Satellite-to-Ground Communications Link

Assignment Specification and General Instructions

SPACE ENGINEERING DETAILED DESIGN PROJECT

AE4904

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1 Course Instructions

1.1 Course Objective

The objective of the detailed design project is to develop a subsystem or its component from a preliminary specification to a detailed design which is ready for production (manufacturing/coding), assembly, integration and testing. The project shall focus on the following Space Engineering profile learning goals, with emphasis on the bold parts:

- The student shall be able to recall facts and explain the physical working principles of elements at detailed level for a specific subdiscipline in the field of space engineering.
- The student shall be able to define, size, **simulate, analyze and evaluate** the functions and performance of a spacecraft in its environmental context at detailed level and using proper verification methods for the specific subdiscipline.
- The student shall be able to **identify, evaluate and select** various options for spacecraft and space systems at detailed level for a specific subdiscipline.
- The student shall be able to **design a spacecraft subsystem or component, making adequate use of systems engineering principles and tools.**

The general starting points for each assignment are:

- Students are assigned to a design project that aligns with one of the profile courses that they have taken, under the responsibility of (one of) the lecturers of that course.
- The design project will have a study load of 5 EC = 140 hours.
- The assignment is performed in a group 4-5 students.
- Each assignment is created for two or three groups. There will be shared activities for groups with a common assignment to learn from the others.
- No hardware or onboard software is yet involved in the project. The detailed design project aims to reach a level that would mean "readiness" for production, coding, assembly, integration, and testing.
- A selection of assignments and groups may be followed up in the Space Engineering Practical for real implementation. Interested and eligible students for this have been considered in the allocation process for the projects.

1.2 Course Planning and Organization

General course planning is provided in Table 1. The exact dates, times and rooms will be communicated on BrightSpace. Attendance for the kick-off, mid-term and final review is mandatory. However, in case of a force majeure or a very important agenda conflict the student can arrange his/her absence in mutual agreement with the other group members. This requires good communication about the communication of individual input before -and output after- the meeting. Once this agreement is made, the student informs the tutor, who does not play a decisive role in this matter. The expected workload is approximately 20 hours per week over the course of 7 weeks. it is important that all group members feel a common responsibility and maintain a steady pace.

Week	Activity	Duration	Whom	Where	Preparation / Deliverables
2.7	Project Introduction	1 hour			
3.1	Introduction lecture	2 hours	coordinating lecturer and all students	lecture hall (see timetable)	
3.1	Kick-off Meeting	1 hour	per assignment	instruction room (see Brightspace)	throrougly read assignment
3.2	Progress Meeting	45 min.	per group	defined by tutor	
3.3	Progress Meeting	45 min.	per group	defined by tutor	
3.4	Mid-term Review	2 hours	per assignment	instruction room (see Brightspace)	First parts of report (see deliverables in assignment) and 20 minute presentation
3.5	Progress Meeting	45 min.	per group	defined by tutor	
3.6	Progress Meeting	45 min.	per group	defined by tutor	
3.7	Final Review	1.5 hours	per group	instruction room (see Brightspace)	Final report, all files (see deliverables) and 45 minute presentation
3.8					Reflection Report

Table 1: Overview of general activities, deliverables and contact moments

1.3 Deliverables and Assessment

The summative assessment is based on the final report and the reflection. These are assessed by the tutor. The final presentation itself is not directly assessed. The objective of the presentations are to collect feedback on the design from the tutor, other student groups and staff within the same space engineering subdiscipline. This can be used for writing the reflection.
If one or more elements are insufficient, the team needs to perform a rework. This can already occur if one of the sub-items (bullets) of the main criteria is insufficient. This means that the passing threshold is higher than for project-based education using grades. The rubrics provided in Table 2 clearly indicate what is expected. The difference between sufficient and good is an indicator of performance (formative feedback). Items assessed as good cannot be used to compensate items assessed as insufficient.
Individual items are not assessed, and the quality of the final deliverables is the responsibility of the whole group. Disagreements on the workload distribution and/or quality of the contribution of an individual member shall first be discussed within the group. If a major dissatisfaction cannot be resolved, the tutor shall be informed as soon as possible and he/she will discuss an appropriate action/outcome with the course coordinator.

1.3.1 Mid-term review

The mid-term review comprises a presentation, questions and discussion involving also the peer-groups(s) doing the same assignment. The presentation itself should be 15-20 minutes, leaving sufficient time for questions and discussion with the other groups and the tutors. The presentation is not graded and it is not needed to have all group members presenting. The intention is that you receive critical questions, feedback and suggestions, not to sell your work. A quick overview of the work and design (< 5 minutes) can thus best be complemented with a careful selection of items which have a high impact and/or high uncertainty for you. You can use the mid-term review of the others for inspiration and comparison. It is not the intention to exactly copy the work of the other groups, but feel free to use it for inspiration and to identify potential flaws and alternative paths in your own work.

	Insufficient	Sufficient	Good
Quality of the report	• lacks key argumentation • lacks key graphs or other visuals • incomprehensible text and/or visuals	• comprises plausible arguments for key steps and choices • comprises key graphs and other visuals • provides readable text and visuals.	• comprises convincing arguments for all steps and choices • comprises high quality graphs and other visuals • provides high quality text and visuals in a consistent style
Simulation and Analysis	• lacks critical simulation and/or analysis • lacks simulation scripts and/or input required for reproducibility • contains major flaws which severely comprise the credibility of design	• includes critical simulation and analysis • includes simulation scripts and input required for reproducibility • contain no major flaws in simulation and analysis of its results which can compromise the credibility of design	• includes all relevant simulation and analysis • includes simulation scripts and input required and is easily reproducible • contains no apparent flaws in simulation and analysis of its results
Systematic Approach	• misses key steps, or explanation thereof, in the applied method • misses critical systems engineering • inappropriate implementation of systems engineering	• explains key steps in the applied method • includes systems engineering on critical items • implements systems engineering in appropriate way	• clearly explains all steps in the applied method • includes systems engineering on all relevant items • implements systems engineering in a convincing and consistent way
Quality of Design	• overlooked significantly better or common design options • shows incompatible design • lacks verification on critical aspects • lacks original design files	• includes multiple design options for key aspects, including at least the most trivial ones • shows compatible design • includes verification on critical aspects • includes multiple design options for key aspects, including at least the most trivial ones	• includes multiple design options for key aspects, including the most trivial ones as well as original solutions. • shows compatible design, which is clearly verified • includes verification on all aspects • includes original design files, which are self-explanatory
Reflection	• does not address the key technical flaws • is too shallow • focuses on external factors rather than internal performance	• addresses the key technical flaws • provides sufficient depth on points of improvement • focuses on internal performance	• addresses almost all technical flaws • provides a complete overview on points of improvement, including suggestions for the future • focuses on internal performance without overly self-defending

Table 2: Assessment Rubric

1.3.2 Final report

The final report should contain all work performed: a complete documentation of the detailed design, following the expected tasks and deliverables, but also addressing potential gaps (only when mutually agreed with supervisors). There is no general page limit for the report, but it is expected that it has a high information density. You should avoid repetition, story telling, basic theory, and lengthy derivations. Often a table, a block diagram, a graph, or an illustration says more than text. The supporting text that refers to the figure should be concise to enable understanding of the figure but should not duplicate the information in the figure.

It is not required to include all engineering output in the report. The engineering files must all be added to the submission of the report as annex in its original format in a ZIP-package. In the report, you can show examples/snap-shots of the material for explanation, and you should refer to the relevant files in the annex. Make sure that the file structure is logical and that all files are explained. For both report and engineering files, you must consider transferability without the need for an oral explanation.

The final report and ZIP-package should be uploaded to BrightSpace in the assignment folder. The deadline for this is the day before the final review 23:59h. Missing or poor performance on one sub-element will yield required rework (except when agreed upon with the tutor prior to submission).

1.3.3 Final review

The final review comprises a presentation, questions, and discussion involving the peer-groups(s) doing the same assignment. The presentation itself should be no longer than 45 minutes, leaving at least 45 minutes for questions and discussion with the other groups and the tutors. The presentation is not graded. It is recommend but not required to have all group members presenting. In this presentation, you should try to show the complete design with an emphasis on items which were most time-consuming, difficult and/or have the highest impact. It is recommended that you take notes of the feedback and questions received, and also relevant insights for the final reviews of the peer group(s), because this will ease the writing of the reflection.

1.3.4 Reflection report

The reflection report is written after the final review. Its length is between 1000 and 2000 words. The idea is that you as a group reflect on the work, after having seen the results of the peer groups and having received feedback and questions at the final review. You are expected to critically reflect on the work performed. Try to answer the following questions: which technical flaws or potential improvements did you identify? What is the impact of the flaw and/or potential improvement? How would you approach an iteration, if needed?
It is also allowed to positively reflect on the highlights of your work, but this should be limited to no more than one-third of the document. You should, however, refrain from criticizing the work of the other group(s), the tutor, and other external contributing factors.
For those groups continuing the project in the Space Engineering practical, an iteration may be required or desired within that part of the project. It is, however, not needed to iterate the final report for AE4904, unless the tutor specifies this as required rework.
The reflection report should be uploaded to Brightspace in the relevant folder. The deadline for submission is one week after the final review.

1.3.5 Potential Rework

In case the tutor has assessed a sub-item of the final report, the engineering files or the reflection report as insufficient, the group is required to perform rework. The deadline for rework shall be set in week 4.1-4.7 (fourth quarter of academic year) ain mutual agreement between the tutor and the group, considering the amount of rework and the preferences of the group members. The re-work continues until all items are assessed as sufficient or good.

2 Satellite-to-Ground Communications Link Assignment Instructions

In this chapter, assignment specific instructions are provided.

Group	Tutor	E-mail	Room
A	Stefano Speretta	s.speretta@tudelft.nl	N2.13
B	Jurgen Vanhamel	J.A.M.Vanhamel@tudelft.nl	N.2.14
C	Rudolf Saathof	R.Saathof@tudelft.nl	N.2.16

Table 3: Tutors for the different groups of the assignment

2.1 Assignment Objective

The assignment objective is to design an optical downlink from a LEO satellite to a ground station. To this end, the conceptual designs of potentially suitable RF and optical terminals are provided. These need to be worked out with sufficient detail to make a fair comparison between optical and RF communications. Based on a trade-off one of the following concepts need to be choosen:

- RF communications
- Optical communications
- Hybrid communications (Optics+RF)

The choosed concept needs to be worked out in a detailed design of the terminal, including component selection, budgets, and specification of the key communications performance parameters: BER, throughput, availability and latency.

2.2 Requirements Specification

In this section, the main design requirements are specified. Please note that this list may not be complete and may require further flow-down. Required or proposed iterations of these requirements need to be discussed with the tutor at the earliest opportunity.

- Link type:
  - LEO-downlink
- Mechanical constraints:
  - Volume envelope = 0.5x0.5x0.5 m^3.
- Communications requirements:
  - Data-type: Observation data
  - RF-band: Ka-band - 20 GHz (TBC)
  - RF Spectral allocation: 100 MHz
  - Optical band: C-band (1550 nm)
  - Availability: 99%
  - Data-volume: 2.5 Terabit per day

  item Envir. conditions:
  - Location of (optical) ground stations in Europe [1]:
  - Turbulence profile: HV57
  - Platform drift: 0.1 degree
  - Platform jitter: $160/(1+f^2)\mu m^2/Hz$.
  - Temperature: -40, 40

2.3 Expected Tasks

The team is expected to fully comply to the assignment objective and the requirement specification in previous sections. They are also responsible to define and distribute underlying tasks. A timely discussion with the tutor is expected if this cannot be met. The tasks below are a (potentially incomplete sub-)set of the tasks which are expected to be performed and properly documented.
Simulate an optical link to perform the following analysis:

- Link budget
- Data budget
- Power budget
- Time trace (optical)
- BER analysis
- Architecture
- Select components

2.4 Expected Deliverables

Besides a complete technical report (see general instructions), the reflection report and the two presentations, the following specific deliverables are expected:
Deliverables at the end of the project are:

- Specification of BER, throughput, availability and latency under several conditions, such as atmospheric conditions and elevation angles.
- 3D CAD drawing including the components.
- In case of optical communications: A basic optical design (to assess feasiblity).
- In case of RF: A (basic) antenna design.
- Specification of the power consumption.

Expected Deliverables Mid-Term

- Specification of BER, and throughput under one benchmark condition.
- Architectural drawing (blockscheme) of the communications terminals, pre-selection of required hardware elements.
- Estimate of the power consumption.

2.5 Applicable Documents and Files

The optical architecture of the optical terminal is depicted in Figure 1. Objects like the CPA and the FSM can be purchased, as well as lenses and beam splitters. The focal length of the lens and the angles of beam splitters and mirrors are still open for detailed design. The tracking detector can be a quad cell or an image detector. The architecture of the optical communications chain is depicted in Figure 3. The coding format, need to be chosen, as well as all components.

- Click mission: https://www.nasa.gov/smallspacecraft/what-is-click/
- Flying laptop: https://www.eoportal.org/satellite-missions/flying-laptop
- Review of several terminals: https://www.sciencedirect.com/science/chapter/edited-volume/pii/B9780128245415000236
- TBIRD: https://www.nasa.gov/wp-content/uploads/2017/10/tbird_fact_sheet_v2.pdf?emrc=e8317f
- Optical telescope for downlink: http://www.alluna-optics.com/Ritchey-Chretien-Telescope.html, we have the 16" on our roof. Ground station design should be compatible.

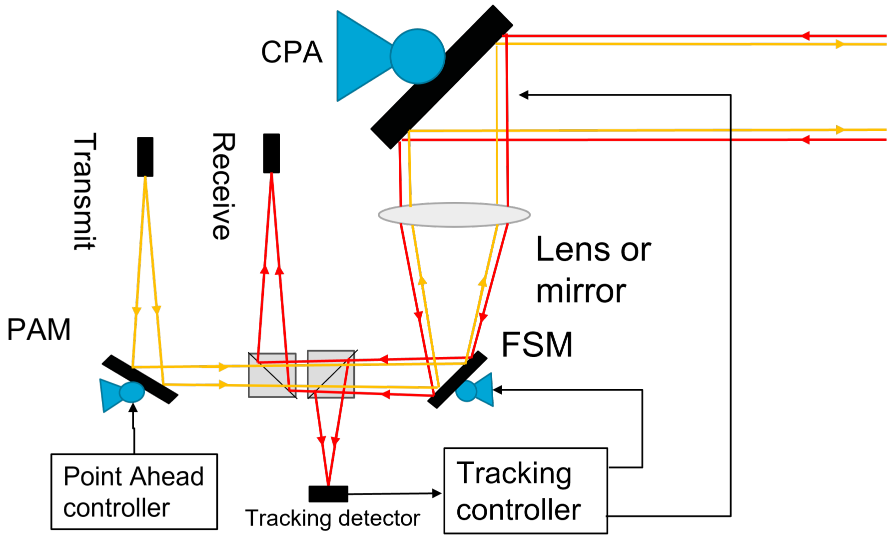

Figure 1: Architecture of the optical bench.

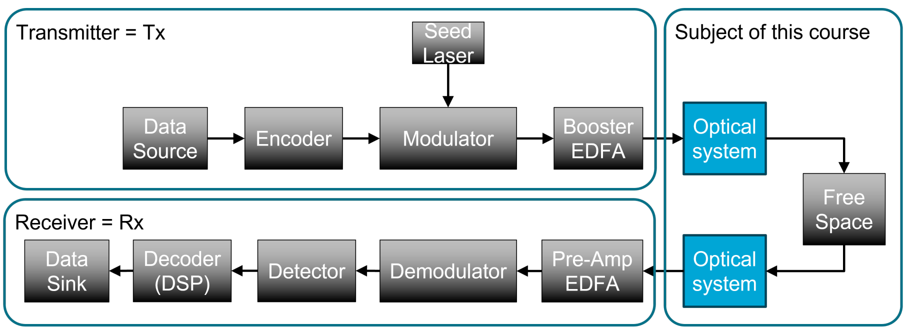

Figure 2: Components chain for optical communications.

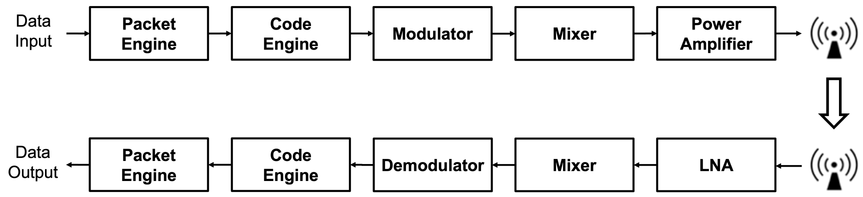

Figure 3: RF Components chain.

- OPT-SAT 2: https://opssat.esa.int/docs/opssat1/OPS-SAT-2%20Final%20Report_v1.pdf
- Ground station NICT: https://www.mdpi.com/2304-6732/11/6/545
- NASAs low cost ground terminal https://www.nasa.gov/technology/space-comms/space-communications/nasa-terminal-transmits-first-laser-communications-uplink-to-space/
- Ground station compatible with SDA: https://satellitemarkets.com/worlds-first-sda-t1-and-t2-compliant-d

References

[1] Poulenard, S., Crosnier, M., and Rissons, A. (2015). Ground segment design for broadband geostationary satellite with optical feeder link. *J. Opt. Commun. Netw*, 7:325–336.