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A NANOSATELLITE MISSION CONCEPT FOR OPTICAL SETI

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Abstract

In view of recent discoveries of the significantly increasing number of extrasolar planets in possibly habitable zones and knowledge about extreme circumstances under which life could exist, it appears to be more and more likely that signs of life outside Earth could be detected soon. If and when his happens, the next logical question will be if intelligent lifeforms may exist and moreover if they are trying to communicate with other civilizations. Under these circumstances, the search for extraterrestrial intelligences (SETI) seems to be natural more than ever, although the search of more than 50 years in radio wavelengths has not delivered a positive sign yet.

One of the possible ways to study potential signals coming from intelligent extraterrestrial lifeforms can be to analyze the optical spectrum, which is usually called OSETI (Optical Search for Extraterrestrial Intelligence). OSETI is also already conducted by several institutions using ground-based facilities on Earth by using an array of photomultiplier tubes. But such observations are limited due to the atmosphere. Therefore, a possible way to overcome the disadvantage of the atmospheric influence could be the use of a dedicated satellite for OSETI in an Earth orbit. Since such a satellite mission would be obviously very expensive, it is worth to be investigated if there is the possibility to reduce the cost of such a mission by utilizing a nanosatellite concept. In recent years, nanosatellites of the order of 1 to 20 kg have reached a high state of maturity and are becoming a more and more useful tool for several applications, ranging from communications to scientific experiments and observations.

The basic idea of this study is to answer the question if a dedicated nanosatellite could be used for OSETI. The study is conducted by the Interdisciplinary Research Center for Extraterrestrial Studies (IFEX) of the University of Würzburg.

Keywords: SETI, OSETI, telescope, extraterrestrial, nanosatellite, autonomy

1. Introduction

According to NASA's exoplanet exploration, the number of confirmed exoplanets was over 3500 in August 2017. More than 4500 were considered as candidates. Some of them are believed to be in a habitable zone, where live could exist. New observatories will for sure expand these numbers in the near future to much higher levels than today. Thus, the chances to find life beyond the solar system is increasing day by day. Assuming that life is not unique on Earth, it is not too difficult to also assume that intelligent life could also exist beyond our solar system. Taking this as a hypothesis, it seems to be logical, to search for intelligent life in the universe. The discovery of intelligent life in the universe would probably be the most dramatic event in mankind's history. The consequences for all aspects of our life would be huge.

So, the basic idea is to search for intelligent life outside of Earth. The difficult question to answer is, how should we do that? As we have in fact no idea how extraterrestrial intelligent lifeforms could be detected, any method could be considered. We humans are mostly dependent on our visual sensor, our eyes. They are optimized to see in the so called visual spectrum from about 400 to 750 nm wavelength. As most of the stars are also emitting light at these wavelengths, it can be assumed, that at least some other potentially existing intelligent lifeforms may also be sensitive to this part of the spectrum. With this assumption, we could than consider that other intelligent lifeforms may also be willing to communicate using visible light. It seems therefore not the worst idea to look not only at the radio wavelengths, as classical SETI does for many decades now, but also in the visible spectrum of light. And as we are more limited in the observation due to the atmosphere of Earth, especially closer to the UV-region, it makes sense to establish an observatory outside of Earth's atmosphere.

This is the starting point of the study, which is presented here. The aim is to study a nanosatellite mission equipped with an optical instrument dedicated to optical SETI, the search for extraterrestrial intelligences in the optical spectrum. As of today, there is no such satellite in orbit. One of the main questions, which is aimed to be answered by the study is, whether it is feasible to design an OSETI satellite in the frame of a so-called nanosatellite. A nanosatellite is a very small satellite in the range of 2-20kg mass and around 30x30x30cm³ size. The reason for the selection of such a small satellite is obviously the low-cost aspect. But the question is, if such a small nanosatellite could be meaningful for the purposes of OSETI? Classical OSETI systems on Earth normally use larger telescopes and sensor systems, which would not fit into such a small satellite. The following chapters describe the findings of the study and present the result, trying to answer this question.

2. Optical SETI

Beside the search for extraterrestrial signals in the microwave spectrum, Schwartz and Townes (1961) suggested the investigation of the optical spectrum which didn't attracted attention in the beginning, probably due to the small level of performance of lasers at this time. But with the upcoming development of more powerful laser technologies, some being able to transmit up to 10^{16}W per impulse [4], the search in the optical band becomes more popular.

Caused by the noise and background light influence, high-peak-power, short-pulse and low duty cycle laser transmissions show a more effective communication path rather than continuous transmission of signals. Taking 1ns as an exemplary pulse width and 1,000 pulses being sent per second, a duty cycle with $1/10^6$ results showing the advantageous usage of the 1,000,000 times higher peak power compared to the average power, e.g. applying the continuous wave method. Therefore, all assumptions in the following are based on pulsed laser beacons rather than continuous signals. The calculations are also based on reference [6].

2.1 Telescope Gain

One reason for the effort of searching for extraterrestrial signals in the optical wavelength is the magnification of optical telescopes compared to radio telescopes. The gain of a telescope can be approximated by

$$G = 20 \cdot \log_{10}\left(\frac{\pi \cdot D}{\lambda}\right) \; [dBi] \qquad (1)$$

where D is the diameter of the telescope and λ the wavelength of the signal. Equation (1) clearly formulates the reason of achieving higher gain for optical signals of short wavelengths compared to radio waves of higher λ. Using for example the radio observatory Arecibo with a 304m dish and observing the 21cm hydrogen line, the observatory obtains "only" 73.2dBi. Another example is the human eye of a radius of 2mm leading to a gain of 87.2dBi at 550nm, being almost 14 dBi larger than Arecibo.

2.2 Peak Power

The sender has to transmit its signal with a defined maximum power for each pulse which can be defined as

$$P_{Peak} = \frac{P_{av}}{\tau \cdot f_{PRF}} \; [W] \qquad (2)$$

with the pulse repetition frequency f_{PRF} and pulse width τ. As an average power P_{av}, one can assume 1GW which is possible by employing today's state of the art technologies. Using 1ns as a pulse width and 1Hz of pulse repetition frequency, one can achieve a peak power of 10^{18}W.

2.3 Equivalent Isotropic Radiated Power

With the peak power and telescope gain of a hypothetical transmitter, the Equivalent Isotropic Radiated Power (EIRP) P_{EIRP} can be calculated as

$$P_{EIRP} = P_{Peak} \cdot G \; [dBW] \qquad (3)$$

which can be calculated to 355.1dBW using the peak power from above and an optical telescope of 10m of diameter transmitting a signal of λ = 550nm. Compared to sun-link stars, their P_{EIRP} is approximately 265.9dBW which illustrates the superb application of lasers for interstellar communication purposes.

2.4 Power Density and received Power

The received power density I decreases with increasing distance R between the sender and receiver such that

$$I = \frac{P_{EIRP}}{4 \cdot \cot(\pi) \cdot R^2} \left[\frac{W}{m^2}\right]. \qquad (4)$$

In the case of a satellite mission, no atmospheric influence can be assumed such that the received power S at the optical telescope can be calculated as

$$S = \eta_{eff} \cdot F_{eff} \cdot \left(\frac{\pi \cdot d^2}{4}\right) \cdot I \; [W] \qquad (5)$$

with the antenna aperture efficiency η_{eff}, influence of optical filters $F_{eff}$and the diameter of d the receiving telescope itself.

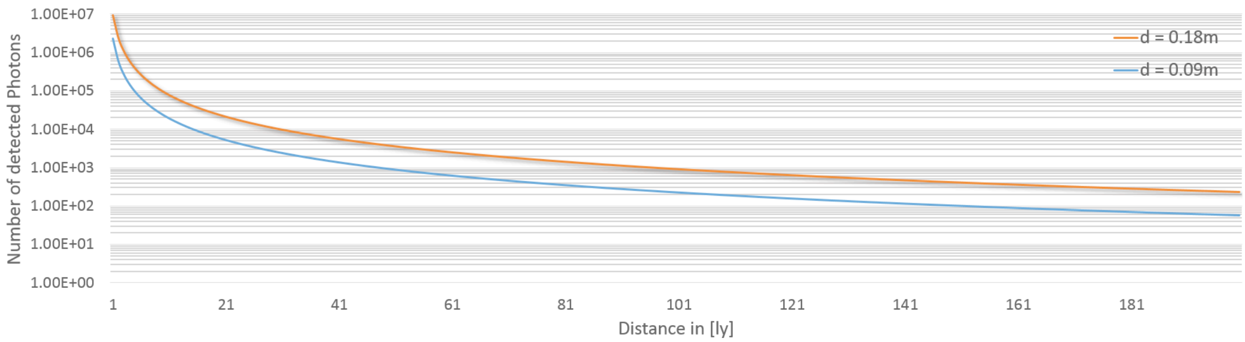

Figure 1. The number of detected photons as a function of the distance for different antenna diameters

2.5 Number of detected Photons

Finally, the theoretical number of photons N detectable by the sensor is

$$N = \frac{\eta \cdot S}{h \cdot f} \; [-] \, . \tag{6}$$

Here, f is the frequency of the signal, η is the quantum efficiency of the sensor and h is the Planck's constant.

2.6 Hypothetical Transmission Path

Of course, nobody can determine the exact properties of an alien signal. Therefore, the following parameters are often assumed for optical SETI calculations:

- Average transmitter power of 1GW
- Pulse duration of 1ns
- Pulse repetition frequency 1Hz
- Aperture opening of the sending antenna is 10m
- Wavelength of the laser signal is 550nm
- Telescope efficiency is 0.5
- Efficiency of optical filters is 0.5

The comparison of the number of detected photons is illustrated in figure 1 for a receiving telescope of 18 and 9cm diameter. As an example, the 18cm telescope still receives 230 photons while the 9cm only receives theoretically 57 photons at a distance of 200ly which sets the larger one as the telescope design constraint.

3. Objectives

For the purposes of this study a short mission statement has been formulated, which will be the starting point for the definition of objectives and requirements. The mission statement is as follows: "Development and operation of a nanosatellite for optical SETI".

The mission objectives derived from the mission statement can be summarized as follows:

1. Autonomously search for short pulsed laser signals in the optical spectrum.
2. Investigation of optical pulsed astrophysical effects.
3. Involvement of students in extraterrestrial science.
4. Test and application of developed satellite bus components.

Regarding the mission objective, all current and past searches for investigating the optical spectrum for short pulsed laser signals are based on Earth observations, either locally or spatially distributed over several ground stations.

Due to the geographical, atmospherically, and temporal limitations of such observations, the investigation of particular areas in outer space are highly limited but can be avoided by the use of a dedicated nanosatellite mission suitable of investigating 24 hours per day defined regions against short pulsed optical signals.

Beside the lack of atmospheric influence, several other human-made sources can be eliminated, too, by the use of a satellite mission and using advanced hard- and software of Earth 2017 technology, the satellite will track and observe specific regions on its own and sends an alarm to the operator on ground only in the case of a positive signal.

The search for short laser pulses seems to be promising due to the expectation, that this type of communication could be used by others because of the long ranges, which can be achieved.

As for the second mission objective, not only the search for extraterrestrial intelligence might be the reason for investigating the optical spectrum but also astrophysical effects which are not very well known or observed yet.

Due to the application of a self-learning intelligence, such effects can be recognized by the payload and in a first instance, will be sent to the operator that tells the satellite about the nature of the effect and if the effect shall further be investigated or not. Such sources of signals can for example be pulsating stars like Cepheid variables and others.

The Interdisciplinary Research Center for Extraterrestrial Studies (IFEX) highly cooperates with the Professorship of Space Technology at the University of Wuerzburg. The research is based on the development of technical systems for space applications and contributes to this field by several lectures. Therefore, students can be involved in the mission in terms of internships and thesis possibilities.

In the last years, satellite components and payloads such as parts of the attitude determination and control subsystem like miniature reaction wheels and high precision star sensors for nanosatellites were developed. Furthermore, a dedicated nanosatellite mission - called SONATE (FKZ 50RM1606) - is in the development phase that will test several autonomous systems e.g. for detecting faults in a satellite (ADIA++, FKZ 50RM1524) or detecting events like meteors in the atmosphere (ASAP, FKZ 50 RM 1208). Therefore, the new satellite mission can draw on a large treasure of experience. Parts which have been successfully used for SONATE could be used again with their space heritage and new components could be tested, if necessary, which is the background for the mission objective number four.

4. Payload

The optical payload, in this report abbreviated by O/P is the core element for detecting possible alien signals in the optical spectrum. The System is divided in an optical collector, the detection module, and the data evaluation hardware fitting in a nanosatellite

4.1 Optical Collector

The task of this component is to collect incoming light from an external source which can be differentiated as optical refractors, reflectors, and combinations of both (catadioptric systems), each with its individual drawbacks and advantages.

Especially chromatic aberation is a huge drawback of normal refractor telescopes since shortwave light suffers from a higher refraction compared to long-wave light. Several suberrors for chromatic aberation are for example the Gauß-Error and the longitudinal aberation due to different focal lengths for blue and red light.

Therefore, a reflector design is the most appropriate collector choice for the optical SETI mission due to its manufacturing process and its robustness concerning chromatic aberration.

Hence, figure 2 illustrates the proposed optical collector which is designed as a Schmidt-Casegrain telescope. The telescope has a diameter of 18cm, focal length of approximately 21.5cm, consists of a spherical primary mirror and a hyperbolic secondary mirror mounted on a Schmidt correction plate. At the exit aperture, an ocular becomes necessary for magnification of the signal and parallelization of the beam. At the output, the detector unit shall be mounted. The theoretical characteristics are summarized in table 1.

Table 1. Proposed reflector design characteristics

Characterization	Design
Type	Schmidt-Cassegrain
Aperture Opening	180 mm
Primary Mirror	180 mm
Secondary Mirror	60 mm
Tube Length	3100 mm (incl. detector)
Tube Weight	4-6 kg
Focal Length Objective	430 mm
F-number	2.4
Focel Length Ocular	Plössl, 4 mm
Magnification	107
FOV Ocular	Plössl, 52°
FOV Telescope	0°28’’
Marginal Brightness	14.2 mag
Resolution at 550 nm	0.74’’

An own design of the collector becomes necessary since commercial telescopes have often a long tube length not fitting in a nanosatellite. The calculated FOV of the designed collector is approximately 0.5° which becomes an important input for the mission scenario.

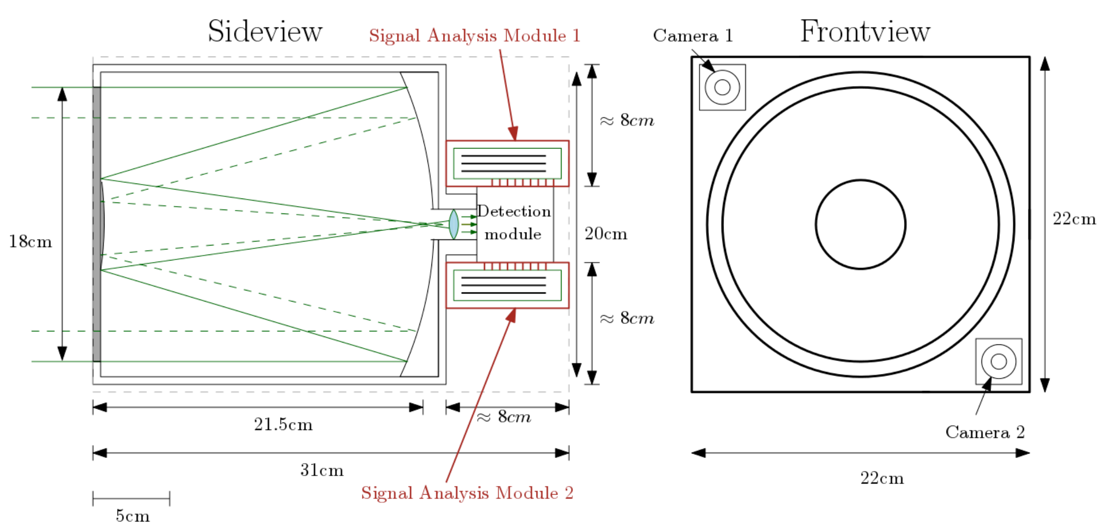

Figure 2. Proposed optical payload

4.2. Photon Detector

Detecting light signals at the photon-counting level requires precise and very sensitive devices with a high gain. On the other side, the detector also need to work in an efficient way concerning power consumption.

According to the manufacturer Hamamatsu K.K., it is advisable to use Photon Multiplier Tubes only in the absence of magnetic sources, namely transformers and magnets, to avoid extra shielding of the devices [1].

To increase the Field of View, Monte Ross [2] and the Harvard all-sky system propose the use of multi-pixel sensors such that each pixel "sees" a different Field of View (FOV). Furthermore, Avalanche Photodiodes can show a higher quantum efficiency compared to PMTs in the near Infrared (IR) where crystal lasers are working most efficiently [2].

Therefore, a relatively new photon detection component is proposed for the counting of incoming photons for the optical payload; Multi-Pixel Photon Counters (MPPC). For the O/P, three parallel channels of MPPCs will be used where signals are fed to the subsequent amplification, threshold detection circuits and analysis hardware that only triggers an event if all 3 channels are recognizing a specific pulse pattern at the same time and if the subsequent detection algorithm is triggering, too. This triple redundancy will reduce the generation of false alarms by internal or external noise events in each channel. Although most PMTs are more sensitive to the visible region, they require higher voltage, power, and space such that they are harder to integrate within a nanosatellite. The optical detection circuit can be integrated in an own housing consisting of the three MPPCs, two optical beamsplitters, an entrance slit for the incoming light and communication and power supply lines to the Signal Analysis Modules.

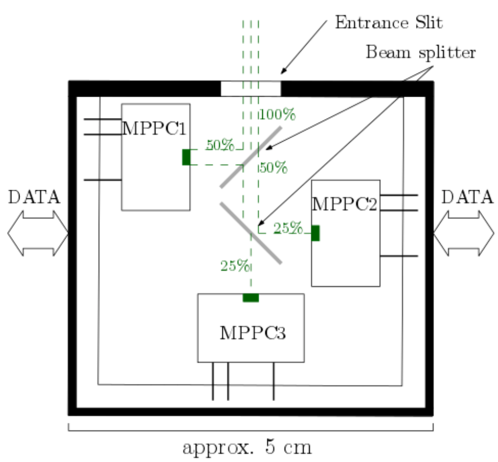

Figure 3. Proposed compact detection module

A suitable MPPC will be the S13362-3050DG with a high Photon Detection Efficiency and the following additional characteristic parameters of table 2.

Table 2. MPPC characteristics

Parameter	Value	Unit
Eff. Photosen. Area	3.0 x 3.0	mm
Pixel Pitch	50	µm
#Pixel/channel	3600	-
Fill Factor	74	%
Cooling	TE-Cooling	-
Operating Temp.	-20 to +60	°C
Element Temp.	-25 below ambient Temperature	°C
Spectral Response	320 to 900	nm
Peak Sensitivity	450	nm
PDE	40	%
Gain	$1.7x10^6$	-

Each MPPC has a diameter of approximately $15.3mm^2$ and a height (without connectors) of 10.1mm. Therefore, the box containing the optical detectors consumes an area of about $5x5x5cm^3$ to be as compact as possible as can be seen in figure 3.

4.3. Data Evaluation

This chapter deals with the regions of interest to be investigated autonomously by the optical SETI nanosatellite, the hardware of the optical signal analysis module and the expected housekeeping data.

4.3.1 Regions of Interest

The last few decades, a lot of astronomical observations have been made considering possible habitable exoplanets. With the increasing capabilities of modern technology, more and more confirmed and unconfirmed exoplanets have been found that are enumerated by several scientific databases. Table 3 shows optimistic samples of potentially habitable exoplanets. Optimistic records are more likely to compose out of a rocky surface as well as liquid water. This means that the planetary radius has to be smaller than $1.5R_E$ but larger than $0.5R_E$, respectively the planetary mass has to be smaller than $5M_E$ and larger than $0.1M_E$, and the planetary orbit is within the conservative habitable zone.

Table 3. Conservative candidates for habitable exoplanets from [3]

Name	T_{Eq}[K]	Distance [ly]	ESI
Proxima Cen b	227	4.2	0.87
TRAPPIST-1 e	230	39	0.86
GJ 667 C c	247	22	0.84
Kepler-442 b	233	1115	0.84
GJ 667 C f*	221	22	0.77
Kepler-1229 b	213	769	0.73
TRAPPIST-1 f*	200	39	0.68
Kapteyn b*	205	13	0.67
Kepler-62 f	201	1200	0.67
Kepler-186 f	188	561	0.61
GJ 667 C e*	189	22	0.60
TRAPPIST-1 g	182	39	0.58

*candidate unconfirmed

For defining regions of interest, one hast to sort the star regions according to defined priorities where the following objects of observation should be investigated with a decreasing time of investigation:

Star systems hosting conservative candidates for habitable exoplanets (3)
Star systems hosting optimistic candidates for habitable exoplanets (2)
Star systems hosting exoplanets with moderate environments (1)
Star systems with moderate environments (0)

Due to the larger distances, each region of interest represents a star system, respectively multiple star systems if several systems are too close to each other. To maintain such relevant data that the satellite need to investigate, a database can be implemented that contains all possible star systems hosting conservative and optimistic candidates for habitable exoplanets as well as star systems hosting exoplanets in general. To increase autonomy and avoid long upload periods, the satellite can store this database onboard to investigate regions of interest autonomously. A useful suggestion is table 4 which is ordered according to its right ascension (RA) which is often used like in the case of the Hipparcos star catalogue.

Table 4. Suggested database format

ID	RA	Decl	Mag	Prio	Remark
…	…	…	…	…	
xxxx.	10h 56m 29s	+07° 00'52''	13.54	0	Wolf 359
…	…	…	…	…	…
xxxx	23h 6m 29.36s	-5° 2' 29.2''	18.8	3	TRAPPIST-1
…	…	…	…	…	…

Furthermore, the declination, magnitude and priority are additional information of the database. Depending on the sensibility of the sensors, the catalogue can also be reduced by filtering the database according to its magnitude. If the magnitude of the star system is larger than the sensitivity of the optical payload, the adjacent star system in the catalogue has to be labeled to the priority of the previous star systems.

4.3.2 Hardware

For the data evaluation, direct incoherent detection instead of coherent detection is the best choice since the knowledge for the signals carrier frequency is not known. Because of the different possible light signals, a flexible hardware concept by the use of an FPGA and microcontroller is illustrated in figure 4. Here, incoming light is distributed among the 3 photon detection units for coincidence detection with succeeding signal amplifiers and discriminators to filter signals below a given threshold. Afterwards, the signals are fed to an FPGA for fast signal processing for detecting events.

Finally, a microcontroller is included for storing objects of observations, their outcomes, and related telemetry data according to the next section. For the nanosatellite mission, two independent redundant signal detection modules are proposed which are working in cold redundancy mode. Over the backplane bus, housekeeping, extended telemetry data and commands are sent to the Onboard Computer and Payload Data Handling System.

The FPGA will be primarily used for the fast detection and analysis of signals while the microcontroller controls and configures the FPGA in a broad range of detection parameters. Each redundant FPGA has to be equipped with two 4GB DDR RAM in order to ensure the implementation of a ringbuffer holding a sample period of at least 10 seconds where each 10ns sample stores the number of received photons in a 32bit value.

Furthermore, the microcontroller's task is to update the FPGA, learn by events based on the operator's response, and to schedule and plan the activity in the case of events or critical values such as exceeding temperature thresholds of the signal evaluation module.

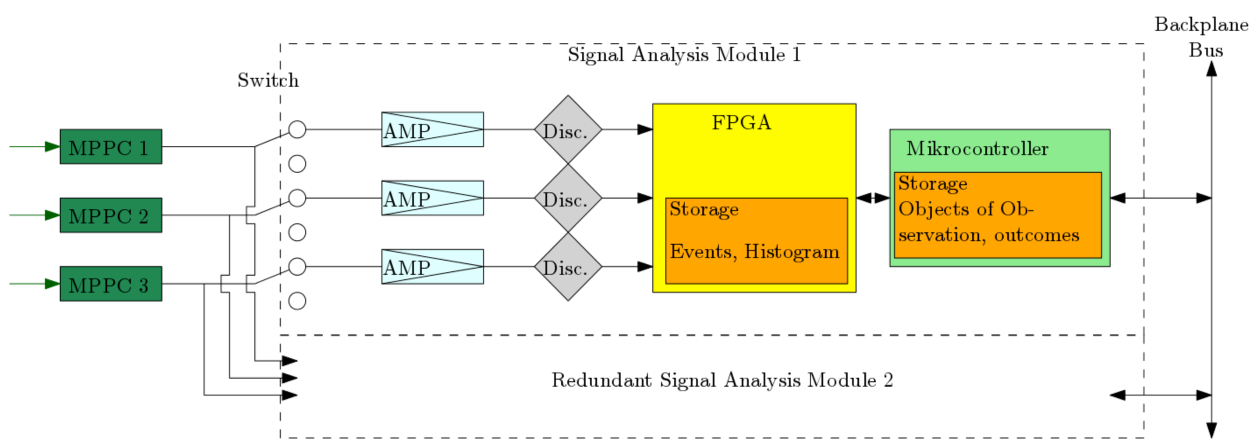

Figure 4. Block diagram for the two redundant signal analysis/detection modules of the optical payload

4.3.3 Telemetry

The optical payload highly contributes to the data budget with expected raw standard housekeeping data of 35 byte and extended data of approximately 190MB per event in a first instance to guarantee a download of the raw pattern sample of the detected event within 24 hours which has a resolution of 100ns and a period of 5 seconds. The raw pattern sample represents a time-photon diagram where for each resolution, the number of incoming photons were counted and stored.

Table 5. Accruing standard housekeeping data for the optical payload

Parameter	Size [bit]	Remark
Mode	3	mm
O/P 1 PWR	1	ON/OFF
O/P 2 PWR	1	ON/OFF
Event Counter	8	Recognized Events
O/P UTC	32	-
ID of last visited star region	32	-
O/P temperature	8	[°C]
PWR consumption	8	[W]
Error counter	8	-
Last error code	8	-
ID of next star region	32	-
Sample time	32	[ns]
Discriminator threshold	32	[mV]
Occupied event memory	32	[MB]
Number of event files	8	-
Total visited star regions	32	-

Table 6. Accruing extended event telemetry

Parameter	Size [bit]	Remark
Triplet algorithm detection	1	Yes/No
Triplet algorithm period	32	In time steps from raw pattern
Triplet algorithm first patter	32	Discrete time steps in raw pattern
Triplet algorithm number of photons	32	Per 10 ns interval
Single photon technique detection	1	Yes/No
Single photon technique first pattern	32	In time steps from raw pattern
Single photon technique signal frequency	32	[Hz]
Raw pattern	16 x 10^8	5sec, 100ns resolution
Raw pattern start UTC	64	[ns]
Raw pattern resolution	16	[ns]

5. Mission concept

5.1 Mission concept overview

The mission concept is made up of a low earth orbiting satellite and a ground segment for operation and payload processing. The mission scenario is based on a highly autonomous satellite, which independently performs the key function of detection on board and informs the ground segment about the results of its work. Results are only transferred to the ground segment if something interesting has been found. A short alert message is sent using a communications satellite constellation to inform the ground segment immediately. This concept is based on a similar mission design, which was proposed to detect and observe the Transient Lunar phenomena [5].

5.2 Operations scenario

As the proposed FOV of the payload is 0,5° (equals the ROI), the celestial sphere can be divided in 2880 segments, corresponding roughly to the FOV. The operating scenario concept provides scanning the entire sky spheres in 10-minute intervals per orbit.

The main sequence of events for this scenario would be to

1. Switch on the ADCS 4 minutes before start of the investigation (T0-4 min)
2. Switch on the PDH 3 minutes before the start of the investigation (T0-3 min)
3. Switch on the optical payload (T0)
4. Switch off the optical payload after 10 minutes (T0+10 min)
5. Switch off the ADCS after 10.5 minutes (T0+10.5 min)
6. Switch off the PDH after 11 minutes (T0+11min)

This procedure is repeated every orbit in order to investigate 1 segment per investigation resulting in 16 possible areas to investigate per day, resp. 5884 theoretical regions of interest per year. This is twice the number of segments required by the O/P and is sufficient enough to look for possible signals where the 4728 Kepler planets are located according to the Exoplanet Orbit Database.

In the case of an event, i.e. the optical payload has detected a possible signal, the optical payload shall command the OBC to keep at the specific region for 10 more minutes to exclude false alarms. A video sequence is recorded in a nonvolatile memory and the ground segment is informed via an ORBComm link. The recorded signals are downlinked later using the high data rate transmitter. The time between two procedures are used to charge the batteries.

6. Space segment

Besides the optical payload, this chapter deals with the space segment concept of the additionally required components.

6.1 Communication

The communication subsystem has the task of transmitting the following data for the mission:

a) Online Housekeeping Data of the most important parameters of the satellite bus and subsystems during contact.
b) Offline Housekeeping Data of the most important parameters of the satellite bus and subsystems in the absence of a contact.
c) Extended Housekeeping Telemetry of additional satellite bus and payload data.
d) Notification of the operator in the case of an event in the absence of the geometrical visibility.

For the communication in the UHF/VHF band, the Lithium transceiver from AstroDev [7] represents a good choice for downloading standard housekeeping data and uploading telecommands. As a transmitter for the extended payload data, the HiSPICO transmitter from IQ Wireless [8] yielding up to 1 MBit/s will be used as a reference hardware. Finally, the user wants to be informed as soon as possible about a registered event, even if the satellite is not in the close vicinity to the ground station. Therefore, the OG2 Modem from ORBCOMM [9] is proposed which uses a satellite relay in orbit.

6.2 Power Subsystem

To find the suitable power system concept, the loads within the satellite are identified, the needed power based on a reference scenario is defined, and the solar cell area and the required capacity of the batteries is determined. The power budget for a reference scenario is illustrated in the following:

Table 7. Operational State and power requirements

System	Max. Power [W]	Duty Cycle [%]	Power Consumption [W]
O/P	12	9	1
OrbComm	5.28	1	0.0528
Camera	5	9	0.45
ADCS	8	18	1.44
TT&C	8	2.5	0.2
OBC	0.35	100	3.350
PDH	1	9	0.09
EPS	0.2	100	0.2
Thermal	0	0	0
Sum			6.7828

Considering the power requirements and the solar, resp. umbra/penumbra periods (~75%, resp. ~25% per day), the required area yields 0.0187m² with $\eta = 26.5\%$ as the EOL efficiency of the solar cells. Therefore, 8 solar cells can be mounted on the -x side of the spacecraft (opposite to the optical payload) resulting in 0.0241m² which fits within the maximum area of 0.0484m² according to the design of the optical payload. At the ±y and ±z axis, 12 solar panels (A_{SP} = 0.362m²) can be added (A_{max} = 0.0682m²) considering spare areas for the star trackers and S-Band antennas.

During eclipse periods, batteries are becoming necessary. Therefore, 4x4=16 Li-ion batteries with a single cell voltage of 3.6V can be integrated at the long corners of the nanosatellite. To ensure a voltage of about ±5V, 4 cells of each corner will be connected in series to form one sub block providing the required voltage for the O/P. Two sub blocks are connected again in parallel to form one block of ±5V with the current of two sub blocks. Since two of these blocks (4 battery blocks) can be included at the corners of the satellite, the secondary power storage can be designed single-failure tolerant.

6.3 Onboard Computer

The Onboard Computer is the central monitoring and data collection system to ensure an autonomous work in space without the operator's interaction if no contacts are possible. Therefore, the OBC has to decode, verify, and execute the operator's telecommands, collect and encode telemetry data, monitor the state of the satellite, navigate and manage the time, communicate with the O/P and satellite bus, and to control the redundancy of the spacecraft.

A good choice which perfectly fits the requirements of storing the firmware of each subcomponent as well as saving housekeeping and telecommands is the SONATE OBC which is currently under development at the Professorship of Space Technology at the University of Würzburg [10].

6.4 Payload Data Handling System

A useful feature would be the record of the current FOV of the optical payload such that the operator can directly investigate the current star pattern and, if possible, sees a light signal if the signal pulse duration and strength is long enough for the optical camera. Since the finding of a suitable camera is not the original part of this feasibility study, it is only mentioned here that in the case of an event, a 512x512x8bit monochrome video sequence can be triggered. The time of a video sequence is set to 10sec and the resolution to 512x512x8bit. Otherwise, a complete payload download within 1 day cannot be achieved anymore [12].

6.5 Attitude Determination and Control System

The ADCS is a necessary subsystem of aligning the optical payload within a given FOV as precise as possible. Therefore, the expected torques of the (31x22x22) cm^3 satellite are expressed in the following for the 500km reference orbit:

Table 8. Estimate worst case torques for the satellite

Disturbance Torque	Value [Nm]
Gravitational Torque	8.8×10^{-8}
Solar Radiation Torque	3.4×10^{-8}
Aerodynamic Drag Torque	2.6×10^{-6}
Magnetic Torque	4.7×10^{-7}

In order to use reference models for precise attitude determination, the position of the satellite at different times is necessary. This can be achieved by implementing the SGP4 Modell and the usage of the ORBCOMM transmitter which is capable of receiving GPS signals. The sole usage of magnetic actuators will not achieve the mission requirements of precise 3-axis control at each point in time. Therefore, additional reaction wheels are becoming necessary.

The ADCS system will therefore consist out of two star trackers, twelve sun sensors, six gyroscopes, and six magnetic field sensors for attitude determination, two redundant ADCS controllers and six magnetic coils and four reaction wheels for redundancy purposes.

6.6 Mass and Size Budget

As a conclusion, the nanosatellite will have physical dimensions of about 31x22x22 cm^3 such that the payload and satellite bus components will fit inside the satellite. Approximating the mass of all components, the final satellite is expected to have a mass of 13.5kg as a maximum.

Table 9. The expected satellite's total mass

Component	Mass [kg]
Structure Subsystem	0.72
Antennas	0.2
2xOrbComm	0.12
2xLithium	0.10
2x HiSPICO	0.12
RF Cabling	0.10
Solar Array	0.14
16x Batteries	0.74
2xEPS	0.10
2xADCS	0.10
Bar Magnets	0.10
Additional ADCS Sensors and Actuators	0.50
Avionic Subsystem (Backplane bus)	0.30
Thermal Coatings and Paints	0.05
2xOBC	0.10
2xPDH	0.10
2xCamera	0.25
2xCamera Mounting Hardware	0.04
1xTelescope	7.00
2xO/P and 1xMPPC Box	0.50
Total Mass	11.47
Total Mass + 18% Uncertainty	13.50

7. Ground segment

The final chapter discusses the necessity of the ground segment. Due to the preferred SSO orbit of 500km height, six geometrical contacts will be available each day for communications with the ground station in Würzburg, Germany. Moreover, the contact duration of one day of the reference orbit yields for 0° minimum elevation approx. 55.4 minutes, for 5° minimum elevation approx. 35.7 minutes, and for 10° minimum elevation approx. 21.3 minutes contact durations per day. The ground station already consists out of a mission control room as well as antennas for UHF/VHF and S-Band communications.

At this moment, the mission control room is extended to show all defined telemetry data for the future SONATE mission which can be further extended for the use of the future OSETI mission. An additional component will be the storage of the huge amount of the data of possible events in the future and the ground analysis of the raw pattern received from the satellite which can be made public via the internet to other interested users and ground based OSETI telescopes. Furthermore, the ground station needs subscriptions to the ORBCOMM network to get notifications of possible events in the absence of the geometrical visibility.

8. Conclusion

The study shows that there are no principal showstoppers for the development of a small satellite for a mission, which would be the first of its kind and would bring the search for extraterrestrial intelligences in the optical spectrum one step further.

With an estimated mass of 13,5 kg and a size of roughly 31x22x22 cm^3 the result of the first feasibility study on a dedicated Optical SETI satellite is promising, that such a mission could be handled within the limited frame of a nanosatellite.

Of course, the performance will be less compared to earth bound larger systems, but the advantages of having much less disturbances and having a dedicated, autonomous system in space will outweigh. If we limit the number of minimum detected photos to 100 per pulse of the assumed link budget, which is comfortable, then the target distance can be up to 300 light years with the proposed system. This will, from today's point of view, correspond to at least 600 star systems with exoplanets to search for intelligent signals.

Such an optical SETI mission would be a significant contribution to the search for intelligent life in the universe and moreover, a motivation for further and more powerful missions in the future.

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