Space technology I
Autumn 2016
TTT 4234

Exercises proposed within the framework of TTT4234 Space Technology I. Time will probably not allow going through all the proposed exercises. Students are invited to prepare these exercises before the exercise session on the 17^{th} of Nov. 2016.

1. Newton's and Kepler's laws
Give Newton's three laws of motion, Newton's law of universal gravity, and Kepler's three laws.

2. Orbital elements and orbital values
Give the six orbital elements referred to the geocentric reference system, and describe how this reference system is defined. Give examples of particular values these orbital elements can take for particular types of orbits.

3. Earth observation
a) What are the atmospheric windows, and which wavelengths are let through?

b) The size of the smallest object a sensor can detect (or separate from another object), is called the resolution. The expression for the resolution is given by the formula $R= 2.44\ \lambda H/D$. Explain what the different parameters are.

c) Earth observation from satellites through the different atmospheric window runs into different problems. What are they?

d) Explain how the resolution can be improved by means of synthetic aperture. Give an example by choosing typical values for λ, H and D.

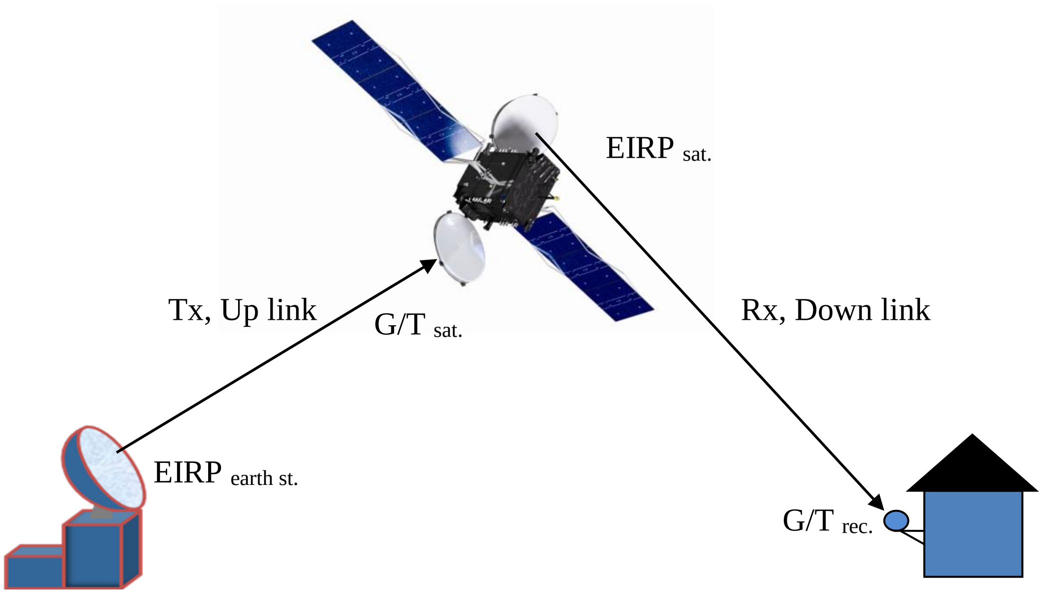
e) What is a chirp signal and why is it employed in earth observation?

f) Why is it so important to know as precisely as possible the position of a satellite used for earth observation, and how can it be derived? What is the order of magnitude for the obtainable resolution of today's satellite systems for earth observation?

4. Link budget calculation from Satellite Communication lecture
We are going to transmit a TV signal, with Modulation: QPSK, and Bandwidth B = 2.048MHz.

Boltzmann constant $k = 1.38 \times 10^{-23}$ W/Hz/K

a) How do you express the signal to noise ratio with linear expression?
b) How do you express the signal to noise ratio with logarithmic expression?
c) What is the expression for the free space loss, L_0?



Given Transmitter (Tx) figures from the earth station to the satellite:
$EIRP_{earth\ st.}$ = 50 dBW
Tx frequency = 29.7 GHz
Pointing loss = 1 dB
Atmospheric loss = 0.9 dB
Terminal to satellite distance = 38 039.81 km
G/T satellite = 13 dB/K

d) What is the up-link signal to noise ratio in dB?

Given Receiver (Rx) figures of the signal transmitted from the satellite to the earth station:
$EIRP_{sat}$ = 29.8 dBW
Rx frequency: 18.5 GHz
Pointing loss: 0.3 dB
Atmospheric loss: 0.6 dB
Coupling loss: 0.5 dB
Satellite to receiver distance: 38 460.53 km
G/T receiver = 35.12 dB/K

e) What is the down-link signal to noise ratio in dB?
f) What is the expression for the total signal to noise ratio, expressed as a function of the up- and down-link signal to noise ratios?
g) What is the value of the total signal to noise ratio expressed in dB?
h) By using the BER-curve vs. E_b/N_0, give the min. E_b/N_0 required to obtain a BER lower than 10^{-6}.
i) Is the calculated link budget good enough for such a BER?

j) If not, what can be done to improve the link budget? For each proposed improvement, give the advantages and disadvantages of the option.

5. Downloading data

CryoSat II is operated (TT&C) from the ESA/ESOC center in Darmstadt in Germany, but it is at the earth station in Kiruna that the earth observation data is downloaded. The TT&C carrier frequency is in S-band, while the download is performed on an X-band down link with a center frequency of 8.1GHz, and has a download transfer rate of 100Mbit/s.

The height of the orbit is 725 km above the surface of the earth, and the earth radius is 6370 km.

If we consider a satellite pass with the satellite passing right over the gateway in Kiruna, and the download cannot start before the satellite is 10 degrees above the horizon on its way up, and similarly stops when the satellite is on its way down with an elevation angle of 10 degrees, for how long time will the earth station see the satellite at this pass, and how much data can be downloaded?

6. Cosmic speeds
Give the expressions for the 1^{st} and the 2^{nd} cosmic speed.

7. Orbit adjustment

In order to adjust for orbit perturbations of a rocket we have to undertake two manoeuvres, #1 and #2, when correcting its speed in its linear trajectory. This of course requires fuel Δm_1 and Δm_2 to produce Δv_1 and Δv_2. Assume that one of the two manoeuvres requires a much higher speed increase than the other. Which manoeuvre should be performed first?

Show that in fact it makes no difference for the total Δm which order we choose (even if the total mass is smaller when firing the rocket motor the second time).

8. Inclination correction

A geostationary satellite weighs 4000 kg at lift off (total weight) and is placed in a transfer orbit whose perigee height Pe = 200 km and whose apogee height Ap = 35780 km. The orbital inclination $i = 38^0$. How much propellant is required to reduce the inclination to 0^0 without disturbing any of the other orbital parameters? The line connecting the points of greatest and least distance from the Earth (the ‘apsides’) lies in the equatorial plane. The thruster’s specific impulse $I_{sp} = 300$ s, the earth’s radius R = 6400 km and the gravitational parameter $\mu = 398\ 600\ km^3/s^2$.

The calculation will show that firing the thruster at the perigee requires more propellant than at the apogee – explain why.

9. Two-stage rocket

Imagine you are preparing the new Falcon launch vehicle for its first mission from Kennedy Space Center. The vehicle must deliver a total ΔV (ΔV_{design}) of 10km/s. The total mass of the second stage, including structure and propellant, is 12000kg, 9000kg of which is propellant. The payload mass is 2000kg. The I_{sp} of the first stage is 350 seconds, and of the second stage 400 seconds. The structural mass of the first stage is 8000kg. What mass of propellant must be loaded on the first stage to achieve the required ΔV_{design} ? What is the vehicle's total mass at lift-off?

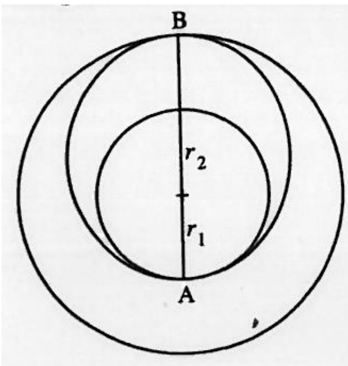
10. Satellites which orbit planets

A small satellite is orbiting a planet with dimensions identical to the one of our Sun (see, e.g., Table 1.1 Microgravity compendium). The density of the planet is ρ_1. Another small satellite is orbiting a much smaller planet, with dimensions equal to those of our moon, and with a density of ρ_2.

The two satellites go in circular orbits close to the surfaces of the two spherical planets. What is the ratio between the two orbital periods of the satellites, i.e. T_1/T_2?

11. Transfer orbit and Kepler laws

In the figure a space vehicle is orbiting around the earth with the distance r_1. It should be transferred to a stationary orbit with radius r_2, and is an example of a so-called Hohman's transfer. The vehicle therefore gets a thrust at A, changing the circular orbit to an elliptical one. When at B it gets a new 'kick' (from a so-called AKM – Apogeoum Kick Machine) and is required to go into the new circular orbit.



Assuming $r_2 = 6 \cdot r_1$ and denoting the orbit time for the inner circular orbit to be T_1, deduce expressions for the speed increases in A and in B. A solution involving Kepler's laws is preferable!