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# State of The Art of Earth Observation Instruments for Small Satellites

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## Abstract

Free access to Earth Observations in various electromagnetic bands, the growing number of available spectral bands in imaging instruments, and the ever-better quality of corresponding products all contribute to the growing number of available applications, especially ones found in the civilian sector. On one hand, the progress made recently in the field of small satellites allows for a significant reduction in cost in both satellite design and launch, which creates numerous new opportunities for the use of small satellites in the Earth Observation field this is thus far dominated by much larger satellites. In this article, we will present an overview of the instruments that are currently used on cubesat, microsatellites and other small satellites. After conducting extensive studies, we present an analysis of the discussed instruments from the point of view of a potential microsatellite mission. This analysis is conducted based on the HyperSat microsatellite platform which is being developed by Creotech Instruments S.A. The HyperSat platform is developed in an open software and open hardware manner, which is also addressed further in this article.

**Keywords:** HyperSat, Remote Sensing, Software Defined Radio, Microsatellite, Open Hardware, Open Software

### Acronyms/Abbreviations

Software Defined Radio (SDR), Earth Observation (EO), SVPX (SpaceVPX).

## 1. Introduction

Technological advancements in the field of small satellites allow for significant cost reductions throughout the entire lifetime of the satellite, i.e. design, launch, operation, and decommission, [1-3]. These advancements allow for anyone to create these satellites, even non-experts by using readily available components. This all started with the creation of the well-known cubesat satellite design, and continues to be moving towards the creation of bigger satellites known as microsatellites. One big advantage is the considerably shorter time-to-market, however this comes at a price of shorter lifetime (which for LEO microsatellites is a span of only a few years). It is envisioned that the overall satellite cost will be low enough in the near future that it will allow for the creation of a backup satellite that will be ready in case of failure to the original. Therefore, there is growing demand for smaller instruments that could perform as well as their larger counterparts. The design cost of a satellite (e.g. microsatellite) could be further reduced by introducing a multipurpose satellite bus. This could be used to configure different missions. Last but not least, a problem that frequently occurs in the design of small satellites is the radio link throughput. Designers are faced with the need of multi-dimensional optimization, which quite often the radio link technology selection is not straightforward enough and is accompanied with some sort of penalties. They have to cope with high power consumption demands, non-upgradeable designs and significantly large masses and volumes. Software Defined Radio is becoming a feasible solution for these current limitations, especially throughput and flexibility.

This paper is divided into four sections. Section 2 will survey the most representative remote sensing instruments used on small satellites. The preliminary analysis will be at the end of this section. Section 3 will portray an example of a current microsatellite platform, i.e. HyperSat which is developed by Creotech Instruments S.A. Several modules as potential payloads are being developed within the project budget. We present three of them as the most representative examples, i.e. UV-VIS camera, SDR transceiver and High-Performance Computing Module. Finally, any conclusions will be found in section 4.

## 2. Remote sensing platforms and instruments

The most representative examples of payloads carried by cubesat, micro- and minisatellites have all been investigated, [4-10]. Some of them present significantly high TLR levels, while others are just pathfinders for desired missions. Nevertheless, many of the investigated instruments are possible candidates for a mission that is to be carried out by a microsatellite, e.g. Hypersat microsatellite platform described in this article. In addition to this, the most representative examples of microsatellite platforms that can carry EO payloads were also investigated. Such an approach was selected to summarize the payload requirements from a payload-ready platform point of view.

### *2.1 EO instruments*

In Appendix A the most important parameters of the analyzed instruments have been presented. The first ten instruments are carried by cubesat type satellites, while the next six instruments are carried by satellites which have a mass that's up to 60 kg. The instruments found in the last part of the table are instruments carried by micro- and small minisatellites which have a mass that's over 60 kg.

Microsatellites feature a mass between 10 and 100 kg. Therefore, we have decided to set a reasonable mass limit of 50-60 kg, which will be the maximum mass of our HyperSat microsatellite platform.

It was also noticed that the instruments carried by bigger satellites with a mass over 60 kg could be carried by microsatellites. Therefore these instruments, due to their potential applicability to the HyperSat microsatellite platform, have also been investigated.

### *2.2 EO platforms*

The most representative examples of microsatellite platforms that can carry EO payloads have also been investigated, and the results can be found in Appendix B and C. Due to the fact that satellite platforms with a mass larger than 60 kg had similar payloads to lighter microsatellites, their payloads have also been included into the calculated averages. The microsatellite found in the last column, which has a mass over 100 kg, has been investigated for reference only, i.e. to reveal the differences between 60 kg and much heavier platforms. There is also a cubesat type platform included, as it has similar characteristics to the other microsatellite platforms.

### *2.3. Payload analysis*

The ranges of the most important parameters of the analysed instruments are summarised in Tables 1-3. There are three values derived from the investigated parameters which are named "minimum value", "maximum value", and "average value" respectively. In some cases the maximum value of a parameter differs from other values significantly. Therefore, the "Outstanding value" is introduced. If some parameters were not possible to obtain, the author has assumed the most practical case.

All of the given parameters, wherever possible, correspond to an instrument as a whole, i.e. an instrument with all the accompanied hardware is essential to its operation. That is, the whole instrument, up to some extent, can be used regardless of whether or not a satellite bus is used. Other assumptions used for instruments analysis are as follows:

- Instrument mass corresponds to its mass as a whole. The size of an instrument and resulting volume corresponds to the total space and volume required to put an instrument in. That is, if an instrument has an irregular shape, the closest approximation (in cubesat units) is assumed.
- Required energy per day (Wh) is calculated based on an assumptions that the satellite will work only: during passes (for Earth observation applications), during a defined amount of time, or specified by mission.
- Downlink throughput is calculated based on an assumptions, that the collected observation data latency shall be less than 24h (from satellite scene acquisition to download) even with non-optimal communication scenario.
- Required uplink throughput is specified by mission.
- Required data storage is based on an assumption that at least a whole day's worth of observations can be stored, or more if specified by mission.
- Required AOCS assumption is specified by mission.

Due to the significant mass and power consumption differences between cubesat type instruments and small satellite instruments, two analyses has been performed: analysis for the cubesat type instruments only and analysis for instruments of all types of investigated satellites. Such an approach was motivated by the fact that some missions could were limited to small instruments only, i.e. a cube of 300 x 300 x 100mm that corresponds to one unit of our HyperSat platform.

For the "Overall satellite payload analysis", Tables 2-3, the required energy per day was computed based on the assumption that an instrument will work continuously. This was motivated by the fact that bigger satellites do not have limited energy sources as compared to the cubesat type satellites and there might be missions where continuous imaging is a client need.

Table 1. Cubesat type payload satellite analysis

| Parameter name | Min value | Max value | Avg. value | Outstanding value |
|---|---|---|---|---|
| Mass [kg] | 0.19 kg | 11 kg | 2.47 kg | na |
| Size [CubeSat U] | 0.175 U | 16.9 U | 3.55 U | na |
| Volume [$dm^3$] | 0.175 $dm^3$ | 16.9 $dm^3$ | 3.55 $dm^3$ | na |
| Instrument power consumption [W] | 2.5 W | 25 W | 9.47 W | na |
| Required energy per day [Wh] | 0.43 Wh | 30 Wh | 9.87 Wh | 250 Wh |
| Uplink throughput [kbit/s] | 0.34 kbit/s | 57 kbit/s | 16.69 kbit/s | na |
| Downlink throughput [kbit/s] | 5 kbit/s | 10,000 kbit/s | 1726.4 kbit/s | 41,280 kbit/s |
| Storage [GB] | 0.032 GB | 12.38 GB | 2.81 GB | 200 GB |
| AOCS pointing accuracy [°] | 10° | 0.0027° (10'') | 2.01° | na |

Table 2. Overall satellite payload analysis, cubesat to micro- and small minisatellites

| Parameter name | Min value | Max value | Average value | Outstanding value |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Mass [kg] | 0.19 kg | 45 kg | 15.08 kg | na |
| Size [CubeSat U] | 0.175 U | 100 U | 29.87 U | na |
| Volume [dm$^3$] | 0.175 dm$^3$ | 100 dm$^3$ | 29.87 dm$^3$ | na |
| Instrument power consumption [W] | 1 W | 50 W | 21.23 W | 10,000 W |
| Required energy per day [Wh] | 24 Wh | 960 Wh | 457.34 Wh | 1,200 Wh |
| Uplink throughput [kbit/s] | 0.34 kbit/s | 57 kbit/s | 11.49 kbit/s | na |
| Downlink throughput [kbit/s] | 5 kbit/s | 41,280 kbit/s | 6,506.66 kbit/s | 160,000 kbit/s |
| Storage [GB] | 0.032 GB | 12.38 GB | 2.23 GB | 256 GB |
| AOCS pointing accuracy [°] | 20° | 0.00056° (2’’) | 2.14° | na |

Table 3. Overall satellite payload analysis, cubesat to micro- and small minisatellites, computed without outstanding values

| Parameter name | Min value | Max value | Average value |
|---|---|---|---|
| Mass [kg] | 0.19 kg | 45 kg | 15.08 kg |
| Size [CubeSat U] | 0.175 U | 100 U | 29.87 U |
| Volume [dm$^3$] | 0.175 dm$^3$ | 100 dm$^3$ | 29.87 dm$^3$ |
| Instrument power consumption [W] | 1 W | 50 W | 21.23 W |
| Required energy per day [Wh] | 24 Wh | 1200 Wh | 516.74 Wh |
| Uplink throughput [kbit/s] | 0.34 kbit/s | 57 kbit/s | 11.49 kbit/s |
| Downlink throughput [kbit/s] | 5 kbit/s | 160,000 kbit/s | 34,405.33 kbit/s |
| Storage [GB] | 0.032 GB | 256 GB | 94.91 GB |
| AOCS pointing accuracy [°] | 20° | 0.00056° (2’’) | 2.14° |

The authors have also performed quantity analysis of payload mass and power consumptions. Similar trends can be noticed for mass and power consumption changes, i.e. with payload mass increase/decrease there is associated payload power consumption increase/decrease.

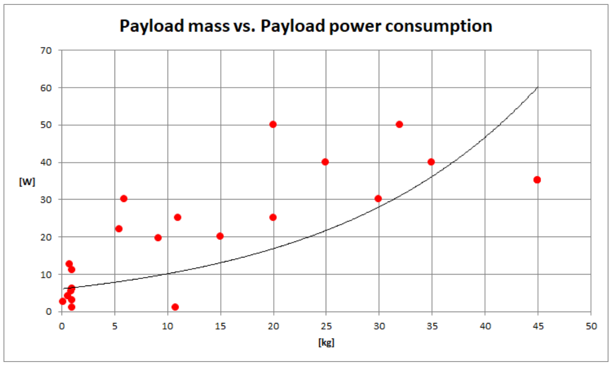

Fig. 1. Trends of Payload mass and Payload power consumption

### 2.4. Concluding remarks

In Table 4 some of the important parameters from the competitiveness point of view of the investigated instruments and satellite platforms are presented.

Table 4. Comparison of selected averages of investigated instruments and microsatellite platform

| | Satellite platform average values | Payload average values (ranging from cubesat to microsatellites, computed without outstanding values) |
|---|---|---|
| Payload volume | 26.30 U | 29.87 U |
| Payload mass | 14.67 kg | 15.08 kg |
| Power for payload | 24.14 W | 21.23 W |
| Downlink (band, data rate) | 80.34 Mbit/s | 34.40 Mbit/s |
| Design life | 4.5 years | na |

The averages of the investigated potential instruments as well as the characteristics of available microsatellite platforms show a convergence of parameters that determine the overall design of a satellite platform. It must also be noticed, that the computed average values of the investigated instruments were not limited to one mission type. That is, the investigated instruments were ranging from different means of Earth Observations to scientific applications. Therefore, the boundary conditions of an exemplar microsatellite platform such as HyperSat should be presented around computed averages, so that the HyperSat platform could be employed to various missions and be competitive with similar platforms. That is, such a multipurpose platform may help in reducing costs associated with launching such a particular mission.

## 3. Hypersat microsatellite platform

### 3.1. Hypersat platform design

Hypersat [11] is an innovative, open-source modular platform based on the new SpaceVPX (VITA-78) modular standard derived from military OpenVPX specifications [12]. The platform is highly modular and enables the construction of microsatellites with a mass between 10-80 kg. The platform is based entirely on COTS components that are space-proven or at least possess credible radiation data.

All avionics equipment as well as payload electronics are enclosed in 3U or 6U modules connected by the backplane. This architecture provides both low-power maintenance and housekeeping as well as high throughput needed by some payloads. Several companies are developing their own SVPX solutions, mostly based on radiation hardened components [13,14].

Although SVPX standard is designed for big satellites it can be optimized for smaller constructions. The Hypersat platform offers several extensions to the SpaceVPX standard:

- The cubesat adapter enables seamless integration of popular existing PC-104-like modules. Cubesat modules are so far the only standardised components that are available on the market. There are multiple vendors that offer to some extent compatible modules: On-Board Computer (OBC), battery, AOCS, star trackers, RF communication, thrusters, etc. Their performance is often sufficient enough for bigger platforms than cubesats.
- The CPCI Serial Space [15] adapter enables the integration of future hardware. The standard was recently ratified but is thus far almost completely unknown.
- In order to improve versatility, a hybrid 3U and 6U chassis is used. The basic unitary building-block for platform holds 4 x 3U + 4x 6U SVPX modules.
- The power supply is defined originally by the standard as separate 3 to 5 SpaceUM modules. Those modules contains power switches, fuses and management. In HyperSat platform, power

supply is highly integrated and occupies a single 6 U module in order to save space. The power supply is fully redundant and utilises multi-channel MPPT converters. Each solar array has a dedicated power entry and path which improves reliability.

- The SVPX Switch which integrates data link from all modules and SVPX controller which suprevizes whole chassis are integrated with satellite OBC. Additional, standalone OBCs are also foreseen.
- The SVPX backplane offers dual-star SpaceWire connectivity plus dual, redundant CAN bus to negate compatibility issues with the CPCI Serial Space and cubesat modules which are connected to dedicated adapters using a harness.
- All SVPX modules are 0.8” wide and are equipped with a front panel that is cost efficient yet space-proven. The Harwin M80 interconnect and harness system enables high density interconnectivity which is especially required by the SpaceUM and Switch&Controller modules.

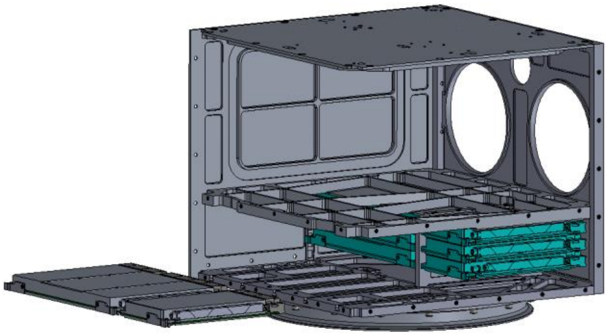

Fig. 2. 3HU HyperSat chassis with 3U and 6U SVPX modules shown

Several SVPX modules are being developed within the project budget, e.g. OBC, Power Supply, AOCS, EO instrument, and RF communication module.

HyperSat platform will have a common base plate of 300x300mm and variable height from 100mm (1 HyperUnit - 1HU) up to 600mm (6HU). Example configuration for 3HU is shown in Fig. 2 and Fig. 4. On the bottom there is a SVPX chassis with 3U and 6U electronics modules, Fig. 3. If needed, two SVPX chassis can be mounted, enabling installation of 16 modules. All big avionics elements such as reaction wheels, battery modules etc. are located in equipment shelf. Payload is mounted in area above chassis. Two optical imaging telescopes are shown as an example payload.

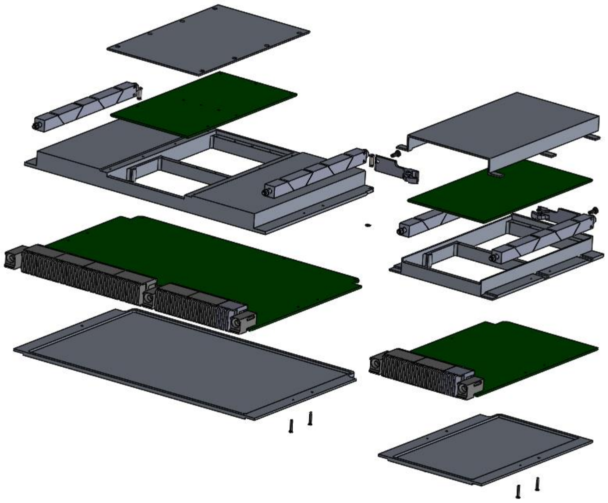

Fig. 3. Mechanical design of 3U and 6U VPX modules

*3.2. Microsatellite payloads*

In this section we will present the most representative payloads that are being developed within the HyperSat project budget. The most important technical requirements are based on our extensive payloads analysis, i.e. mass, power consumption, downlink throughput, computing demands.

*3.2.1. Astronomical multispectral camera*

Multispectral astronomical observations are very difficult to conduct by earth telescopes due to atmospheric absorption, especially in ultraviolet (UV) spectrum. Many stellar objects have UV spectrum stronger than visible. Therefore building a multispectral telescope will allow to fill an important instrumental niche. UV-VIS instrument will consist two dedicated cameras, for UV and VIS bands. The camera will be equipped with dedicated on-board computer which will perform all necessary operations for a proper images acquisition. Acquired images will be processed on-board and transmitted to a user. Taking into account results of our instruments analysis, limited resources of microsatellite platforms, and UV-VIS mission requirements, we have envisaged that such an instruments will feature 11kg of mass, 25W of power consumption, 200GB of storage, and will need at least 250Wh per day. Such preliminary assumptions are consistent with microsatellite averages (Table 3). Satellite concept for this mission is shown in Fig. 4.

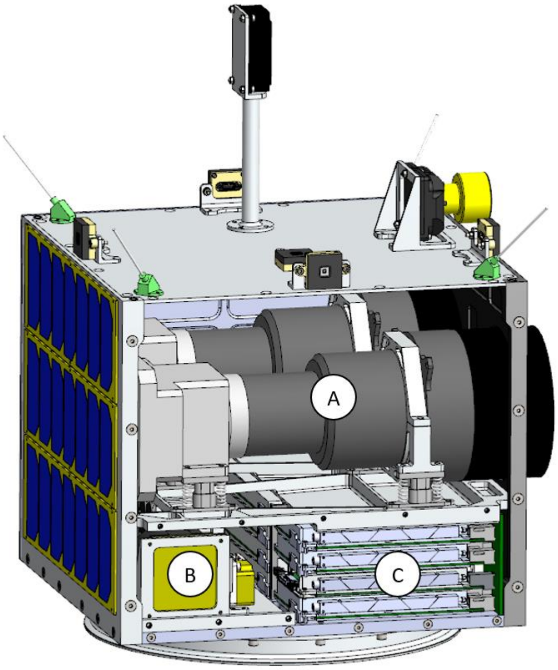

Fig. 4. Artistic vision of the HyperSat platform with multispectral payload. A - payload bay, B - equipment shelf, C - SVPX chassis

### *3.2.2. SDR radio communication module*

Radio communication module will consist of two separate transceivers: S-Band (basic) and X-Band (supporting). S-Band transceiver will provide handling telemetry (TM) and telecommand (TC) services in any time, position in orbit and satellite position relative to earth, while high speed X-Band transceiver will be activated in case of a need for greater bitrate downlink transmission. By default, the device will fully support CCSDS standards on the Network and Data Link layers. SDR technology employed by both transceivers will provide a wide range of remotely reconfigurable parameters. Also full gateware exchange possibility is foreseen. The radio architecture will be redundant and will have the ability to read and download basic platform diagnostic registers even when the AOCS, switch, OBC and power supply are damaged.

Except the communication module, design of a signal analyser based on an SDR transceiver is considered. Such module, installed as a payload, would be used for an analysis of Earth-sourced noise spectral density in LEO in RF and microwave bands, collecting data from sensors and few more.

### *3.2.3. High-performance computing modules*

Downlink bandwidth is often the biggest constraint on microsatellite operation. It is desirable to process the data onboard and transmit only compressed results. For that reason a high-performance computing modules utilising recent Nvidia and Xilinx SoC technologies are developed for the HyperSat platform.

Nvidia offers high performance Jetson GPU modules, which are very well suited for image processing. In order to utilise those modules, a high speed interface for SVPX will be added as well as a supervisory and protection circuits. Radiation tolerance will be achieved by the design (i.e. repeating calculations and running memory checks).

Xilinx SoC technology offers high performance Coretex-A microprocessors with FPGA fabric. Those are very well suited as a general purpose payload OBC with hardware co-processing capabilities. SoC FPGAs can also be used as a Space Fiber switch when an additional high speed interconnection in SVPX chassis is needed.

## 4. Conclusions

In this article, we presented a cross-cutting analysis of scientific instruments that are good candidates for microsatellite missions, and developed set of requirements that a multipurpose microsatellite platform should fulfil.

Than the Hypersat microsatellite platform, currently being built by Creotech Instruments S.A was introduced, as an example of a universal and configurable base for various types of missions. Its design can be easily adapted to a specific mission without making major changes.

Several microsatellite payload modules following the HyperSat open software and open hardware design approach are being developed. The ones described in the last paragraph are examples of payloads for various microsatellite missions and shows that such a platform universality is feasible.

## Appendix A (Small satellite instruments), [6]

| Instrument or satellite | Mass, Volume | Instrument power consumption | Energy/day | Uplink bit/s | Downlink bit/s | Storage MB | AOCS accuracy, knowledge |
|---|---|---|---|---|---|---|---|
| UV-VIS Photometer | 11 kg, 330 x 320 x 160 mm | 25 W | 250 Wh | UHF: 9 kbit/s<br>S-band: 57 kbit/s | X-band 10 Mbit/s | 200 GB | Pointing accuracy 0,0028° |
| Solar Photometer | 1kg, 1dm^3 | 6 W | 30 Wh | 0.34 kbit/s | 333.34 kbit/s | 100 MB | Pointing accuracy 10° |
| VIS Telescope | <1 kg, Φ100 x 800 mm | 6 W | 0.43 Wh | - | 41.28 Mbit/s | 12.38 GB | - |
| ICEYE SAR | 70 kg, 700 x 600 x 450 mm (SAR antenna panels stowed)<br>700 x 600 x 3250 mm (SAR antenna panels deployed) | Up to 10 kW (in 30 s) | 690 Wh | - | - | - | Pointing accuracy 0.1° |
| MiRaTA microwave radiometer | 0.907 kg, 100 x 100 x 180 mm | 5.5 W | 5.5 Wh | UHF: 5 kbit/s | UHF: 5 kbit/s | - | Pointing accuracy 0.5° |
| MicroMAS-1 microwave radiometer | <1 kg, 100 x 100 x 100 mm | <3 W | 3.3 Wh | UHF: 19.2 kbit/s | UHF: 16 kbit/s | - | Pointing accuracy 0.5°<br>attitude determination accuracy 0.1° |
| RaInCube profiling radar | 5.5 kg with antenna, 3 U | Transmit-mode 22 W | 22 Wh | - | 720.84 kbit/s | 1.5 GB | - |
| MinXSS Miniature X-ray Solar Spectrometer | 0.19 kg, 1 U (instrument size 70 x 100 x 25 mm) | 2.5 W | 2.5 Wh | UHF: 9.6 kbit/s | UHF: 9.6 kbit/s | - | Pointing accuracy 2° (3σ) and 0.05° (3σ) knowledge |
| Aalto-1 Spectral Imager | 0.6 kg, 97 x 97 x 48 mm | 4 W | 4 Wh | - | 1 Mbit/s | 32 MB | Pointing accuracy < 1º<br>Pointing knowledge < 1º<br>Attitude knowledge 0.0083º |
| IceCube submillimeter wave radiometer | <1 kg, 1.3 U | 11.2 W | 11.2 Wh | - | - | 32 MB | Pointing knowledge < 25 km |
| VesselSat AIS receiver | - | - | - | UHF: 9.2 kbit/s | UHF: 9.2 kbit/s | - | - |
| Chibis-M Microsatellite ULF/VLF receiver | 10.8 kg | 1.025 W | 11.2 Wh | UHF: 9.6 kbit/s | S-band: 1.2 Mbit/s | 0.5 GB | Pointing accuracy ±0.1-0.2° |
| BX-1 VIS imager | - | - | - | S-band: 2 kbit/s | S-band: 768 kbit/s | - | Pointing accuracy 2° |
| UNIFORM-1 imager | 0.8 kg, 1.23 U (instrument size 100 x 100 x 123 mm) | 12.6 W | 302.4 Wh | S-band: 4 kbit/s | X-band: 10 Mbit/s | - | - |
| JC2Sat-FF Infrared Radiometer | 1 kg, 2.205 U (100 x 105 x 105 mm single instrument) | 1 W | 24 Wh | UHF 9.6 kbit/s | S-band: 38.4 kbit/s | - | - |
| SSTL-X50 imager | 45 kg, 91.16 U (530 x 430 x 400 mm instrument/satellite volume) | 35 W | 840 Wh | 160 Mbit/s | 160 Mbit/s | - | Control 0.07° |
| MIOSat Interferometer, imager | 20 kg, 40 U (400 x 200 x 500 mm) | 25 W | 600 Wh | S-band: 4kbit/s | X-band 20Mbit/s | 1.25 GB | Pointing, knowledg 0.1°, 0.02° |
| Yubileiny-2/ MiR imager | 35 kg | 40 W | 960 Wh | - | S-band: 1 Mbit/s | - | Roll: ±3°, Pitch: ±3°, Yaw: ±20° |
| M3MSat AIS receiver | 25 kg, 83.09 U (535 x 545 x 285 mm payload bay) | 40 W | 960 Wh | S-band: 4kbit/s | C-band 20 Mbit/s | 2 GB | Pointing accuracy 5° |
| IMS-1 VIS, NIR imager | 30 kg | 30 W | 720 Wh | S-band: 4 kbit/s | S-band: 8 Mbit/s | - | Pointing accuracy ±0.1º |
| BIRD Infrared camera | 16.45 kg | 125 W | 3000 Wh | S-band: 19.2 kbit/s | S-band 2.2 Mbit/s | - | Pointing accuracy ±0.083°, pointing knowledge ±0.0034° |
| KR1 VNIR, SWIR, NIR imager | 5.96 kg, 7.58 U (131 x 221 x 262 mm) | 30 W | 720 Wh | - | 100 Mbit/s | 248 GB | |
| STSat-2 microwave radiometer | 15 kg, 17.82 U (330 x 270 x 200 mm) | 20 W | 480 Wh | - | - | - | Pointing accuracy < 0.10°, knowledge < 0.066° |
| POLDER-P radiometer, polarimeter | 32 kg, 100 U (800 x 500 x 250 mm) | 50 W | 1200 Wh | S-band 20 kbit/s | X-band: 16.8 Mbit/s | - | Pointing accuracy 0.1°, knowledge 0.02° |
| DST (Dobson Space Telescope) | 20 kg, 400 x 400 x 250 mm folded (40 U) 400 x 400 x 1000 mm unfolded (160 U) | 50 W | 1200 Wh | - | 150 Mbit/s | - | Pointing accuracy ± 0,00056 (knowledge) |

## Appendix B (Microsatellite platforms, up to 65kg ), [7], [8], [9]

| Satellite platform | LEOS-30 | S-50 | LEOS-50 | Triton-X Earth Observation |
|---|---|---|---|---|
| Platform category | Microsatellie | CubeSat | Microsatellie | Microsatellie |
| Platform volume[*4] | 300 x 300 x 500 mm | 340 x 340 x 660 mm | 500 x 500 x 300 mm | 400 x 500 x 600 mm |
| Payload volume | - | 320 x 320 x 280 mm3 | - | - |
| Platform mass | 30 kg (inc. payload) | 50 kg (inc. payload) | 60 kg (inc. payload) | 65 kg |
| Payload mass | 8 kg | 20 kg | 15 kg | 15 kg |
| Power for payload | Avg. 15 W | Avg. 15 W | Avg. 20 W | 30 W |
| Available power for platform | Peak 60 W | Peak 28 W | Peak 140 W | - |
| Battery capacity | - | - | - | - |
| Pointing accuracy (control) | - | - | - | - |
| Pointing knowledge | - | - | - | - |
| Downlink (band, data rate) | 2 Mbit/s (S-band) | 20 Mbit/s (S-band) | 100 Mbit/s (X-band) | S/C/X/Ka downlink via two ground stations |
| Design life | 2 years | 3 years | 5 years | - |
| Manufacturer | Berlin Space Technologies GmbH | SITAEL | Berlin Space Technologies GmbH | LuxSpace |
| Space heritage | - | Yes | Yes (KR1 (Kent Ridge 1) Microsatellite) | - |
| Price | - | - | - | - |

## Appendix C (Microsatellite platforms, 75 to 98kg ), [9], [10]

| Satellite platform | Triton-2[*1] | SSTL-X50[*5] | NASA Rapid III SSTL-100[*2] | NASA Rapid III SSTL-150[*3] |
|---|---|---|---|---|
| Platform category | Microsatellie | Microsatellie | Microsatellie | Microsatellie |
| Platform volume[*4] | 500 x 500 x 650 mm | 530 x 430 x 400 mm | - | - |
| Payload volume | - | - | 321 x 303 x 246 mm3 | Ext. Payload: 730 x 455 x 774 mm3<br>Int. Payload: 279.5 x 231.5 x 252.5 mm3 |
| Platform mass | 75 kg | 75 kg | 98 kg (inc. payload) | 153 kg |
| Payload mass | 15 kg | 45 kg | 15 kg | 50 kg |
| Power for payload | Avg. 30 W | Avg. 35W (Peak 85 W) | Avg. 24 W (Peak 48 W) | 50 W (Peak 100 W) |
| Available power for platform | 250 W | - | - | - |
| Battery capacity | - | - | Li-ion 15 Ah | Li-ion 15 Ah |
| Pointing accuracy (control) | - | 252 arcsec | 2880 arcsec | 36 arcsec |
| Pointing knowledge | - | 10 arcsec | 2520 arcsec | 25 arcsec |
| Downlink (band, data rate) | 120 Mbit/s | 160 Mbit/s (X-band) | 80 Mbit/s (X-band) | 80 Mbit/s (X-band) |
| Design life | 5 years | 7 years | 5 years | 7 years |
| Manufacturer | LuxSpace | Surrey Satellite Technology | Surrey Satellite Technology | Surrey Satellite Technology |
| Space heritage | - | No (Future mission, Q1 2018, KazSTSAT) | Yes (ADS-1b, UK-DMC-2, Deimos-1, UK-DMC-1, AISat-1, Bilsat-1, Nigeriasat-1) | Yes (RapidEye, DMC+4, TopSat) |
| Price | - | - | $11 M | $18.315 M |

## Appendix D (Average values of microsatellite platforms in Appendix B and C )

| Satellite platform | Average values |
|---|---|
| Platform volume[*4] | 95.76 U |
| Payload volume | 26.30 U |
| Platform mass | 68 kg |
| Payload mass | 14.67 kg |
| Power for payload | 22.34 W |
| Available power for platform | 119.5 W |
| Downlink (band, data rate) | 64.4 Mbit/s |
| Design life | 4 years |

*1 – Satellite platform over 60kg; included in averages due to reasonable payload mass

*2 – Satellite platform over 60kg; included in averages due to reasonable payload mass

*3 – not considered in average values

*4 – average platform value in CubeSat U units

*5 – Only Power for payload, Downlink, and Design life considered

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