Exercise Sheet 1
An Introduction to Space

Unless specified otherwise, use the following constants throughout this document:

- Gravitational constant $G = 6.67 \times 10^{-11}\,\mathrm{m}^3/(\mathrm{kg\,s}^2)$
- Earth mass $M_\oplus = 5.9722 \times 10^{24}\,\mathrm{kg}$
- Speed of light $c = 3 \times 10^8\,\mathrm{m/s}$
- Earth radius $R_\oplus = 6.37 \times 10^6\,\mathrm{m}$

A1 – Space Applications

Exercise E1.1 *(Multiple Choice)*
Check the correct answer. There is only one correct answer per question.

(a) How does the Voyager spacecraft orient itself, where does it get its energy from, and how does it communicate with Earth?

- ☐ Voyager orients itself using onboard cameras, derives energy from nuclear reactors, and communicates via Morse code.
- ☐ Voyager orients itself using a GPS system, derives energy from solar panels, and communicates through radio waves.
- ☐ Voyager orients itself using star trackers and gyroscopes, derives energy from radioisotope thermoelectric generators (RTGs), and communicates with Earth through radio signals.
- ☐ Voyager orients itself based on Earth's magnetic field, derives energy from wind turbines, and communicates via laser beams.

(b) Which statement accurately describes the characteristics of Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Orbit (GEO)?

- ☐ LEO is located between 2000 and 35 786 km in height, MEO is at 500 km in height, and GEO is at 35 786 km in height.
- ☐ LEO is located between 2000 and 35 786 km in height, MEO is at 500 km in height, and GEO is at 2000 km in height.
- ☐ LEO is located between 500 and 2000 km in height, MEO is between 2000 and 35 786 km in height, and GEO is at 35 786 km in height.
- ☐ LEO is located at 35 786 km in height, MEO is at 2000 km in height, and GEO is between 500 and 2000 km in height.

(c) At what height was Telstar-1 launched, how long did it work, and what provoked its end-of-service?

- ☐ Telstar-1 was launched at 6000 km in Medium Earth Orbit (MEO), worked for 7 months, and its end-of-service was provoked by a solar flare.
- ☐ Telstar-1 was launched at 1000 km in Medium Earth Orbit (MEO), worked for 7 months, and its end-of-service was provoked by a high-altitude nuclear test.
- ☐ Telstar-1 was launched at 1000 km in Low Earth Orbit (LEO), worked for 7 years, and its end-of-service was provoked by space debris collision.
- ☐ Telstar-1 was launched at 250 km in Low Earth Orbit (LEO), worked for 7 months, and it is still in orbit.

(d) Why were geostationary orbits preferred for satellite communication?

- ☐ Geostationary orbits allow for faster data transmission.
- ☐ Geostationary satellites are cheaper to launch into orbit.

☐ Geostationary orbits provide a stable position in the sky, allowing for continuous coverage of a specific geographic area.
☐ Geostationary orbits are closer to Earth, reducing the latency in communication.

(e) What are the main features of both bent-pipe and router types of transponders?

☐ Router transponders provide signal routing capabilities, while bent-pipe transponders passively transmit signals without processing.
☐ Bent-pipe transponders are known for their high processing capabilities, while router transponders only relay signals.
☐ Both bent-pipe and router transponders actively process and route signals as they are relayed through the satellite.
☐ Bent-pipe transponders are used for data transmission, while router transponders are used exclusively for voice communication.

(f) Which satellite communication company is known for providing worldwide mobile data services through Geostationary Earth Orbit (GEO) satellites?

☐ Intelsat ☐ Inmarsat ☐ Iridium ☐ Eutelsat

(g) Compared to satellite-based systems, what are some advantages and disadvantages of using aerial systems for remote sensing?

☐ Aerial systems provide higher spatial resolution but are more expensive and less accessible.
☐ Aerial systems offer larger coverage and lower cost per unit area but have lower spatial resolution.
☐ Aerial systems are less expensive and more accessible, with higher spatial resolution but smaller coverage.
☐ Aerial systems have no significant differences compared to satellite-based systems.

(h) What are some advantages of satellite-based remote sensing?

☐ Limited coverage area, infrequent data acquisition, and reliance on atmospheric windows.
☐ Continuous data acquisition, irregular revisits, and narrow coverage area.
☐ Frequent and regular revisits, broad coverage area, and utilization of atmospheric transmission windows.
☐ Low-resolution imagery, limited spectral bands, and dependence on ground-based stations.

(i) How are remote sensing satellites typically classified based on their source of radiation and spectral regions used for data acquisition?

☐ Passive and active for source of radiation; optical, thermal infrared, and microwave for spectral regions.
☐ Passive and active for source of radiation; ultraviolet, visible, and infrared for spectral regions.
☐ Reflective and thermal for source of radiation; radio waves and microwaves for spectral regions.
☐ Active and passive for source of radiation; radio waves and X-rays for spectral regions.

(j) What is the fundamental principle behind passive optical remote sensing systems?

☐ They emit their own light for imaging.
☐ They rely on the reflection and absorption properties of materials at different wavelengths.
☐ They use lasers to measure distance.
☐ They are not affected by weather conditions.

(k) What is the main disadvantage associated with optical remote sensing systems?

☐ They require a constant power source.
☐ They are not capable of measuring reflectance and scattering.
☐ They are not suitable for imaging in cloudy or overcast weather.
☐ They cannot operate at different wavelengths.

(l) How is the ground resolution of a remote sensing sensor determined?

☐ By the wavelength of the sensor.
☐ By the spectral resolution of the sensor.
☐ By the IFOV (Instantaneous Field of View) of the sensor and the altitude of the platform.
☐ By the radiometric resolution of the sensor.

(m) What type of spectral resolution is characterized by having several narrow-band wavelength bands?

☐ Panchromatic ☐ Multispectral ☐ Hyperspectral ☐ Radiometric

(n) Which of the following defines spatial resolution in remote sensing?

☐ The smallest detectable change in radiation intensity.
☐ The number of days in which a satellite revisits a target.
☐ The smallest distance between points in the ground.
☐ The number of narrow-band wavelength bands used.

(o) What does temporal resolution in remote sensing refer to?

☐ The smallest distance between points in the ground.
☐ The number of days in which a satellite revisits a target.
☐ The smallest detectable change in radiation intensity.
☐ The number of narrow-band wavelength bands used.

(p) Why are Low Earth Orbit (LEO) satellites often preferred for Earth's atmospheric monitoring compared to Geostationary Earth Orbit (GEO) satellites?

☐ LEO satellites provide better spatial resolution.
☐ LEO satellites offer a wider coverage area.
☐ LEO satellites have a longer operational lifespan.
☐ LEO satellites have a higher altitude.

(q) What is the primary difference between trilateration and triangulation when it comes to determining the locations of points?

☐ Trilateration uses angles to determine locations, while triangulation uses distance measurements.
☐ Trilateration uses distance measurements to determine locations, while triangulation uses angles.
☐ Trilateration and triangulation are essentially the same and can be used interchangeably.
☐ Trilateration and triangulation are unrelated concepts and have no common elements.

Exercise E1.2 *(Inaccurate GPS)*
Calculate the *range inaccuracy* for a GPS system, where the synchronization between the receiver clock and the satellite clock is off by 100 ps.

Exercise E1.3
The code pattern generated by a transmitter is given in Figure 1. The same pattern is also generated in the receiver. The pattern of the transmitter is received by the receiver after some time delay. The receiver pattern and delayed received pattern are shown in the figure. Calculate the distance between the transmitter and the receiver, if the bit rate is 1 Mbps.

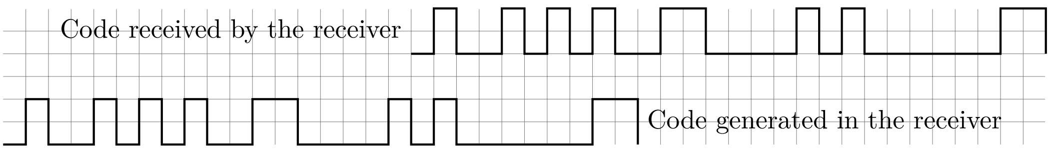

Figure 1: Figures for Exercise E1.3.

A2 – New Space

Exercise E1.4 *(Multiple Choice)*
Check the correct answer. There is only one correct answer per question.

(a) What term refers to an emerging space paradigm characterized by rapid adoption of new technology, agile development cycles, and the use of Commercial Off-the-shelf (COTS) components?

☐ Distributed mission deployment ☐ Satellite Constellation ☐ Satellite clusters
☐ Small-satellite (smallsats)

(b) What type of satellite communication system is Globalstar known for, and when did it face financial difficulties?

☐ Globalstar is known for its Geostationary Earth Orbit (GEO) satellites and faced financial difficulties in 2005.
☐ Globalstar is known for its Low Earth Orbit (LEO) satellites and faced financial difficulties in 1998.
☐ Globalstar is known for its Bent-Pipe type communication and faced financial difficulties in 2002.
☐ Globalstar is known for its hyperspectral imaging satellites and faced financial difficulties in 2010.

(c) What type of satellite communication system is Iridium known for, and when did it face financial difficulties before being rescued by the U.S. Department of Defense (DoD)?

☐ Iridium is known for its Geostationary Earth Orbit (GEO) satellites and faced financial difficulties in 2003.
☐ Iridium is known for its Low Earth Orbit (LEO) satellites and faced financial difficulties in 2001.
☐ Iridium is known for its Routed communication type and faced financial difficulties in 1999.
☐ Iridium is known for its hyperspectral imaging satellites and faced financial difficulties in 2005.

(d) Why did the business cases for Globalstar, Iridium, and Teledesic fail, resulting in significant financial losses?

☐ Technological challenges were not met, leading to operational failures.
☐ The mission and manufacturing paradigm evolved from the cold war era.
☐ The financial community remained supportive despite the losses.
☐ Business cases failed due to losses of approximately USD 10 000 million.

(e) What significant developments occurred around 2000 in the field of Earth observation missions and technology?

☐ The emergence of CubeSats and the successful deployment of observation constellations.
☐ The launch of large, single Earth observation satellites.
☐ The introduction of geostationary weather satellites.
☐ The development of hypersonic spaceplanes for Earth observation.

(f) How are CubeSats typically launched into space for space research purposes? Multiple answers are correct.

☐ As primary payloads on dedicated launch vehicles.
☐ As standalone missions on their dedicated launch vehicles.
☐ As payloads on the International Space Station (ISS).
☐ As secondary payloads on a launch vehicle.

(g) What was the primary concept behind the Future Fast Flexible Fractionated Free Flying (DARPA) mission that originated in 2007 but was canceled or classified in 2009?

☐ The mission aimed to explore interplanetary travel.
☐ The mission focused on Earth observation using advanced imaging technology.
☐ The mission proposed to fractionate a satellite, distributing power, control, payload, and other functionalities.
☐ The mission aimed to establish a network of ground stations for satellite communication.

(h) What significant developments occurred in the field of Smallsats and private initiatives as of 2010?

☐ Old investors continued to invest in large, traditional satellites.
☐ Private initiatives from companies like Google, Facebook, Amazon, and SpaceX reemerged.
☐ Earth observation and communications services became less important.
☐ Smallsats were entirely replaced by mega-constellations.

(i) What significant achievement is associated with Planet, formerly known as Skybox and Terra-Bella, in the field of Earth observation?

☐ Planet launched its first satellite in 2023.
☐ Planet changed Earth observation from science to a commodity.
☐ Planet reported an annual revenue of $113 million in 2009.
☐ Planet operates a constellation of more than 250 LEOs (Doves) as of 2023.

(j) What was the primary purpose of the GOMX-4 – Ulloriaq Earth Observation Constellation, which was launched in 2018 and consisted of two 6U Cubesats named GOMX-4A and GOMX-4B?

☐ To monitor the Amazon rainforest.
☐ To study the Earth's climate.
☐ To monitor Greenland in collaboration with ESA and the Danish Department of Defense.
☐ To provide high-resolution Earth observation imagery.

(k) What is the primary target number of LEO satellites for the OneWeb constellation?

☐ 100 ☐ 324 ☐ 584 ☐ 648

(l) What is the primary type of communication used within the SpaceX mega-constellation, which was announced in 2017 and consists of thousands of LEO satellites?

☐ Bent-Pipe
☐ Routed with optical Inter-Satellite Links (ISL)
☐ Microwave-based
☐ Geostationary communication

(m) As of 2023, approximately how many LEO satellites from the SpaceX mega-constellation are in orbit?

☐ Over 1000 ☐ Over 2000 ☐ Over 3000 ☐ Over 4000

(n) What is the primary focus of Spacebelt, a company founded in 2015?

☐ Space tourism
☐ Satellite-based internet services
☐ Data storage and security in space
☐ Space exploration missions

(o) What is one of the significant governance concerns associated with modern mega-constellations?

☐ Space debris management
☐ Launch vehicle availability
☐ Data security in space
☐ Rapid response time for satellite deployment

A3 – Physics and Orbits

Exercise E1.5
A satellite is orbiting Earth in a uniform circular orbit at a height of 630 km from the surface of Earth. Determine the velocity of the satellite.

Exercise E1.6
A satellite is moving in an elliptical orbit with the major axis equal to 42 000 km. If the perigee distance is 8000 km, find the apogee and the orbit eccentricity.

Exercise E1.7
Refer to Figure 2. Satellite A is orbiting Earth in an equatorial circular orbit of radius 42 000 km. Satellite B is orbiting Earth in an elliptical orbit with apogee and perigee distances of 42 000 km and 7000 km respectively. Determine the velocities of the two satellites at point X. Use $\mu = 39.8 \times 10^{13}\,\mathrm{m^3/s^2}$.

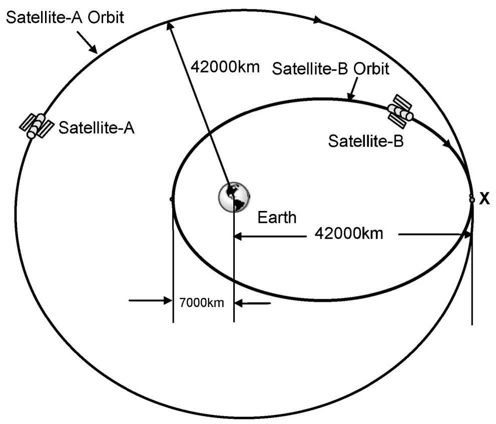

Figure 2: Figure for Exercise E1.7.

Exercise E1.8
Refer to Figure 3. Satellite A is orbiting Earth in a circular orbit of radius 25 000 km. Satellite B is orbiting Earth in an elliptical orbit with apogee and perigee distances of 43 000 km and 7000 km respectively. Determine the velocities of the two satellites at the indicated points X and Y. Use $\mu = 39.8 \times 10^{13}\,\mathrm{m^3/s^2}$.

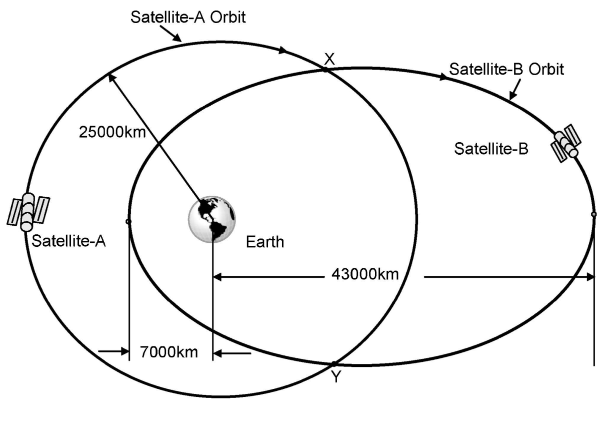

Figure 3: Figure for Exercise E1.8.

Exercise E1.9 *(Geostationary Satellite)*
The key property of a geostationary satellite is its orbit duration of an entire day, such that its relative position towards the equator does not change. Calculate the altitude of such a satellite w.r.t. the surface of the Earth. Determine its velocity, too.

Exercise E1.10 *(STK: Get Started)*
Install STK on your computer and make sure that it is running. Check the Project 1 description for detailed install instructions.

Exercise E1.11 *(STK: Orbit Magic)*

(a) Use the Orbit-Wizard in STK to create:
   - Circular LEO orbit: 400 km height (+ avg. Earth radius: 6371 km)
   - Circular MEO orbit: 20 000 km height (+ avg. Earth radius: 6371 km)
   - Circular GEO orbit: 42 166.3 km radius (semi-major axis)
   - (Use orbits with 0° inclination)

(b) Use the 3D and 2D windows to visualize the orbits.

(c) Use the report tool to explore numerical values. Create a custom report with the velocity and orbital period to evaluate the equations presented in the lecture.

Exercise E1.12 *(STK: Molniya Orbit)*
Use the Orbit-Wizard in STK to create a **Molniya** orbit:

- Inclination: 63.4°
- Apogee Longitude: 0°
- Perigee Altitude: 500 km
- Argument of perigee: 270°

Use the report feature of STK to observe the change of velocity of the satellite over time.