Examination
Space Missions and Applications I (AE2103)
Faculty of Aerospace Engineering
Delft University of Technology

November 3, 2010, 9:00–12:00

Please read these instructions first:

This exam consists of 20 multiple choice questions worth a total of 135 points. The value of each question is listed in parentheses next to the question label. Record your answers on the answer sheet provided, making sure that you only fill in one box for each question. Note that different versions of the answer sheets will have a different order of the answers. **The exam is closed-book**, meaning you are not allowed to have any books, hand-outs, or notes on your table during the exam. You may use a pocket calculator; however, for programmable calculators, you must clear the memory beforehand (and show this to the exam proctor, if asked).

True/False (2 pts each, 10 pts in total): State whether the following statements are **True** (A) or **False** (B).

Q1: A geostationary orbit can be geosynchronous, but not all geosynchronous orbits are geostationary.

Q2: The geoid is a mathematically perfect ellipsoid that is sized to closely coincide with the mean sea level.

Q3: The troposphere is a layer in the Earth's atmosphere that consists primarily of electrons and electrically charged atoms and molecules, stretching from a height of about 50 km to more than 1000 km.

Q4: For a given reference system, there can exist many different reference frames.

Q5: The Earth's magnetic center is not at the geographic center of the Earth.

Q6: Positioning and navigation (5 pts)

Which of the following is NOT part of the of the Global Navigation Satellite System (GNSS):

A) GPS B) NAVSYS C) COMPASS D) Galileo

Q7: Positioning and navigation (5 pts)

Which of the following GPS system errors, when not accounted for, results in the largest amount of position error for a ground-based receiver:

A) Satellite clock errors B) Ephemeris data C) Multipath D) Ionospheric delays

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Q8: Space platform, time and reference systems (10 pts)

When collecting observations from a satellite, it is often very important to precisely know where a measurement was taken, i.e., georeferencing. If, by accident, you did not account for the recent addition of a leap second in your data processing, approximately how much error would you introduce to the geolocation of your data? Assume your satellite has a circular orbit at 780 km altitude, and that the satellite is exactly nadir pointing (e.g., the measurements are collected exactly along the sub-satellite point).

A) 0.78 km B) 1.2 km C) 7.5 km D) 235 km

Q9: Mission Design (10 pts)

Assume that a hypothetical laser altimetry satellite has been placed into a circular, sun-synchronous orbit at roughly 705 km in altitude, with a repeat period of 16 days, meaning that the satellite would fly over the same location on the Earth once every 16 (sidereal) days. What would the sampling density at the equator be for such a mission design? In other words, if you were to plot the ground track of the satellite, how far apart would the ascending tracks be along the equator?

A) 2500km B) 14.5km C) 232 km D) 173km

Q10: Gravity (10 pts)

A spherical harmonic model (SH) of the moon's gravity field may include SH coefficients $\bar{c}_{nm}$, $\bar{s}_{nm}$ complete to degree n_{max}=150. The SH model corresponds to a ground resolution of about:

A) 9km B) 73km C) 133km D) 267km

Q11: Gravity (10 pts)

The normal gravity field is a spherical ellipsoid of constant potential designed to closely approximate the geoid. Below is a table of computed values of the normal gravity field for a range of latitudes and longitudes.

lat	lon	normal gravity (m/s^2)
0 N	15 W	9.794
15 N	25 E	9.810
35 S	57 E	9.821
72 S	120 W	9.836

Using this table, determine the value of the normal gravity field at the lat/lon location (35N, 12W).

A) 9.794 B) 9.810 C) 9.821 D) 9.836

Q12: Optical remote sensing, 10 pts.

What is the peak spectral irradiance from the sun, as observed at the top-of-the-atmosphere? Assume the sun is a perfect blackbody radiator at T=5900K and that the wavelength is that which gives maximum radiant exitance, as predicted by Wien's Law.

A) 1991 W-m^{-2}-μm^{-1} B) .4912 W-m^{-2}-μm^{-1} C) 9.1978 $\times 10^7$ W-m^{-2}-μm^{-1} D) 2.741 W-m^{-2}-μm^{-1}

Q13: Space platform, time and reference systems (5 pts)

Which of the following time systems is NOT based on atomic time measurement:

A) UT1 B) UTC C) GPS time D) TAI

Q14: Optical remote sensing (5 pts)

Earth observing satellites carrying imaging systems operate in various spectral bands. Which of the following has the correct sequence of spectral bands, from smallest to largest wavelength:

A) Visible, Thermal InfraRed, Near InfraRed, C-band Microwave, X-band Microwave
B) Thermal InfraRed, Near InfraRed, Visible, C-band Microwave, X-band Microwave
C) C-band Microwave, X-band Microwave, Visible, Near InfraRed, Thermal InfraRed
D) Visible, Near InfraRed, Thermal InfraRed, X-band Microwave, C-band Microwave

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Q15: Gravity (10 pts)

Assume that a there exists a satellite that can measure slight changes in gravity over time from space (e.g., GRACE). The satellite orbits at an altitude of 465km, and it makes two passes over a lake that has a surface area of 140 km^2, during which the lake level increases by 12.3 cm. In order to detect the gravitational signal due to this change in lake level, how sensitive would the satellite sensors need to be? Assume a spherical earth and that the density of water is 1000 kg/m^3.

A) 1.722$\times 10^{-10}$ m/s^2 B) 5.314$\times 10^{-12}$ m/s^2 C) 6.049$\times 10^{-9}$ m/s^2 D) 1.844$\times 10^{-3}$ m/s^2

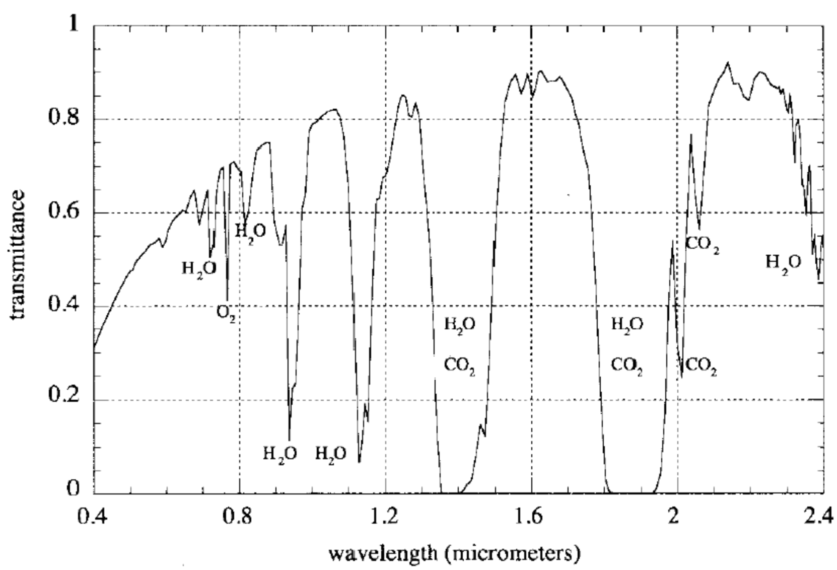
Q16: Radar (10 pts)

A radar transmits a signal with a power P_t of 1 kW. The return signal P_r is 90 dB weaker in power. How many Watts is the return signal?

A) 1 W B) 1$\times 10^{-2}$ W C) 1$\times 10^{-4}$ W D) 1$\times 10^{-6}$ W

Q17: Remote sensing (5 pts)

You are designing a remote sensing mission with the objective of monitoring Earth's cloud structure. The imager on your spacecraft is limited to the solar-reflective spectral region, characterized by the following transmittance properties:



Which one of the spectral bands near the following wavelengths should be used to best satisfy the mission objectives?

A) 0.8 μm B) 1.2 μm C) 1.9 μm D) 2.3 μm

Q18: Solid angles (10 pts)

The average distance Earth–Moon is 384403 km, and the Moon has an average diameter of 3476 km. What is the approximate solid angle covered by the Moon when viewed from Earth?

A) 2.6$\times 10^{-4}$ sr B) 8.6$\times 10^{-4}$ sr C) 6.4$\times 10^{-5}$ sr D) 1.3$\times 10^{-4}$ sr

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Q19: Mission Design (10 pts)

A satellite on an exact repeat orbit completes 244 orbital revolutions in 17 days, at inclination i=108°. If the satellite passes the equator northbound at UT 9h 00m, at what time (UT) does it pass the latitude 70° North?

A) 9h 22m B) 9h 33m C) 9h 53m D) It never reaches that latitude

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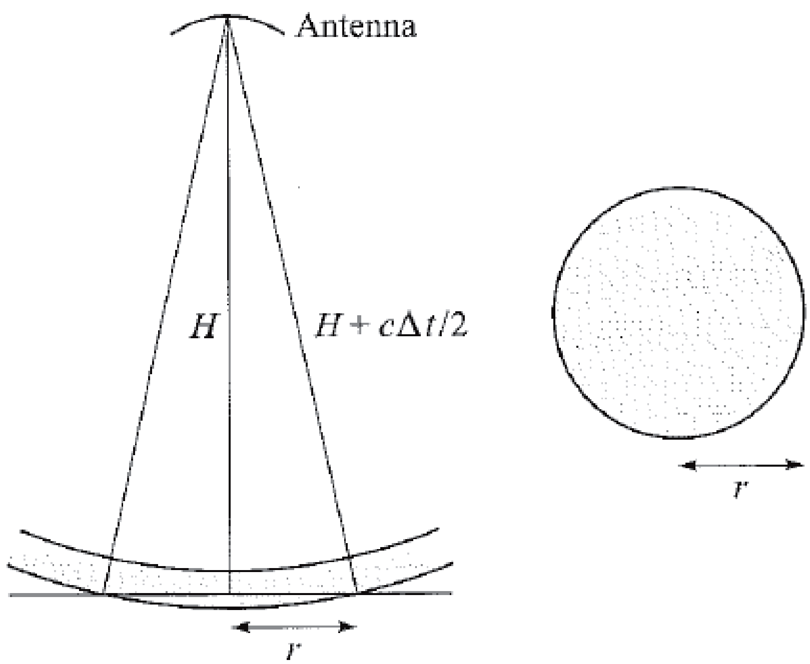
Q20: Altimetry (10 pts)

If a pulse of $\Delta t = 2$ns (1 ns $= 1 \times 10^{-9}$ sec.) duration were emitted from a radar altimetry satellite flying at an altitude of 800km (see figure below), approximately how large would the area of the illuminated area (in km^2) be on the Earth's surface? Assume that r $<<$ H.

A) 0.75 km^2 B) 1.5 km^2 C) 3.0 km^2 D) 6.0 km^2



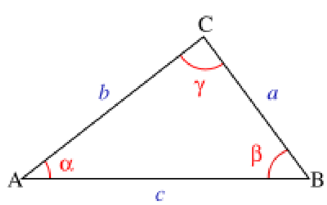
Equation sheet AE2103, Space Missions and Applications I

Physical constants		
c	Speed of light *in vacuo*	2.9979×10^8 m s^{-1} (defined as 299 792 458 m s^{-1})
h	Planck constant	6.6261×10^{-34} J s
e	Charge on the proton	1.6022×10^{-19} C
m_e	Mass of the electron	9.1094×10^{-31} kg
u	Atomic mass unit	1.6605×10^{-27} kg
m_0	Permeability of free space	1.2566×10^{-6} H m^{-1} (defined as $4\pi \times 10^{-7}$ H m^{-1})
ε_0	Permittivity of free space	8.8542×10^{-12} F m^{-1}
Z_0	Impedance of free space	$3.7673 \times 10^2\,\Omega$
G	Gravitational constant	6.6726×10^{-11} N m^2 kg^{-2}
R	Gass constant	8.3145 J K^{-1} mol^{-1}
N_A	Avogadro number	6.0221×10^{23} mol^{-1}
k	Boltzmann constant	1.3807×10^{-23} J K^{-1}
σ	Stefan-Boltzmann constant	5.6705×10^{-8} W m^{-2} K^{-4}
A	Wien's displacement constant	2.8978×10^{-3} K m

Units		
AU	Astronomical unit	1.496×10^{11} m

Properties of the Sun and Earth	
Sun's radius	6.96×10^8 m
Sun's mass	1.99×10^{30} kg
Total radiated solar power	3.85×10^{26} W
Sun's black-body temperature	5770 K
Earth's equatorial radius	6378135 m
Semi-major axis of Earth's orbit around the Sun	1.496×10^{11} m
Earth's mass $M_\oplus$	5.976×10^{24} kg
Standard gravitational parameter $\mu = GM_\oplus$	3.986×10^{14} m^3 s^{-2}
Mean global albedo	0.35
Moon's radius	1.738×10^6 m
Average Earth-Moon distance	3.844×10^8 m

Law of cosines: $c^2 = a^2 + b^2 - 2ab\cos\gamma$



Surface area of a sphere: $4\pi r^2$
Volume of a sphere: $\frac{4}{3}\pi r^3$
Area of a circle: πr^2
Circumference of a circle: $2\pi r$

Wave Equation:

$$\begin{aligned} E &= Ae^{j(kr-\omega t+\phi)} \\ k &= 2\pi\sqrt{\varepsilon_r}/\lambda \\ \lambda &= 2\pi c/\omega \\ \omega &= 2\pi f \end{aligned}$$

Remote sensing:

$M_\lambda = \frac{C_1}{\lambda^5\left(e^{C_2/\lambda T}-1\right)}$ $\qquad C_1 = 3.74151 \times 10^8$ W-m^{-2}-μm

$\lambda_{\mathsf{max}} = C_3/T$ $\qquad C_2 = 1.43879 \times 10^4$ μm-K

$C_3 = 2898$ μm-K

$E_\lambda^0 = \frac{M_\lambda}{\pi} \times \frac{\text{area solar disk}}{(\text{distance-to-earth})^2}$

$dB = 10 \cdot \log^{10}(P)$

$P_r = \frac{A_e G P_t}{(4\pi)^2 R^4}\sigma^0 A$ $\qquad G = \frac{4\pi A_e}{\lambda^2}$

$P_n = k \cdot T_{sys} \cdot B$ $\qquad \text{SNR} = P_r/P_n$

$\Omega = 2\pi(1-\cos(\alpha/2))$ $\qquad \Theta = \lambda/D$

$\Omega = A/R^2$

Miscellaneous:

$\text{GSI} = \text{inter-detector spacing} \times \frac{H}{f} = \frac{\text{inter-detector spacing}}{m}$

$\text{GIFOV} = 2H\tan(\frac{IFOV}{2}) = w \times \frac{H}{f} = \frac{w}{m}$

Keplerian orbits:

$$\begin{aligned} r &= \frac{a(1-e^2)}{1+e\cos(\theta)} \\ e &= \frac{r_a - r_p}{r_a + r_p} \\ T &= \frac{2\pi}{n} \\ n &= \sqrt{\frac{\mu}{a^3}} \end{aligned}$$

Repeat orbits:

$$\begin{aligned} j(\Delta L_1 + \Delta L_2) &= k2\pi \\ \Delta L_1 &= -2\pi\frac{T}{T_E} \\ \Delta L_2 &= -\frac{3\pi J_2 R_e^2 \cos(i)}{a^2(1-e^2)^2} \end{aligned}$$

Node rate: $\frac{d\Omega}{dt} = -3\pi J_2(\frac{R_e}{a(1-e^2)})^2 \cos(i)\frac{1}{2\pi}\sqrt{\frac{\mu}{a^3}}$

Newton's 2nd Law: $\bar{F} = m\bar{a} = \frac{\mu m}{r^2}\frac{\bar{r}}{r}$

Gravity:

$\Gamma = M + \dot{\Omega} + \Omega\Omega$ $\qquad M = \begin{pmatrix} \frac{\partial V}{\partial x^2} & \frac{\partial V}{\partial x \partial y} & \frac{\partial V}{\partial x \partial z} \\ \frac{\partial V}{\partial x \partial y} & \frac{\partial V}{\partial y^2} & \frac{\partial V}{\partial x \partial z} \\ \frac{\partial V}{\partial x \partial z} & \frac{\partial V}{\partial y \partial z} & \frac{\partial V}{\partial z^2} \end{pmatrix}$

$M = (\Gamma + \Gamma^T)/2 - \Omega\Omega$ $\qquad \Omega = \begin{pmatrix} 0 & \omega_3 & -\omega_2 \\ \omega_3 & 0 & \omega_1 \\ \omega_2 & -\omega_1 & 0 \end{pmatrix}$

$V(r,\phi,\lambda,t) = \frac{GM}{r}\sum_{n=2}^{\infty}\sum_{m=0}^{n}\left(\frac{a_e}{r}\right)^n \overline{P}_{nm}(sin\phi)[\overline{C}_{nm}(t)\cos m\lambda + \overline{S}_{nm}(t)\sin m\lambda]$