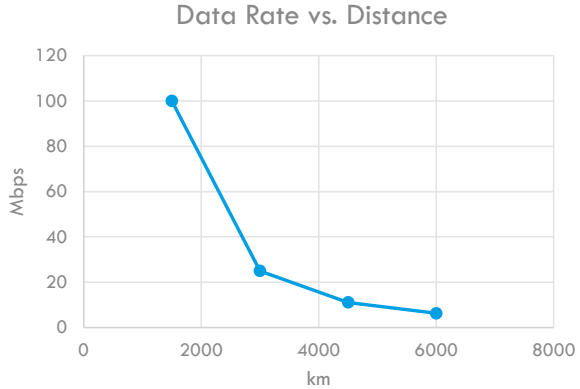
CubeLCT 1 GBPS DTE – Next Generation Terminal
+ ISL capability

- **New Product "CubeISL"**
  - Full bidirectional design enables intersatellite links
- **Expansion towards 1 Gbps channel rate for Direct-to-Earth links (DTE)**
  - Extension with Data Receiver, Optical Amplifier and dedicated Onboard Computer for upcoming Inter-Satellite-Link mission between two 6U CubeSats in 2023
- **Introduction of dedicated LCT Onboard Computer**
  - for handling of advanced ISL commanding
  - for data handling incl. FEC
- Use of S/C body pointing
  → internal fine steering capability +/- 1°
- 9x9,5x10 cm³
- ~0,8 kg, ~30 W (peak)

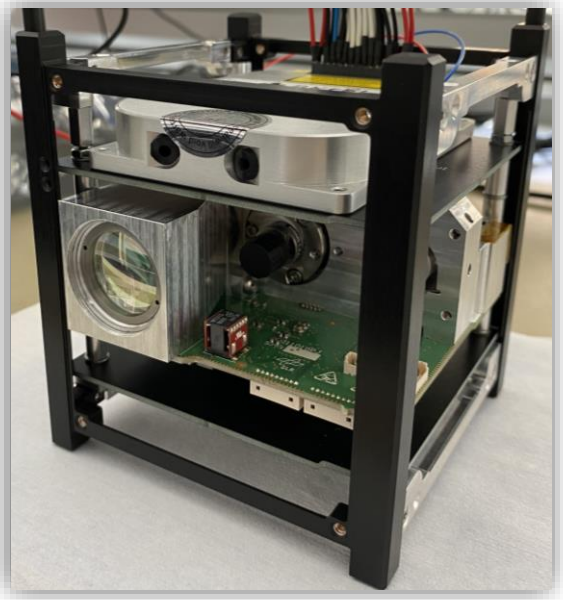


CubeISL – Capabilities & Status

- **ISL capability:**
  - Data rate depends on link distance:



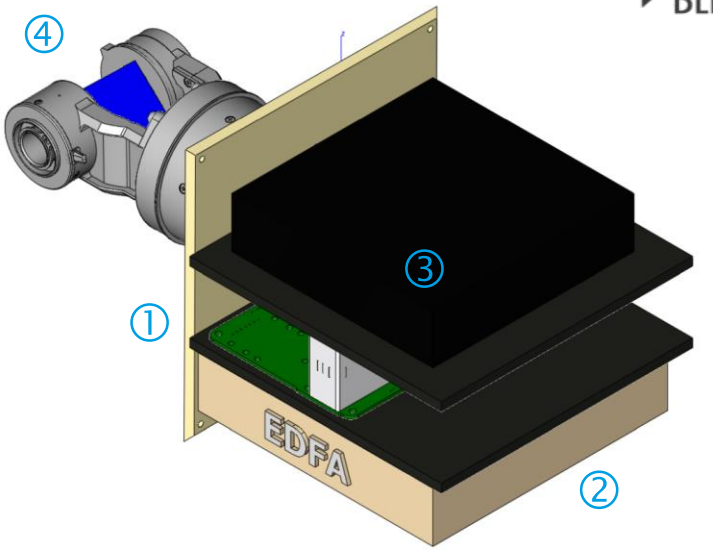
- DTE Data Rate: 1 Gbps at max. distance of 1800 km
- Status of CubeISL:
  - EM successfully tested
  - Manufacturing of EQM: Q3/2022
  - EQM Qualification: Q4/2022



CubeISL Engineering Model

CubeISL CONCEPT WITH CPA
Further Extension

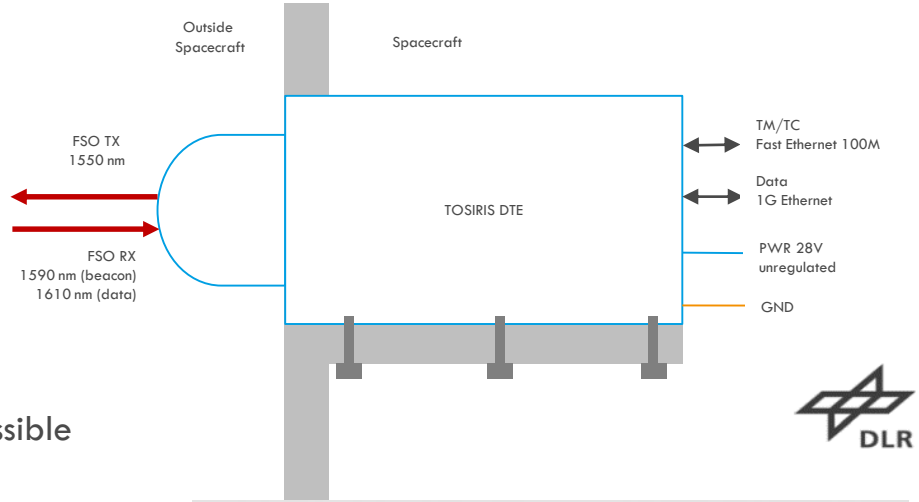
CPA removes need for S/C Body pointing!



- **Design elements:**
  - Core Module based on existing CubeLCT ①
  - Laser diode and optical amplifier (EDFA) ②
  - APD reveiver module ③
  - Full hemispheric Coarse Point Assembly (CPA) ④
- Independent beam steering capability (if 2 or more LCT's per S/C are needed)
- Total Mass: ~2 kg
- Total power consumption: ~35 W (peak)

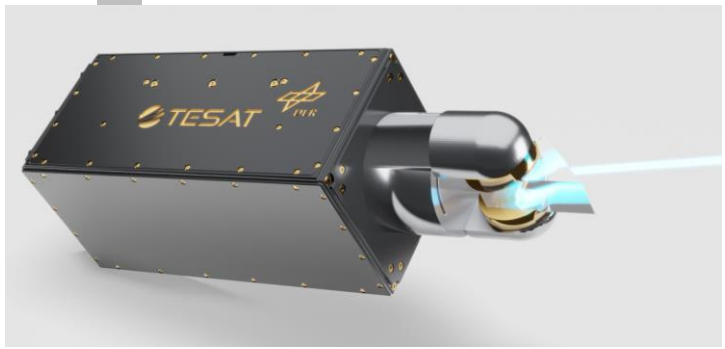
TOSIRIS DTE 30
Key parameters

- Mass: 9 kg
- Dimensions (CPA + Terminal): 150 x 180 x 555 mm³
  (CPA: 165 mm length, 125 mm diameter)
- Power: ~ 90 W (typically), ~ 130 W (peak)
- Data Interface:
  - Current Baseline 1 Gbit/s Ethernet
  - Options: SpaceFibre => Hi-Side
- TM/TC Interface:
  - Currently 100 Mbit/s Ethernet
  - Options: CAN Bus preferred, others (e.g. serial BSD) possible



- Switchable channel data rates 1,25; 2,5; 5; 10 Gbps
- User data rate up to 7Gbps in downlink
- Optical uplink for ARQ (or tasking with up to 1,5 Mbps)

- Mass Memory for data buffering
  - allows using full DL datarate even with limited onboard data rate
- Reference implementation of CCSDS O3K standard
- Support of DTN approach and CFDP planned



Thank You

Tesat-Spacecom GmbH & Co. KG
Gerberstraße 49
71522 Backnang
www.tesat.de