TT4234 Space Technology I Summary

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Abstract

This is a short summary of the course TTT4234 Space Technology I.

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Contents

1. The space environment

1.1. Magnetosphere

Earth is protected by the magnetosphere. Contains free charged particles. The magnetosphere is bounded by the magnetopause, bullet shaped. Magnetotail formed by pressure of solar winds on magnetosphere. Driven by rotation of Fe in Earth's core $\rightarrow$ magnetic dipole, 11 degrees inclination from rotational axis.

1.2. Radiation

1.2.1. Radiation from the sun

Solar flares are due to magnetic reconnection. Intense magnetic fields in plasma (neutrally charged gas with ionized particles) emerge on the corona $\rightarrow$ magnetic reconnection (magnetic energy turned into kinetic and thermal energy), mostly in solar spots $\rightarrow$ solar wind, energy from magnetic reconnection enough to accelerate particles and propel them around the solar system $\rightarrow$ collapse in magnetotail $\rightarrow$ injection of solar plasma at inner magnetosphere poles $\rightarrow$ aurora borealis.

1.2.2. Val Allen Belts

There are two radiation belts around Earth called the Van Allen Belts. The inner belt is mainly of protons and some electrons, while the outer radiation belt is mainly of electrons and some protons. The belts follow the magnetic field lines of Earth. Inner belt is due to neutron decay and solar winds. The inner belt consists of stable ionized particles built up over time. The outer belt consists of unstable particles, currents due to particles bouncing between the magnetic poles. Due to break-down of magnetic field around Earth. There is a safe zone in the gap between the two belts, caused by radio waves that eject any particles that would accumulate there.

1.2.3. South Atlantic Anomaly

The inner surface of the inner Van Allen belt is as low as 200-800km from the Earth's surface above South America. Satellites passing through are bombarded by high energy protons $\rightarrow$ glitches in data, problems with operation of electronic systems, premature aging of components. Also affects astronauts' vision!

1.2.4. Earth plasma fountain

Pressure from solar flares squeeze out gas from the ionosphere. Oxygen, helium and hydrogen ions gush into space from the Earth's poles. Most of the particles flow back towards Earth again.

1.2.5. Impact on space travel and satellites

Solar cells, integrated circuits, sensors and humans are vulnerable to radiation! Electronics on satellites must be hardened against radiation to operate reliably. Charged particles may cause bit flips, material damage, sputtering (ions hit surface $\rightarrow$ cascade of collisions $\rightarrow$ atom could be ejected. The sputter yield is the average number of atoms ejected from the target per incident, depends on angle, energy, masses, surface binding energy, orientation of crystal axes), damage of components, solar cell damage, interference, electric discharge. Ionized particles come from radiation belts, solar events or cosmic rays. Ionosphere is a shell of electrons and ions from the thin atmosphere, affects LEO sats.
Solar radiation force:

$$F = \frac{F_s}{c} A_s (1 + \rho) cos(I), \tag{1}$$

, where F_s is solar constant, A_s is illuminated surface area, ρ is surface reflectance, I is incident angle to the sun.

1.2.6. Radiation from space

The heliosphere protects the solar systems from cosmic radiation. Cosmic rays + thermal radiation from space.

1.2.7. Radiation from Earth

Thermal radiation + reflected radiation.

1.2.8. Satellite protection

Orbital position, switch off equipment in exposed areas, orient sat to protect vulnerable parts, equip sat with protection against solar wind.
Problem: different component have different operating temperature ranges. Measures to reduce the thermal effect impact on a sat is therefore necessary. Active thermal control such as heat pipes, shields or electrical heating. Passive thermal control by designing the system such that thermal equilibrium is gucci.

1.2.9. *Other effects*

Magnetic field effect: electrically leading material spinning in magnetic field will induce electrical current, oh no!
Gravitational effects: orbit changed due to gravitational fields from sun, other planets, moon and fluctuations in Earth's own field.
Outgassing in vacuum → contamination of components on sat.
Atomic oxygen erosion in LEO: changes in mass, surface properties, generate flux from oxygen erosion.
Space debris: natural material + space junk. Sat graveyard orbit outside of GEO used to reduce man-made debris. Still a yuge problem.

1.3. Man in space

Sputnik in 1957, Explorer 1 in 1958, Yuri Gargain in 1961.
Dalton's law: decrease in barometric pressure results in decrease in partial pressure of oxygen, duh... → availability of braething oxygen in ambient air decreases → risk of hypoxia.
Physiological zones: efficient(-3km): humans can adapt, supply of oxygen not required, gas expansion can cause problems to sinuses. Deficient zone (3km-15km): humans cannot adapt to lve at this altitude, supplementary oxygen required. Space equivalent zone (15km+): sealed cabins from low air density, body fluids boil at 19km due to low pressure (Armstrong Line), aerodynamic flight impossible at 60-80km (Von Karman Line).
Hypoxia: reduced transition of oxygen from the lungs to the blood (lung diseases), reduced oxygen carrying capacity in blood (CO poisoning), reduced blood circulation (heart failure, fainting, stroke), blockage of metabolism (cyanic acid, CO).
Weightlessness, reorientation, changes in circadian rhythms, workload, habitability, visual environment affect us in space. Sum of partial pressures of all gases are higher than environmental pressure → gas bubbles → decompression sickness more likely. This is a problem when doing EVAs.

2. Orbits

2.1. Kepler and Newton

1. The orbit of the planets are ellipses with the sun at one focus.
2. The line joining a planet to the sun sweeps out equal areas in equal times. $t_1 = t_2 \Leftrightarrow A_1 = A_2$

3. The square of the orbital period is directly proportional between the planet and the sun. With Newton:

$$T^2 = \frac{4\pi^2 r^3}{\mu}, \tag{2}$$

where $\mu = gM$

Then we have Newton's laws, and Newton's law of universal gravitation:

$$F = G\frac{m_1 m_2}{2} \tag{3}$$

Newton also proves Kepler's first law with the two-body equation:

$$R = a(1 - \epsilon^2)(1 + \epsilon \cdot \cos\nu), \tag{4}$$

where a is the longest distance to the center of the ellipse, $\epsilon = c/a$ is the eccentricity, c is the distance from focal point to center, ν is the true anomaly (sat angle in orbit). Perigee is the closest point to body, apogee is at the opposite side.

2.2. The six classical orbital elements

The reference frame is defined such that $\hat{K}$ points to the north pole, $\hat{I}$ points towards the constellation Aries, the vernal equinox direction. Line from Earth centre through the sun on first day of spring. Sure... $\hat{J}$ is then obviously normal to the other two axes. The six COEs can then be described as:

- a: semi-major axis
- ϵ: eccentricity
- i: inclination
- Ω: right ascension of the ascending node
- ω: argument of perigee
- ν: true anomaly

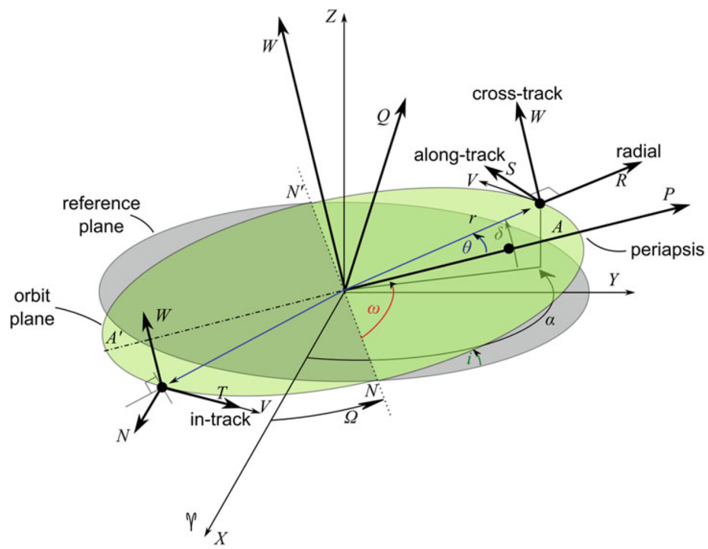

Figure 1: COE

2.3. Spacecraft velocity

Energy analysis yields:

$$v = \sqrt{\mu(\frac{2}{R} - \frac{1}{a})} \tag{5}$$

The two cosmic speeds are defined using this equation. The first cosmic speed is the speed needed to set a spacecraft into orbit just above the Earth's surface: $v = \sqrt{\frac{\mu}{R}} \approx 7.9$ km/s. The second cosmic speed is the speed needed for a spacecraft to escape from Earth's gravity, and never return: $v = \sqrt{\frac{2\mu}{R}} \approx$ 11.2 km/s. Therefore propellant is the limiting factor for placing a sat in orbit. Need several stages in order to reach these speeds.

2.4. Satellite orbits

Low Earth Orbit(160 km < LEO < 2000 km): ISS, earth observation

Medium Earth Orbit(2000 km < MEO < GEO): navigation

Geostationary Earth Orbit(GEO: 36000 km): communication, broadcasting, always equatorial, oen sidereal day period. The GEO orbit is a limited natural resource! All countries have their own bands in the GEO belt. $a = r, \epsilon = 0, i = 0$

Highly Elliptical Orbit(HEO: an elliptic orbit): characterized by a relatively low-altitude perigee and an high-altitude apogee, communication

Polar orbit: orbit along both poles - $a = r, \epsilon = 0, i = 90$

Sun synchronous orbit: sat should be above same point on Earth every day. Therefore we need a nodeal regression rate of 0.986 degrees. Typically a morning-evening orbit or day-night orbit.

Molniya orbit: sat above a fixed point on Earth for a long time (typically 11 hours ish). Special case of HEO orbit to achieve this. Choose orbit with no perigee drift i.e. i = 63.4 degrees. T choosen to be 12 sidereal hours. Cool and good!

Most of the atmosphere is below 30km, but drag is impactful below 200km.
Satellite groundtrack: plot the sat position over time on Earth map.
Satellite footprint: plot areas on map that indicate dish size needed to receive sat signal on earth.
Launch window: in order to launch directly into orbit your launch site must be situated directly below the orbit. So you may only launch sats into orbits with higher inclination that your latitude. The Earth's rotation must also be taken into account when calculating the right launch angle.
Sidereal time: one sidereal day = one complete rotation of Earth. Different with solar day: then the Earth rotates 360 + 0.986 degrees from the solar orbit!

2.5. Hohmann transfer

Optimal transfer orbit is at apogee. Calculation: find Δv needed at transfers, use eq:v. Then use the rocket equation to find fuel needed.

2.6. Orbital perturbations

Gravitational effects: discussed above. One example is changes in inclination at GEO orbit because of inregularities in Earth's gravity. Due to Earth's rotation, the radius of Earth is different at equator than at the poles (J2 effect) $\rightarrow \Omega$ and ω will not stay constant! Since the Earth's center of mass is not exactly at the Earth's center, the orbit will start precessing $\rightarrow \Omega$

will change.
Atmospheric drag, direct solar radiation pressure, solar radiation reflected from Earth's surface, ...

3. Earth observation and navigation

3.1. Observation systems

Transmitted signal from craft - propagation channel - object for observation - channel - sensor, analysis on craft - channel - analysis, archiving on Earth
Active(ladar, radar) vs. passive systems(photos, radiometry), radio waves vs. optical waves. Atmospheric windows at radar and a few bands around light and infrared.

3.2. Resolution

$$R = \frac{2.44\lambda H}{D} \tag{6}$$

From the definition we see that light has much better resolution from the shorter wavelength, but not as practical as radio waves has much better penetration in the atmosphere. Synthetic aperture: radar pulses processed with amplitude, phase and position to fake a larger aperture. We can also use chirp signals to increase resolution.

3.3. Interferometry and altimetry

Tracking distance changes of points over time using radar, used to track volcanos, earthquackes etc. Can also measure sea level and sea floor developments and the like using similar technique. Transmit radar pulses at sea, calculate distance, need to correct for atmospheric and instrumental effects. Can obtain really accurate measurements, like 3-4cm! Need to know sat position. Laser ranging from ground stations to sat reso-reflectors (SLR) + radio/microwave doppler (DORIS) + GPS. Track sea surface, geoidal height, gravitational anomalies, ocean circulation etc. To clarify, altimetry tracks changes over time, interferometry uses several radar images from slightly different locations and tracks differences between these images to calculate changes in landscape.

3.4. The geoidboi

The Earth's figure is defined in different ways in Geodesy. Earth's physical shape vs. Earth's mathematical shape (the reference ellipsoid). The Geoid comes in between these shapes, and takes how the Earth's gravity field changes into account. The geoid is an equipotential surface which would coincide exactly with the mean ocean surface of the Earth, if the oceans were in equilibrium, at rest, and extended through the continents. A better model than the reference ellipsoid, fitted experimentally from data. It can be presented by its deviation from the reference ellipsoid. Measure climate changes, tsunamis, hurricanes, snow depth, ship routing, offshore etc.

3.5. Bragg scattering

Measure resonance when radio waves hit surface from different angles. Backscattered power from waves depend on wind speed and direction $\rightarrow$ estimate wind velocity. Measure sea waves, wind, oil spill etc.

3.6. Passive techniques

Photographic, radiometry(measure radiation, used for snow depth measurements), gravitational, spectral measurement of stars, infrared measurements from albedo (reflection of solar radiation).

3.7. GPS

Global satellite navigation system developed by US DoD, constellation of between 24 and 32 MEO satellites. There are six orbital planes equally spaced. There are control stations located all around the world in charge of control. There is the Precise Positioning System for authorized users, and the Standard Positioning System for civil users. Determination of location, time and velocity. Need 3 sats to give 3 coordinates in space, 4 for time information as well. 4 sats = 4 equations with 4 unknowns. This is needed to correct the receiver's clock as GPS receivers do not have high quality clocks. The satellites transmit two microwave carrier signals, L1 carries the navigation message and code signals, and L2 is used to measure the ionospheric delay. The signals are shifted by the three following binary codes: the C/A code modulates the L1 phase, the P-Code modulates both of the phases for encryption and the Navigation Message also modulates the L1 signal with the bits that describe the GPS sat orbits. The ephemeris defined the GPS sat's orbit with 16 variables.
Differential GPS uses error measurements from ground stations to correct

GPS signals, real-time or in post-processing. Errors in orbit, clock, ionospheric and tropospheric delta, signal multipathing, jamming and other noise. GNSS stations on the ground lets us track global velocities at these points (deformation of the Earth).

3.8. Satellite gravimetry

Position + gravity measurement = model of Earth's gravity, tracking changes in Earth's gravity due to changes in mass distribution. Old gravimetry sats were equipped with reflectors and high-precision laser ranging instruments. Next gen sats use inter-satellite instruments, GPS, accelerometers.

4. Microgravity

Microgravity: very low g conditions. Research done with drop towers, parabolic flights or on the ISS. Drop towers simulate microgravity by dropping a capsule in a vacuum, free fall in vacuum is the same as microgravity in the reference frame of the capsule. The same effect happens in parabolic flights, where the plane accelerates upwards and then moves in free fall. On the ISS you can do microgravity research for extended periods of time. It is possible to simulate free fall using buoyancy experiments, clinosats that slowly turn plants around an axis to average out some of the vectorial stimulations to the organism.
Phenomena affected by gravity: convection, sedimentation and buoyancy, capillary forces(fluid flows in narrow spaces, enhanced in microgravity), surface tension(more dominant in microgravity, as buoyancy and sedimentation is reduced), pressure, combustion phenomena. Plants use sedimentation to find "up", this is not possible in microgravity. Furthermore, we need forced ventilation.
Since sedimentation of a particle in an organ is the key process of the mass perception in the balance system, the body is confused in microgravity. Furthermore, the blood circulation is increased when first exposed to microgravity, and then it is decreased at prolonged microgravity exposure. Bone loss, muscle loss and perception errors are also problems.

5. Satellite platforms

5.1. Requirements

Start with requirements from the customer. Could be requirements linked to mission, linked to operation in hostile space environment, operation time, launch specs, requirements for keeping the orbit and craft orientation, requirements to keep contact with sat, cost requirements, requirements for control after its dead.

5.2. Mass control

Rocket equation:

$$\Delta v = I_{sp} g_0 \ln \frac{m_i}{m_f} \tag{7}$$

You could rewrite some stuffs in the equation like $v_e = I_{sp} g_0$, where v_e is the exhaust velocity, or $m_f = m_i - m_p$. Note that m_i, m_p, m_f is respectively the initial mass, propellant mass and final mass, and $I_s p$ is the propellant's specific impulse and g_0 is the gravitational acceleration at sea level. Note that this equation does not take gravity or drag into account, therefore more precise when calculating orbits than launches.

5.3. Orbit control

Attitude control: control the craft's orientation in space. Orbital perturbations such as atmospheric drag, irregularities of the Earth's gravitational field, lunar and solar gravity, solar pressure must be taken into account. Drift of node and perigee as previously discussed are also problems.
Pointing accuracy:

$$\Psi = \frac{D}{h}, \tag{8}$$

where D is the diameter of the target and h is the distance to the target.
Antenna beamwidth:

$$\theta_{3dB} = k\frac{\lambda}{A}, \tag{9}$$

where k is the reflector coefficient, A is the antenna diameter and λ is the wavelength.
Torques on a satellite: gravity-gradient torque, solar radiation torque, magnetic torque, aerodynamic torque $\rightarrow$ Oh frick, my satellite is spinning:(
Different systems for stabilizing satellites, like spin stabilized(if our sat if spinning in a controlled direction, it is more stable), thrusters to exercise

opposite torques, or momentum-control using conservation of momentum. Momentum-control can be done using reaction wheels that oppose the torques. These wheels can be operated as momentum wheels by keeping the spin constant and then they work as spin stabilized.
We also have to orient the antenna! We either have three-axis stabilization or dual-spin stabilization. In order to reduce precession in the sat we can passively use a tube of viscous fluid from the friction of the liquid, or actively with pulse mode thrusters. If we have two axis stabilized, we have 2 radial and 2 axial thrusters, in three axis we position thrusters on each face along four corners.
We need sensors as well for orbit control! Can use sun, earth, star, gyroscope, etc...

5.4. Power control

Usually available power, not aging of structure/components, that determine sat lifetime. Therefore it is important to be energy efficient.
Rocket engines: solid propellant(simple, reliable, cannot be stopped, high thrust), liquid propellant(mono or bi, can be stopped and started, moderate thrust), ion propellant(propellant atoms are injected into discharge chamber and gets ionized by electron bombardment. Positively charged ions move due to diffusion, are accelerated by the potential difference between two grids. Electrons are also emitted to avoid a negative net charge on the craft. Can be stopped and restarted, high specific impulse, low thrust, complicated). Will discuss this topic more later.
Total impulse:

$$I_{tot} = F\Delta t = \Delta p \tag{10}$$

Specific impulse:

$$I_{sp} = \frac{F}{g_0 \dot{m}} = \frac{I_{tot}}{\Delta m g_0} = \frac{v_e}{g_0} \tag{11}$$

Measure of propellant efficiency, unit in seconds.
The main power supply for the electrical energy needed for all subsystems onboard is solar cells and batteries. Alternatives are primary batteries (no charging), fuel cells(short missions) and nuclear power(long missions). The output power of a solar cell depends on the solar incidence angle:

$$P \ \alpha \ \rho_{solar} \cos(\delta A), \tag{12}$$

where ρ_{solar} is the solar power flux density at the solar panel, δ is the sun angle and A is the solar panel area. Furthermore, the solar flux changes with

the seasons, and the efficiency of the panel is exponentially degrading as well, due to high energy particles and UV radiation.
Depth of discharge is the ratio between the used electrical charge and the battery's total stored electrical charge:

$$DoD = 100\frac{W_{used}}{W_{total}} \tag{13}$$

The smaller DoD, the more times a battery can be cycled before it dies. So if you let the battery deplete more, you get less uses of it. That makes a lot of sense.
When dimensioning the system, you need to find the necessary W_total needed, and the necessary solar panel output.

5.5. Temperature control

We have touched on this before, different component have different temperature operating ranges. We need to keep a stable temperature in mad hostile conditions yall. Use passive protection like blankets and heatpipes or active components like heaters. Heatpipes are based on evaporation and condensation of a fluid, if a lot of the thermal energy goes into evaporating a fluid instead of heating your precious components, the system does not heat up as fast. Blankets change the absorption coefficient of the exposed surfaces of the spacecraft and shit. Electrical heating elements are controlled by thermostat or remote control.
Absorbed power:

$$P_{abs} = S\alpha A_a, \tag{14}$$

where S is the solar constant, α is the absorption coefficient and A_a is the area of the absorbing surface. Radiated thermal power:

$$P_{rad} = \epsilon A_r \sigma T^4, \tag{15}$$

where ϵ is the emission coefficient, σ is Stefan-Boltzmann, T is temperature and A_r is the area of the radiating surface. Thermal equilibrium:

$$T = (\frac{\alpha A_a S}{\epsilon A_r \sigma})^{\frac{1}{4}} \tag{16}$$

5.6. Telemetry

The communication channel between the control centre on Earth and the satellite. Telemetry is measuring the sat's physical parameters, tracking is measuring the orbital information and command is corrections of orbit/attitude, switching of antennas, transponders etc (TTC). Components: Sat + gateway station + TTC station + satellite control center + user terminals. The control center processes telemtry data from sat, calculates orbital data from satellite position, plans and executes commands, controls and supervises the TTC stations. The TTC station transmits the commands to the sat and receives data from the sat. It also determines the distance and elevation angle to the sat. Measures distance from phase shift of signal you send to the sat, need to send several tones to solve the system unambiguously. $\phi = d2\pi/\lambda$, $D = \phi\lambda/4\pi + n\lambda$.

5.7. Mechanical requirements

Need to consider structures for mounting the components, protection from radiation and debris. Mechanical deployment of antennas and solar panels. Need motors to drive solar panels, despun motor(for dual spin satellites, where the main body is rotating for stability, and for instance the antenna part is pointing towards target, need motor), reaction wheels, hinges for antennas, electro-mechanical valves, gyros, thrusters and on and on...

5.8. Payload

Navigation(GPS), remote sensing, communication payloads...

5.9. Debris

Problem: only debris with a size above 10cm in diameter is tracked. But much smaller debris (0.2mm flake with Challenger) can be really destructive.

6. Communication via satellite

Why? Coverage, availability, invulnerable to terrestrial damage, bandwidth. But vulnerable to space damage and difficult to repair, interference, cost, development time, large distance.

6.1. Satellite communication networks

Broadcasting: uplink $\rightarrow$ downlinks at same frequency, large coverage, $f_{up} > f_{down}$
Point to multipoint: uplink $\rightarrow$ many downlinks at different frequencies, may require on-board processing, addresses the individual receiver, broadcast doesn't do this.
Point to point: uplink $\rightarrow$ downlink, the two terminals are paired.
Interactive systems: terminals are also transmitters. Star: if terminal A wants to talk to terminal B it has to go to sat operator on uplink. Internet browsing, file transfer... Mesh: on-board processing, two seperate satellite networks, control network + communication network. So A can talk to B only through sat, doesn't need to go through sat operator terminal.

6.2. Link budget

Requirements for a satellite communication system can be in cost, fuel, mass, real-time, coverage, availability, link ... We will discuss link requirements by setting up a link budget.
Signal to noise ratio:

$$\frac{S}{N} = \frac{\text{EIRP}}{L_0}\frac{G}{T}\frac{1}{kB}\frac{1}{L_a}, \tag{17}$$

where EIRP is the equivalent isotropically radiated power, G/T is the figure of merit, $L_0 = (4\pi d/\lambda)^2$ is the free space losses, B is the bandwidth and k is Boltzmann. G is the antenna gain:

$$G = \eta 4\pi A\ \lambda^2, \tag{18}$$

where η is the antenna efficiency, A is the aperture area of the antenna, λ is the radio wavelength of the carrier. Ratio between the amount of energy propagated in a certain direction and the energy that would be propagated if the antenna was isotropic(radiates energy equally in all directions).
EIRP is the amount of power that an isotropic antenna would emit to produce the power flux density observed in the direction of maximum antenna gain: $\text{EIRP} = G_{max}P_0$.
Received power: $P_r = \phi A_e$, efficient antenna surface: $A_e = \eta A_r = G_r\lambda^2/\pi$, radiated power flux: $\phi = P_tG_t/\pi d^2 \Rightarrow \text{EIRP}G_r(\lambda/4\pi d)^2 = \text{EIRP}G_r/L_0$, where we define free space loss as $L_0 = (4\pi d/\lambda)^2$.
L_a are the various additional losses like pointing error, implementation loss, quantification noise, interference(from other sats into station, from other

stations into sat, from station to station, natural radiation, pointing errors), nonlinearities, rain fade(dB loss/km - reduction in availability, larger when we have to go through more atmosphere, i.e. low angle to sat), ... Usually a margin is added to the link budget to cover all these possible losses in L_a. Challenges: latency, source encoding, BER, availability, network control.
T is the system temperature, describing the amount of noise. White noise is generated by internal and external thermal noise, system temperature takes all temperatures in the system into account somehow? G_r/T is called the figure of merit, and signalizes the quality of the receiver. For a system with uplink and downlink we get:

$$\frac{S}{N} = \frac{1}{\frac{1}{S/N_{up}} + \frac{1}{S/N_{down}}} \tag{19}$$

We use this to calculate margins, dimension the system, determine best modulation and coding, evaluate vulnerability and availability. The signal to noise ration is usually expressed in dB: $10\log_{10}(x)$.

6.3. Modulation

signal → source encoder → modulator → filter → upconvert
Digital information to be transmitted will be matched to modulated signal waveforms representing one or several bits depending on the chosen modulation format. Binary phase shift keying (BPSK) vs. quarternary pahse shift keying (QPSK), basically cos vs. cos+sin. Since cos and sin does not interfere, we can transfer twice as many bits per period with QPSK. Also higher order modulations, like 16-QAM.
Since modulated symbol is limited in time, it has an infinite spectrum (sink). Use matched Nyquist filtering: set $G(f) = H(f) = \sqrt{Ny(f)}$, where G is the transmission filter and H the reception filter. This comes from the fact that we want zero intersymbol interference (ISI, distortion where one symbol interferes with other symbols). With a lot of Nyquist filtering we can do the approximation $S/N = E_s B_t / N_0 Br \approx E_s/N_0$.

6.4. Error rates

Introduce bit error rates(BER). Want to dimension the satellite system with power, antennas, bandwidts, modulation schemes etc., so that your signal comes through with the correct E_b/N_0, in order to give the correct BER for your application.

6.5. Channel coding

Shannon limit: theoretical limit to channel encoding efficiency. Channel encoding is to introduce redundancy in a controlled manner, in order to increase the distance (Hamming or Euclidean) between code words. Repetition code: $0 \to 000$, $1 \to 111$, the received word is decoded to match the code word that is closest. Hard decision: above or below zero (Hamming), soft decision: also look at value of signal (Euclidean).
The cost of the increased accuracy is redundancy. $S/N = E_b mR/N_0$
Use high power amplifier, means code words are changing phase and scale, need to find optimal operating point, where the degradation is at a minimum.

6.6. Access schemes

FDMA: frequency division, TDMA: time division, CDMA: spread signal in frequency, use coding schemes, MF-TDMA: FDMA + TDMA. Ob-board processing: router in the sky, reduced latency + efficiency, but complex.

7. Chemical rocket propulsion

7.1. Chemical rocket basics

Chemical rockets generate thrust by combusting energetic matter (propellant) producing a thermal hot gas which is then converted into kinetic energy. We use the rocket equation to do basic calculations. Rocket mass ratio:

$$R = \frac{m_0}{m_f} = \frac{m_p + m_s + m_{pl}}{m_s + m_{pl}} \tag{20}$$

Thrust:

$$F = \dot{m}_d v_e + (p_e - p_{\text{inf}})A_e \tag{21}$$

Combustion chamber + nozzle, we hit mach 1 at the narrowest point in the nozzle (speed of sound). Total impulse is thrust integrated over time, specific impulse is the total impulse over propellant mass, as discussed previously.

7.2. Solid propellant rockets

Oldest, most frequently used rocket engine. Best thrust compared to mass, used to boost heavy launchers. Compact and reliable, but explosive and hard to control. The solid propellant rocket motor consists of igniter + solid propellant grain. Types: double base(nitrocellulose + nitroglycerin) or composite(oxidizer+fuel+binder+hardener). Need to take geometries into account, usually 2D star shape to increase burning area.

7.3. Liquid propellant rockets

Propellant in liquid form in separate tanks. Very complex, but controllable. Liquids are pressure fed or pumped into the combustion chamber. Higher specific impulse than solid.
Pressure fed system: 2 high pressure propellant tanks with flow control values into combustion chamber + pressuring gas and value to obtain high pressure in tanks. This is simple and low cost, but propellant ranks are really heavy at larger sizes.
Turbo pump system: 2 low pressure propellant tanks + turbo pump driven by gas generator + flow control valves into combustion chamber. More efficient at large scale, high specific impulse, but very complex and high cost.
Mono-propellant thrusters: propellant into catalyst pack, need only pressuring gas. Cheap and compact.

7.4. Hybrid rocket engines

Not as complex as liquid, but still controllable. Sounds amazing right? Nah, it is very hard to get the fuel to burn efficiently, the burn rate is low, the burn is unstable and it's hard to mix. The build consists of solid fuel in combustion chamber + oxidizer fed into the chamber.

8. Aurora borealis and some other stuff

8.1. Aurora borealis

We have previously discussed solar wind and the magnetosphere as the cause of the aurora. The ionosphere is a shell of electrons and ions from the thin atmosphere, ionization depends on sun activity, seasons, location, time of day. Ionosphere mostly due to UV radiation from the sun. In northern regions energetic electrons, protons and alpha particles from the sun and magnetosphere penetrate the atmosphere and produce extraordinary amount of ions, results in aurora. The aurora oval is determined by the position of the sun and the magnetic pole. The oval is fixed with respect to the sun, the earth rotates below. Kp index is a useful predictor of aurora, log scale, compiled from magnetometer measurements.
Homogeneous arch (orthogonal to field lines) vs. beam structure (parallel to field lines). Ribbon, drape, corona. Phases: stable arches, intensity increases and beams, outburst, intensity diminishes.

8.2. Spectral lines

Spectral lines are caused by electron transitions in the atoms, spectral ribbons are caused by electron transitions in the molecules. Three states arise from the oxygen ground state. Strongest spectral line is the green-yellow oxygen line.

8.3. Noctilucent clouds

Highest clouds in the atmosphere, reflect sunlight, composed of tiny crystals of ice and dust. Believed to come from micrometeors, as the clouds are too high to be created by regular means. Only in summer, as it is only cold enough to form the crystals in summer(yes i know it doesn't make any sense).

8.4. Terrestrial gamma flashes

Sprites are large-scale electrical discharges that occur high above a thunderstorm cloud, triggered by discharges of positive lightning. Blue jets project from the top of the cumulonimbus above a thunderstorm. ELVES are flat, circular, expanding glows in the ionosphere.

9. The Earth's atmosphere

The troposphere(6-18km): global wind systems, clouds, most water and weather is here, planetary boundary layer: turbulent layer of air from earth radiation (ish 1km).
The stratosphere(-50km): ozone, polar vortex, it's dry.
Mesosphere(-90km): really boring, too high for balloons, too low for sats. Noctilucent clouds are here.
Thermosphere/ionosphere: ions from UV, northern lights.