NTNU – Trondheim
Norwegian University of
Science and Technology

Department of Electronics and Telecommunications

Examination paper for TTT4234 Space Technology I

Academic contact during examination: Vendela Paxal

Phone: 95110981

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Permitted examination support material: Calculator, of a make according to a list approved by NTNU. Printed material: formula sheet attached to the exam.

Other information: Answers should be short and concise.

Language: English

Number of pages: 3

Number of pages enclosed: 1

Checked by:

Date Signature

Exercise 1. Orbits

a) If a rocket is launched from the equator, how much velocity is the obtained for "free" due to the peripheral speed of the earth, and in which direction do you have to launch?

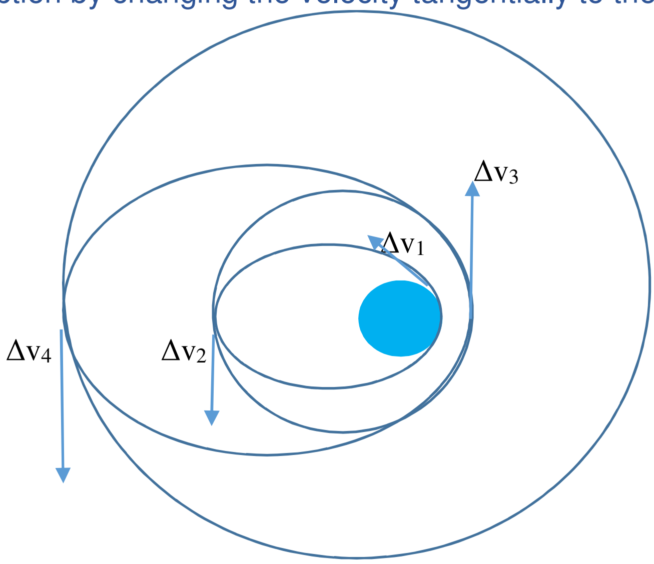
Answer: R_E = 6370km, giving the circumference of the earth $2\pi R_E$ = 40000km, and with a rotational speed of 24 hours, this gives the speed at the equator 463m/s. It is preferable to fire eastwards to profit from the roration of the earth, as the earth rotates from west to east.

b) If a space ship in a similar manner should leave the solar system, what would be the "free" velocity given by the Earth orbiting the sun?

Answer: Assume that the orbit of the earth around the sun is approximately circular, and with a radius of T= 8 light-minutes the speed of the earth in orbit becomes $v=O/t=2\pi r/t=2\pi cT/t=2\bullet c\bullet 8\ \text{min}\bullet 60\text{s}\bullet\pi/(365\bullet 24\bullet 60\bullet 60))$. This gives the «free speed» provided by the earth = 28.69km/s, that may be beneficial for extra planetary excursions, and it is interesting to compare it with the free speed obtained in a).

c) In order to place a satellite in orbit, a so-called Hohman transfer orbit is often used. Give a short description of the principle of the use of the Hohman transfer orbit, using as an example that the final orbit of the satellite shall be circular.

Answer: The principle is to use one or several intermediate orbits, in order to optimise fuel consumption by changing the velocity tangentially to the orbit.



d) A satellite is at launch first given an elliptical orbit, with a perigee distance from the earth surface of $2R_E$ and an apogee distance from the earth surface of $5R_E$, where R_E is the earth radius. What will be the orbit parameter a for this orbit?

Answer: $a = \frac{1}{2}(R_a+R_p) = \frac{1}{2}(3+6)R_E = 28665$ km

e) The satellite is then lifted up via this elliptical Hohman transfer orbit, to the final circular orbit where the radius is equal to the apogee distance. The formula for the velocity at the tranfer can be written as:

$$v = \sqrt{\mu(2/r - 1/a)}$$

What are the different parameters in this formula, and what will the transfer velocity?

Answer: As this question appeared to be ambiguous, both the following answers were accepted:

1. v is the speed at the change of orbit. μ is the gravitational parameter for the earth $\mu = GM$, where G is the universal gravitational constant, and M is the mass of earth.

   Hence $v = \text{sqrt}(3{,}986 \cdot 10^5(2/(6 \cdot 6370) - 1/28665)) =$ 2.63km/s

2. Or v is the velocity in the new orbit $v=\text{sqrt}(\mu/r) =$ 3.23km/s.

f) Derive Kepler's third law for a circular orbit.

Answer: Newton's universal law of gravity gives $F = \mu m/r^2$. For a satellite in orbit, e.g. around the earth, the centripetal force equals this gravitational force $mv^2/r = \mu m/r^2$

$v^2 = \mu/r$ and in orbit around the earth, the satellite will have a constant velocity $v=2\pi r/T$

$(2\pi r/T)^2 = \mu/r$

$4\pi r^3 = \mu T^2$, being Kepler's 3rd law.

Exercise 2. The AIS satellite

The Norwegian AIS (Automatic Identification System) satellite was launched in order to survey maritime traffic. The customer is the Norwegian coast authorities, the Norwegian Space Centre is the owner of the project, and the satellite itself is developed by the University of Toronto, the Norwegian Defence Research Institute and Kongsberg Satellite Services.

Every ship over 300 tons, or with passengers, is obliged to send out AIS signals in order to inform on identity, position, speed and destination. Until recently, only earth stations were able to receive these signals, thus limiting the surveillance to near costal areas. The AIS satellite is designed to complement this with surveillance of the open sea.

a) The AIS satellite is in a circular orbit at a height of h = 600 km from the earth's surface, with an inclination of 98 degrees. Calculate the orbital period of the satellite and its velocity.

Answer: By using Kepler's 3 law: $T^2 = 4\pi^2 a^3/\mu$, $\mu = 3{,}986 \cdot 10^5\ km^3/s^2$, $R_E = 6370km$, $a=R_E+h$.
Then $T^2 = 33535855s^2$, T=5791s, i.e., it will take approximately 96 minutes or 1.6 hours.
The velocity can be calculated as v = sqrt(μ/a) = sqrt((3,986·10^5 km^3/s^2)/((6370+600)km) = 7.56km/s.

b) The spot of the satellite (i.e. the coverage area on Earth) is circular with a diameter of 2300 km. What will be the distance between spots (uncovered area) at the equator between two passes of the satellite, and how many times will the satellite orbit the earth in 24 hours?

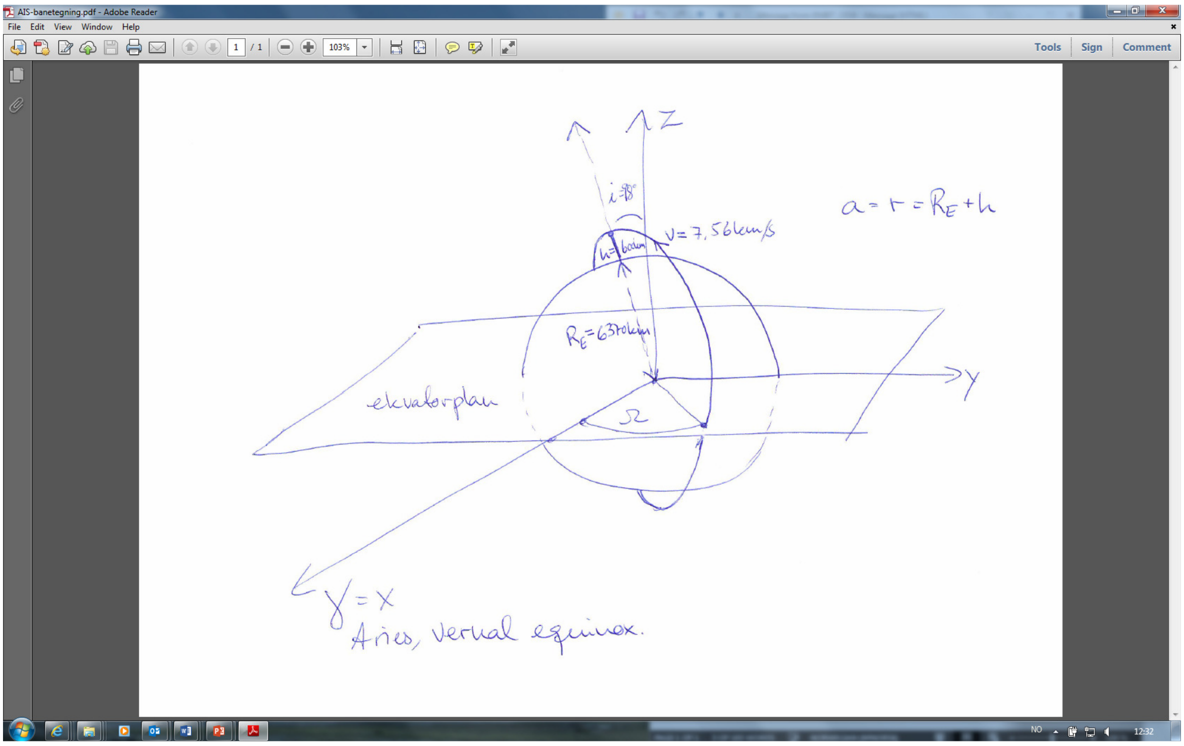
Answer: The radius of the earth is 6370km, then the circumference O = 2 πRE = 40074km, and the velocity at the equator v = 40074km / (24*60*60s) = 0.46km/s. At each new revolution around the earth, the satellite will be displaced s = 0.46km/s * 5791s = 2664km compared to the previous orbit, so there will be an uncovered distance between the two passes of 364km.

There was unfortunately a slight difference between the English and the Norwegian text, so we have been generous when evaluating the answers.

The number of revolutions in one day and night is N = O/s = 40074km/2664km = approx. 15.

c) The AIS satellite is sun synchronous, but not in a morning-evening orbit, and will therefore spend time in the earth shadow. The right ascension of the ascending node is at 45º grader. Draw a figure of the satellite orbit around the earth with the 6 classical orbital elements, and give their values.

Answer: Drawing of the satellite orbit.



The 6 classical orbital elements:
Semi-major axis: a = RE + h = 6370+600 = 6970km
Eccentricity: e = 0 as the orbit is circular
Inclination: i = 98º
Right ascension of the ascending node (rektasesjon for oppadstigende knute in Norwegian) Ω = 45º
The length/argument of the perigee, ω, is undefined as the orbit is circular
The true anomaly, v, is undefined as the orbit is circular.

d) How is it possible to keep the satellite in operation in the earth shadow?

Answer: By using batteries.

e) The satellite has an estimated lifetime of 3-5 years. Which factors do you think will limit the lifetime of the satellite?

Answer: several factors will limit the lifetime of a satellite in LEO; friction of a few atmospheric atoms (drag), the lifetime of the batteries, gravitational influence from sun/moon/…. If a LEO satellite has fuel on-board for orbital corrections, the amount of fuel is also limited.

f) An AIS message consists of 360 bits, and the transfer rate is 4 kbit/s. The access technique used is TDMA. Describe what is characteristic for this access technique.

Answer: Time division multiple access. All ships will send AIS messages on the same frequency, but in different time slots.

g) If the capacity is fully exploited, and a TDMA slot is exactly the length of an AIS message, which capacity, or how many ships maximum can the AIS satellite identify in a time period of 5 seconds if you suppose that there are no collisions (this is not true in reality).

Answer: A slot with 360bit with a rate 4kbit/s has a duration of 360/4000 s = 0.09s. In 5s the satellite will receive 5/0.09 = 55.5 messages in 5s.

h) The AIS satellite is vulnerable to frequency interference. What do you think are the main sources of interference?

Answer: Interference comes mostly from interference from transmitters within the same frequency range over land. These signals may interfere with the AIS messages sent from ships close to land, in narrow ship passages like the English channel or the Suez channel, or ships in traffic on lakes. In addition, the lack of collision detection also generates a type of interference.

Exercise 3. Gravity

a) The gravitational acceleration at sea level on earth is denoted g_0. How big percentage difference is the gravitational acceleration for a satellite in orbit 400km above sea level (ISS)?

Answer: Newton's gravitational law says: $F=GMm/r^2$.
If F_0 is the gravitational force of an object at sea level and F_1 the same in ISS, then: $F_0 = GMm/R_E^2 = mg_0$ and $F_1 = GMm/(R_E+h)^2$. Then the difference will be $GM/(R_E+h)^2/g_0 = 8.696/9.81 = 0.89$.
It is possible just to calculate $(R_E+h)^2/ R_E^2$
Hence, the gravitational force on-board the ISS is 89% of what we have on earth, or vice versa, the gravitational force on earth is 113% when compared to the ISS.

b) Describe the human balance system and its most important input signals. In particular, discuss the special condition of free fall for a human.

Answer: Three main input signals should be mentioned:
1. the eyes/sight
2. the mussels/skeleton, the proprioceptive system
3. the otolithe organ/inner ear

It is possible to draw this as a block diagram with input and output signals, output signals going to the respective mussel systems to compensate for the biases.

The difference between free fall and 1g condition is that the otolithes are floating around in cells/balance organs when in free fall, whereas they are lying against the walls of the cells/balance organs in 1g conditions, and thereby can stimulate the cells/balance system.
Additional info: when simulating space by diving in water, the proprioceptive system is mostly disconnected, and at large depths, also the sight. But the otolithes are still lying against the walls. Work under water is therefore not a 100% satisfactory replacement

for weightlessness, but the most practical for astronaut training.

Exercise 4. Description

Select <u>one</u> of the topics below, and give a short description.

a) Describe different earth observation techniques, from satellite, that you know.

   The following should be mentioned: use of optical signals and radio/radar signals, and the atmospheric windows. Active vs. passive systems. Resolution improvements and some techniques; synthetic aperture, chirp signals, Bragge scattering, interferometry,….

b) Describe possible differences in the choice of parameters in a downlink budget for the two applications TV broadcasting and download of observation data.

   Parameters that may be adjusted are; power, size of the antennas, carrier frequency and bandwidth. For TV broadcasting, we usually want to cover a large area, so the frequency should not be too high, Ku-band is very common. The transmit antenna on the ground is usually big, with high EIRP and a large bandwidth. The transmit antenna on the satellite has a more limited size and EIRP. User receiver antennas are usually small, due to the esthetical, but also to limit installation challenges (proper ground fixation and pointing accuracy becomes more difficult with big antennas). This is why the link budget is usually quite poor for TV broadcasting.

   When downloading observation data, it is important usually that the quality is good, so the link budget must be better than for TV signals. It is possible to increase the size of the receiver antenna on earth, as the installation is presumably more for professional use, e.g. the meteorological institute for weather forecasting will be able to install a bigger antenna than a private user with a balcony. The carrier frequency may be increased, then the spot will be more concentrated, and the bandwidth can be reduced to reduce noise.