# OSIRIS Optical Communication Demonstration on CubeSat

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With the increasing need for higher data rates on small LEO spacecraft, highly compact laser communication systems are required to overcome the limitations in the downlink channel. The group of Optical Communication Systems (OCS) at the Institute of Communications and Navigation of the German Aerospace Center (DLR) is working on the program OSIRIS (Optical Space Infrared Downlink System). DLR is closely cooperating with Tesat Spacecom for the industrial application of the OSIRIS technology.

CubeSat missions have been seen as technology demonstration missions in the past, but made its way to both scientific as well as commercial missions especially in the framework of Earth Observation and Remote Sensing. Increasing capabilities of small scale sensor systems raised the need for higher data rates in the Direct To Earth (DTE) channel also for CubeSat missions. In the cooperation between DLR and Tesat, the first demonstrator has been developed that will be launched in 2018 to demonstrate the performance of the technology. Therefore, OSIRIS heritage from previous missions has been optimized for the application on a CubeSat. Especially size, weight and power have been taken into account, but also the compatibility to different CubeSat bus interfaces, and influences from a mass manufacturing point of view. The optimization leads to a payload weight of 350 grams and a volume of 0,3 CubeSat units. With an electrical power consumption of 8 W, the optical communication payload enables downlink data rates of up to 100 Mbps.

This paper will give an overview over the OSIRIS payload and the design constraints, the foreseen mission scenario as well as an investigation on the data throughput together with the commercial application “CubeL” envisaged after the demonstration mission.

## 1 INTRODUCTION

Increasing sensor resolutions drive the need for higher data rate capabilities in the downlink channel for nanosatellites in the LEO orbit. Nanosatellites come with a total weight of 1-10 kg and play an increasing role in the overall small satellite market, which consists of satellites with a total weight of 1-50 kg. Figure 1 shows the launched nano- and microsatellites in the time between 2008 and 2017. It can be seen that the number of launched satellites increased in 2013 and after a plateau the number raised again in 2017 to a new record of more than 300. The major driver of this number is the class of Nanosatellites with 1-10 kg. This trend is estimated to continue over the next five years to a total number of launched satellites of 2600. This gives a clear indication about the market of those satellites, with both commercial interest as well as scientific missions and projects.

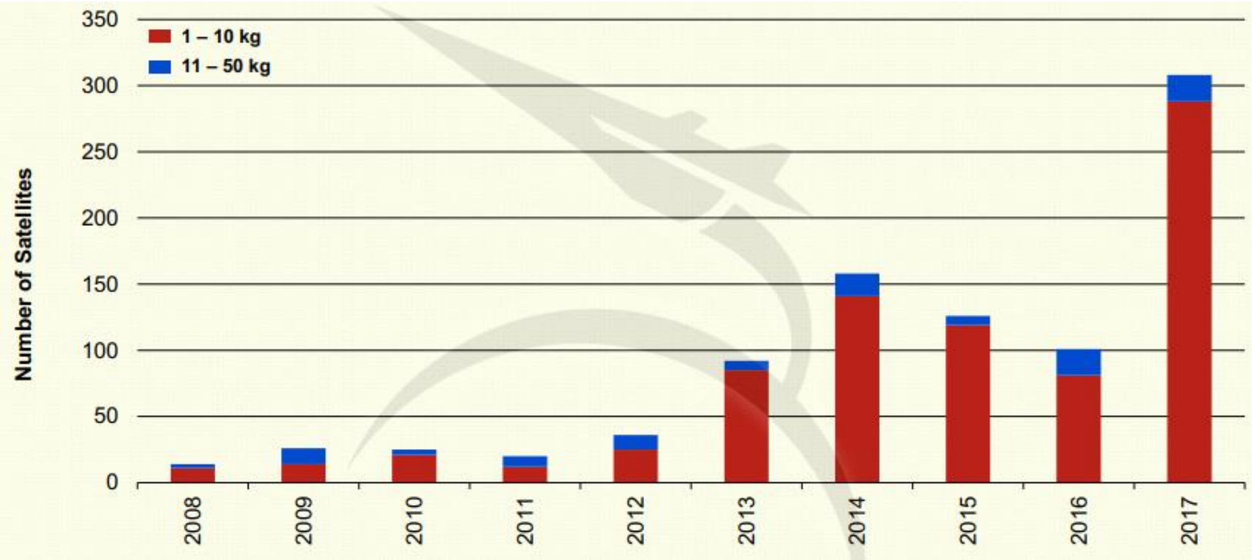


**Figure 1: Launched Nano- and Microsatellites 2008 – 2017 [1]**

Figure 2 shows the applications and trends of Nano- and Microsatellite missions in the past and as estimation for the next coming years. It can be seen, that more than 50% of the Nano- and Microsatellite missions in the years 2013 – 2017 are in the framework of Earth Observation and Remote Sensing (EO/RS). Scientific missions also play an important role with 26% while the number of technology demonstration missions has been decreased to 12%. In the first years of Nano- and Microsatellite missions, especially the technology demonstration missions were a major driver. With the stronger focus on EO/RS, the Nano- and Microsatellite missions found their way towards mission concepts and increasing sensor resolutions drive the need for higher capacity downlink channels to ground.

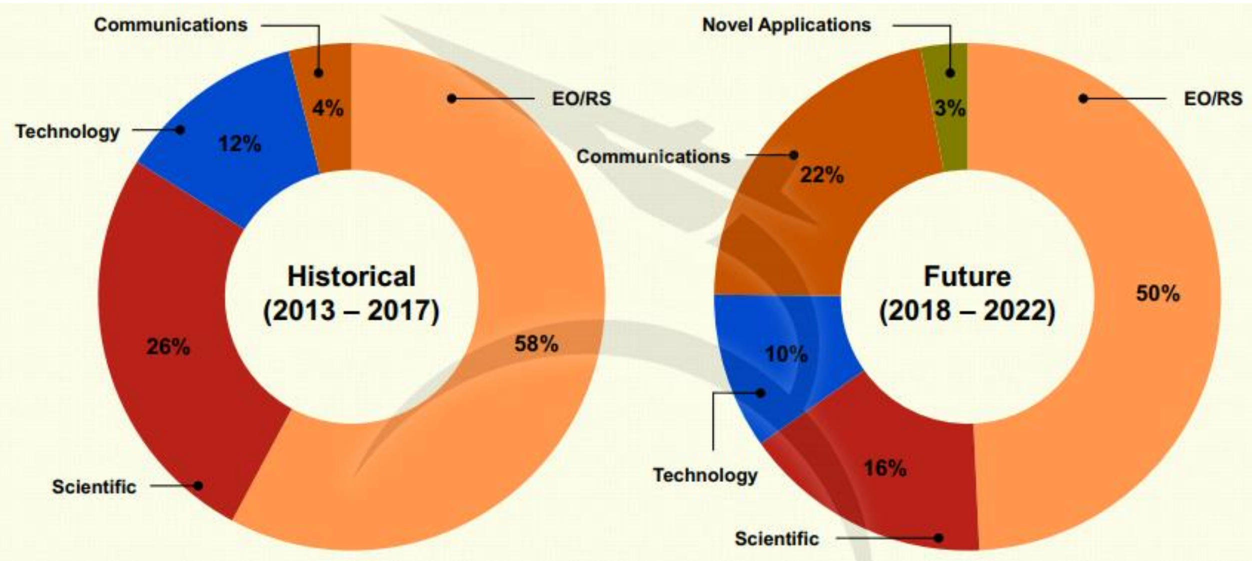


**Figure 2: Nano- and Microsatellite trends by application [1]**

For the next 5 years (2018 – 2022), the communications sector is the biggest change of applications. With the increasing need to accommodate payloads for missions, the spacecraft mass also changes over time. Figure 3 shows the development of launch mass of Nano- and Microsatellites. While 2011 – 2013, the 1-3 kg class was dominating, the spacecraft mass raised to 4-6 kg in 70% of the launches in 2017. For the next years, this trend seems to continue towards larger spacecraft masses in the 7-10 kg range.

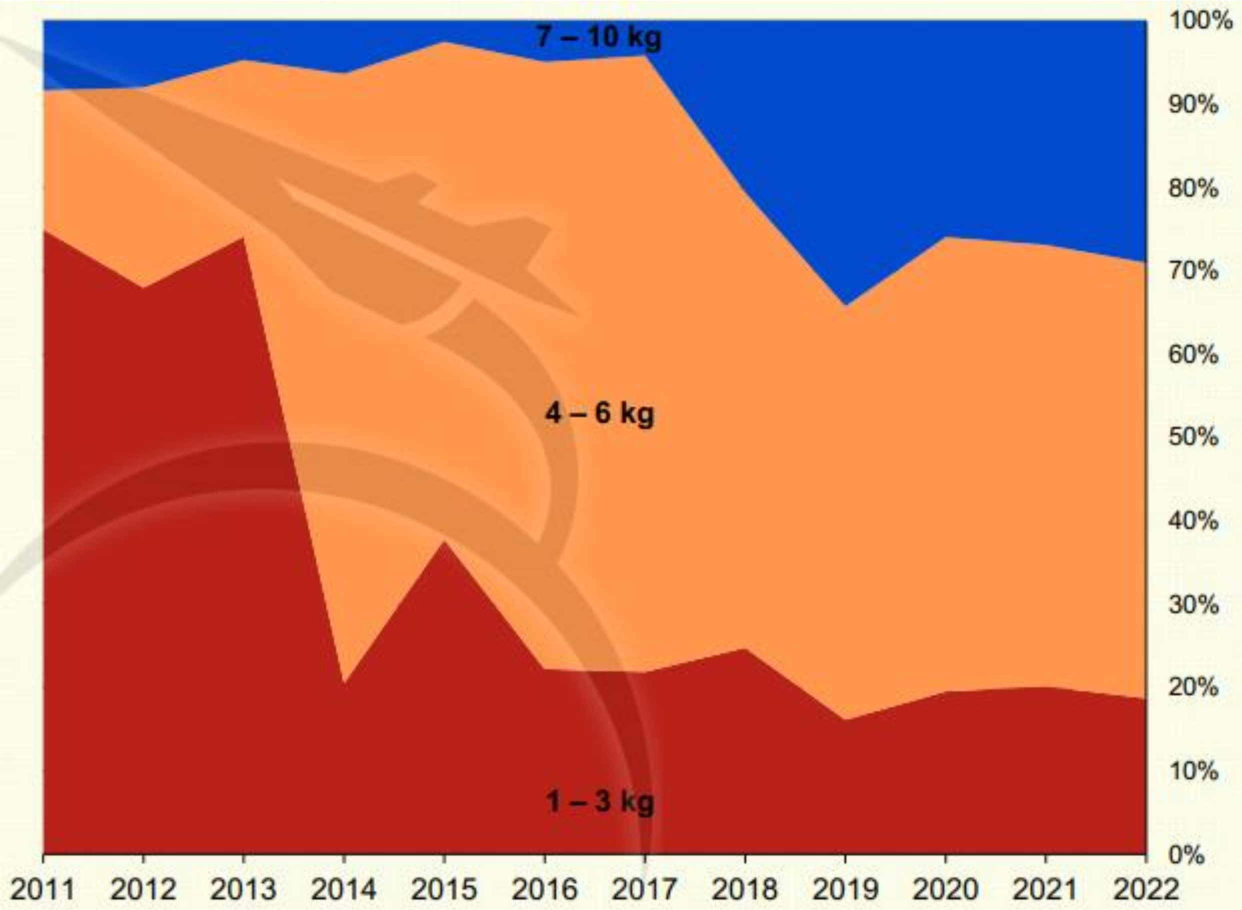


**Figure 3: Development of spacecraft mass over the years [1]**

Nano- and Microsatellites are highly standardized to be compatible for easy and quick access to space and to reduce development cost. For CubeSats, 10 x 10 x 10 $cm^3$ are the relevant building blocks, called Unit (U). Applied on Figure 3, 3-6U CubeSats dominated the launches in 2017 while the trend is leading also to larger spacecraft of up to 12U.

## 2 OPTICAL SPACE INFRARED DOWNLINK SYSTEM: OSIRIS

The Institute of Communications and Navigation (IKN) of the German Aerospace Center (DLR) is working on the development of highly compact optical communication payloads for small LEO satellites. What started as a project for a prototype development developed towards a space program in the meantime – Optical Space Infrared Downlink System (OSIRIS). OSIRIS started as a development of prototypes for scientific measurements in the field of Free-space Optical Communication (FSO) on the Earth Observation satellites Flying Laptop of the University of Stuttgart and BiROS of DLR.

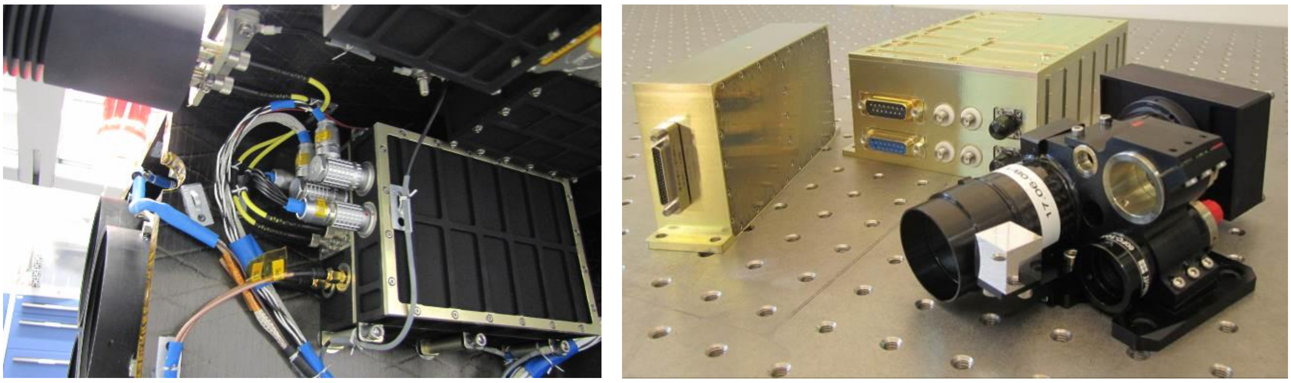

**Figure 4: OSIRIS flight hardware for Flying Laptop (left) and OSIRIS for BiROS (right)**

FSO payloads use modulated laser light for the transmission of data. For OSIRIS, wavelengths in the range of 1550 nm are used for the communication. Optical communication allows for very high modulation frequencies and high data rates. In the OSIRIS scenario, DTE missions are the reference scenario that leads also to challenges in the availability of ground stations due to atmospheric effects like clouds as well as the stable pointing of the laser beam towards the ground station. To perform an optical downlink from a LEO spacecraft, the satellite is illuminated with a beacon laser from ground. The OSIRIS payload starts to scan for the beacon, acquires the signal and goes to closed-loop tracking mode for a permanent tracking of the ground station and a parallel data transmission.
Figure 4 shows the flight hardware for the two missions on Flying Laptop and BiROS, while Table 1 lists the physical parameters of the payloads.

| | **Flying Laptop** | **BiROS** |
|---|---|---|
| OSIRIS weight: | 1,3 kg | 1,65 kg |
| OSIRIS power consumption: | 26 W | 37 W |
| OSIRIS data rate: | Up to 200 Mbit/s | Up to 1 Gbit/s |
| OSIRIS downlink wavelength: | 1550 nm | 1550 nm |
| OSIRIS beacon wavelength: | N/A | 1560 nm |
| OSIRIS pointing: | Satellite Body Pointing | Satellite Body Pointing |
| Launch Date: | July 14$^{th}$, 2017 | June 22$^{nd}$, 2016 |

**Table 1: Payload parameters of OSIRIS**

Based on the flight model development for Flying Laptop and BiROS, the OSIRIS technology has been analyzed for further miniaturization. For the next development step and demonstration, a CubeSat platform has been selected due to advantages presented in the introduction. Besides the huge potential of the CubeSat market, the major drivers for the adaptation to a CubeSat are:

- Quick access to space for technology demonstration
- Short development cycles from idea to experiment
- Scientific measurements and experiments
- Demonstration of miniaturized OSIRIS hardware
- Industrial application of OSIRIS technology

## 3 PAYLOAD DESIGN

CubeSat platforms come with strict requirements regarding Size, Weight and Power (SWaP) of the payloads. Those requirements are the limiting factor during the payload development and with this fact also the major design driver. OSIRIS4CubeSat has been developed based on the following design goals:

- Maximum volume: < 0,5U
- Maximum weight: < 500 grams
- Maximum power consumption: < 10W
- Downlink data rate: 100 Mbit/s
- Compatible to CubeSat standard dimensions
- Compatible to standard CubeSat system performance
- Optimization towards an industrial application and lean production

The selected design goals are adapted to the targeted CubeSat platform and mission. The mission will be flown together with DLR's cooperation partner Tesat, taking care of the optimization towards an industrial application and lean production with the name "CubeL". As discussed in the introduction, one main application of high data rate downlinks are EO/RS missions. OSIRIS4CubeSat is designed to be integrated in a 1U CubeSat, but most EO/RS missions use 3U or even 6U platforms to be able to fit high resolution camera payloads into the satellite. The demonstration mission CubeL of the OSIRIS technology will also use a 3U platform accordingly.

Currently, there is no standard for CubeSats besides the size of the spacecraft which would cover all CubeSats of all manufacturers. For OSIRIS4CubeSat, we performed a market research and compared different concepts and performance parameters to use as reference implementation for OSIRIS. The compatibility to a reference implementation requires a pointing concept to point the communication laser beam towards the ground station. OSIRIS4CubeSat will use a combination of the satellite's attitude control system with a dedicated fine pointing unit within OSIRIS. This combination allows reducing the complexity of the satellites attitude control system to a range of +/-1° while the OSIRIS payload compensated the remaining error with the integrated fine pointing unit. This approach is based on a Pointing, Acquisition and Tracking (PAT) algorithm which performs a scan for the ground station beacon laser, acquires the beam within the +/-1° cone of the satellite's attitude control and tracks the ground station during the entire overflight. OSIRIS4CubeSat is designed to acquire a beacon from the ground station from 10° elevation on.

To fulfil the strict limitations regarding payload volume, a highly compact combination of electronics and optomechanics has been developed at DLR. This allows for a high integration density in the payload and reduced the payload volume as well as the weight. For high power efficiency, OSIRIS4CubeSat uses a directly modulated laser diode with a data rate of 100 Mbit/s, which is adapted to the communication bus speed in the reference implementation.

Besides the optical downlink with a wavelength of 1550 nm, OSIRIS4CubeSat uses a beacon laser from the ground station for the closed-loop optical tracking of the ground station. The payload uses a beacon with a wavelength of 1590 nm which is modulated for background light suppression and can be used as optical uplink channel.

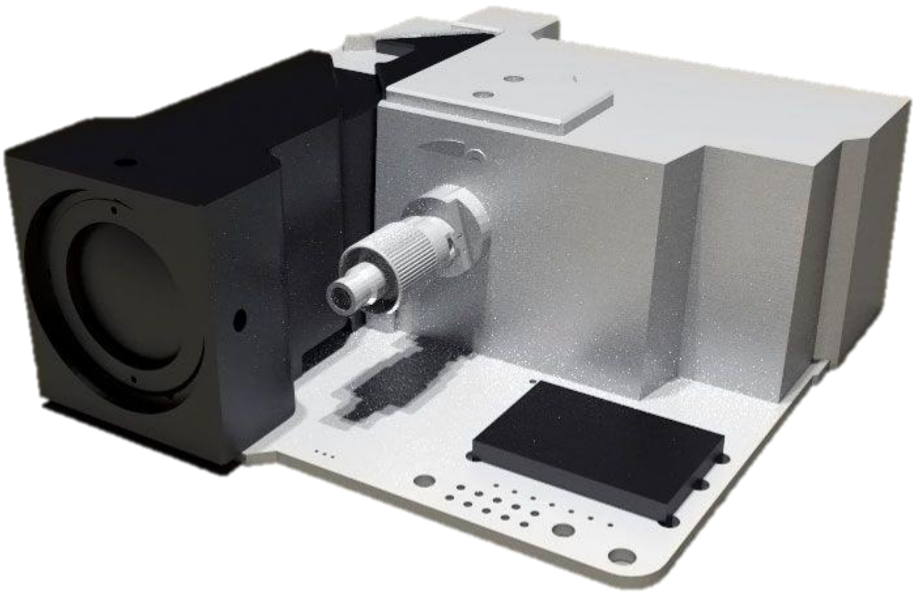

**Figure 5: OSIRIS4CubeSat/CubeL System Design after CDR [source: Tesat]**

Figure 5 shows the OSIRIS4CubeSat system design including optomechanics, electrical and optical components as well as all interfaces. The system design has passed the Critical Design Review (CDR) and is currently under integration in the laboratory. After a successful qualification, the payload will be prepared for the demonstration mission CubeL and the lean production. The final system design comes with the technical parameters presented in Table 2.

| | |
|---|---|
| OSIRIS size: | 90 x 95 x 35 $mm^3$ |
| OSIRIS weight: | 350 grams |
| OSIRIS volume: | 0,3U |
| OSIRIS power consumption: | 8 W |
| OSIRIS optical downlink data rate: | 100 Mbit/s |
| OSIRIS downlink wavelength: | 1550 nm |
| OSIRIS beacon wavelength: | 1590 nm |

**Table 2: OSIRIS4CubeSat technical parameters**

With the technical parameters in Table 2, the OSIRIS4CubeSat payload development fulfills the goals presented at the beginning of chapter 3. With those parameters, OSIRIS4CubeSat shall have to highest achievable compatibility to different CubeSat platforms and implementations to allow integrating the OSIRIS technology in many missions for data transmission as well as for scientific experiments.

## 4 DEMONSTRATION MISSION: CUBEL

The OSIRIS4CubeSat technology will demonstrate its performance in a dedicated CubeSat mission – the Mission CubeL. Therefore, the flight proven GomSpace platform has been selected due to the success in the first ESA CubeSat mission. For the performance demonstration, the CubeSat is equipped with:

- UHF and S-Band communication links for TM/TC
- Attitude control system with star camera and reaction wheels
- GPS receiver for precise orbit information
- Earth observation camera for mission data to be transmitted
- OSIRIS4CubeSat payload for the demonstration as well as for scientific measurements

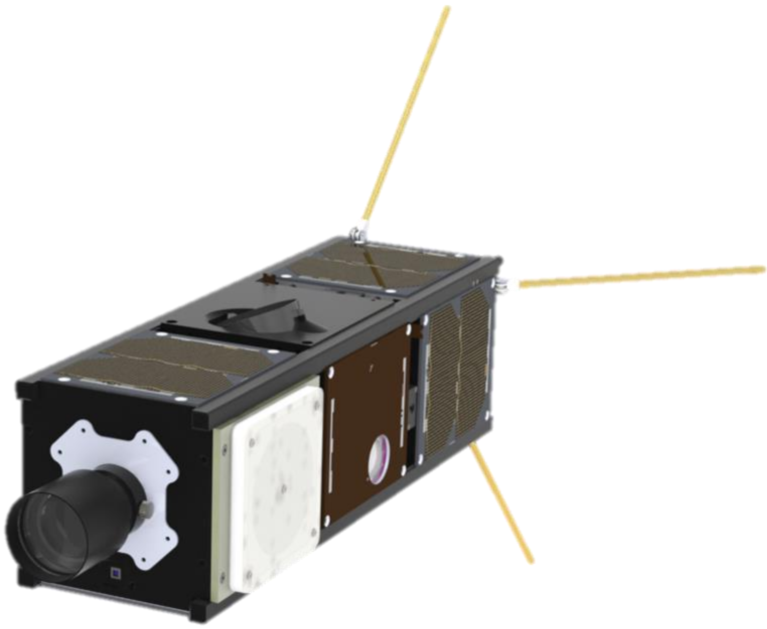

**Figure 6: 3U GomSpace CubeSat platform for the demonstration mission [source: GomSpace]**

Figure 6 shows the configuration of the 3U CubeSat platform including all subsystems. The launch of the demonstration mission is scheduled for the end of 2018.

In the demonstration, the generated data on-board the CubeSat in the LEO will be transmitted via the optical link direct to earth. The receiver on the ground will be an Optical Ground Station (OGS). DLR-IKN uses two ground stations. The Optical Ground Station Oberpfaffenhofen (OGS-OP) is mainly used for scientific channel measurements while the Transportable Optical Ground Station (TOGS) focusses on the pure mission data reception.

## 5 INDUSTRIALIZATION

With the development of OSIRISv1 and OSIRISv2, DLR’s Optical Communication Systems group gained experience in the design and qualification of optical communication payloads for small LEO satellites. Especially in the domain of COTS components, which are an essential part of CubeSat missions, DLR developed new concepts for the application in the space environment. With the reuse of qualified components from the former developments, a high qualification standard can be achieved which minimizes the risk on a CubeSat mission drastically.

Tesat, as the industrial partner of the OSIRIS technology, is able to provide deep knowledge and experience due to their experience with 10 years of successful optical communication in orbit. Furthermore, Tesat accompanies the industrialization of the terminal technology thanks to the heritage in high volume production. Therefore design to cost and design for manufacturing approaches have been implemented at a very early stage of the development process. Also AIT requirements have been incorporated into the system design to assure an optimized design for manufacturing, testability and cost. This industrialization concept for the OSIRIS technology foresees certain milestones to enable a lean production, as shown in Figure 7.


**Figure 7: Foreseen milestones towards a lean production [source: Tesat]**

## 6 SUMMARY & OUTLOOK

The paper showed the development of the OSIRIS4CubeSat Laser communication Terminal as well as the way towards the demonstration mission and industrial application as CubeL as a method to help overcoming the bottleneck in downlink capacity for Nano- and Microsatellite missions in LEO orbit. Therefore, OSIRIS is designed to fit most of the mission's needs as well as most of the available CubeSat platforms. With a combination of body pointing and fine pointing unit, the OSIRIS payload adds about 350 grams of weight and a power consumption of 8 W to the satellite and provides data rates up to 100 Mbit/s.

The future path of the OSIRIS4CubeSat development is split into a number of phases: after demonstrating the technology and performing scientific channel measurements, the path is leading towards an industrial application CubeL with IKN's cooperation partner Tesat Spacecom. Furthermore, the OSIRIS4CubeSat development is used as a basis for scientific projects and demonstrations, especially towards optical inter-satellite links (OISL) for CubeSat IOT and swarm constellations as well as Quantum Key Distribution (QKD) experiments and applications.

DLR is leading the standardization of the Optical On-Off-Keying (O3K) efforts within CCSDS. This is happening in close collaboration with NASA, CNES, JAXA, NICT and ESA. The OSIRIS technology is one of the inputs of the standardization work and will be compliant to the upcoming standard.

## 7 REFERENCES

[1] SpaceWorks Enterprises Inc., "2018 Nano/Microsatellite Market Forecast, 8th Edition", http://www.spaceworkscommercial.com/download-forecast/Nano-Microsatellite-Market-Forecast-8th-Edition_2018.pdf, checked May 5th, 2018.