Space Technology

Attitude Control

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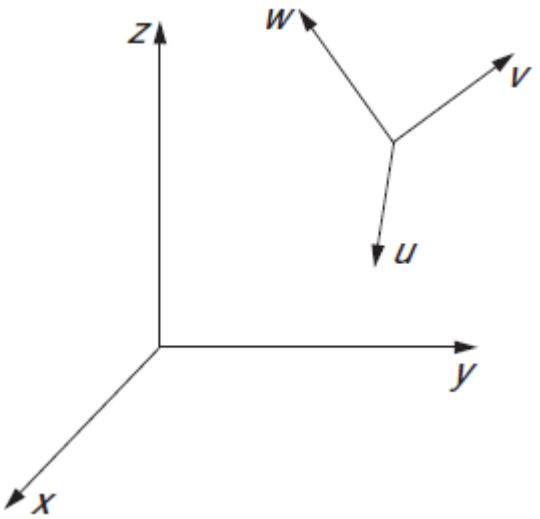
The attitude control system (ACS)

Determines and controls the orientation of the spacecraft (not orbit control!)

Attitude: the angular deviation of two coordinate systems (reference system/body system)



References:

- stars
- geocentric
- spacecraft mass centre

- ❑ Measures and determines the actual attitude — gyroscope and gimbals
- ❑ Compares with the desired attitude
- ❑ Drives the actuators in order to achieve the desired attitude
  - ❑ Passive attitude control: steering of the attitude without the use of actuators
  - ❑ Active attitude control: actuators are used within a control loop

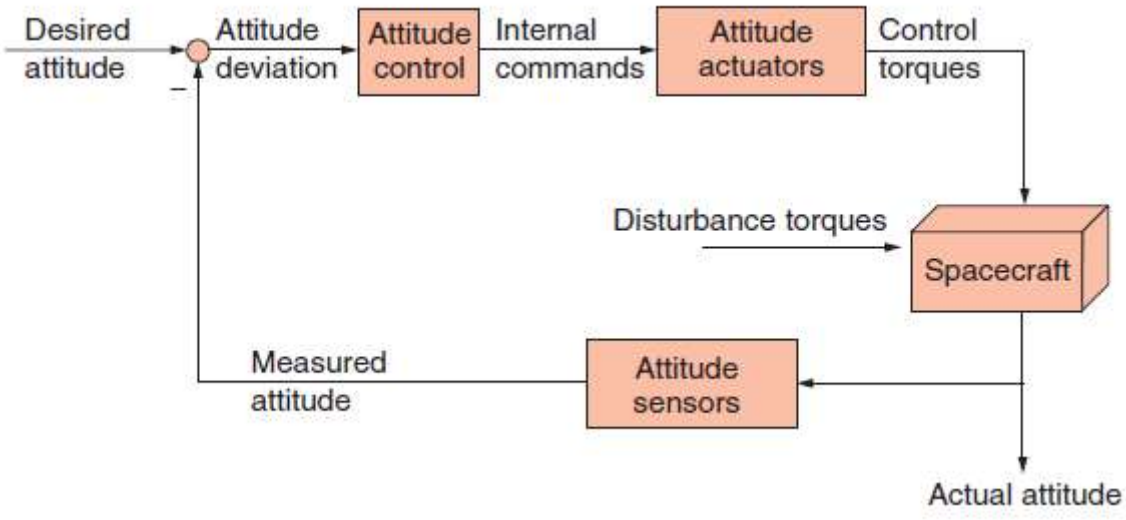
- ❑ Accuracy, stability and speed requirements (+cost, +lifetime)

Source of disturbances

- Internal torques: actuators and moveable mechanisms
- External torques: interaction with the space environment
  - Gravity gradient (e.g. Earth)
  - Solar radiation pressure (geometry dependent)
  - Aerodynamic torque (atmosphere, LEO orbit)
  - Earth's magnetic field
  - Others: fuel leakage, crew movement, etc.

Attitude determination and control

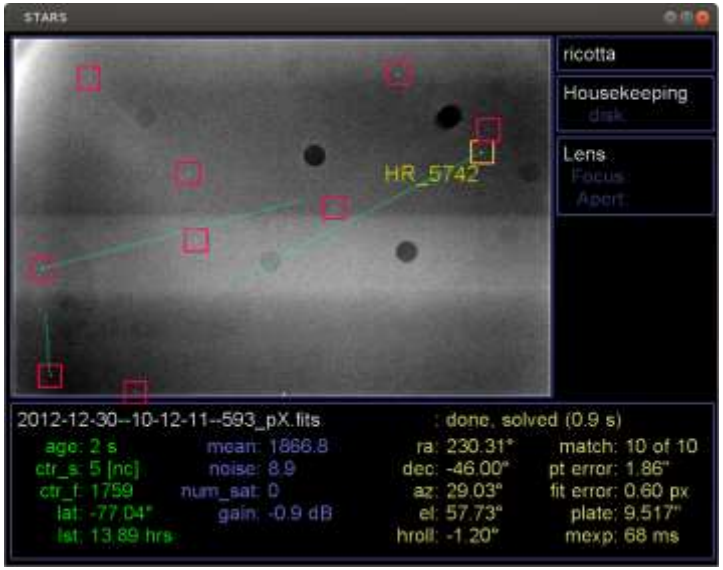
1. Calculate the actual satellite attitude (three-axis attitude)
2. Active modification of the satellite's attitude

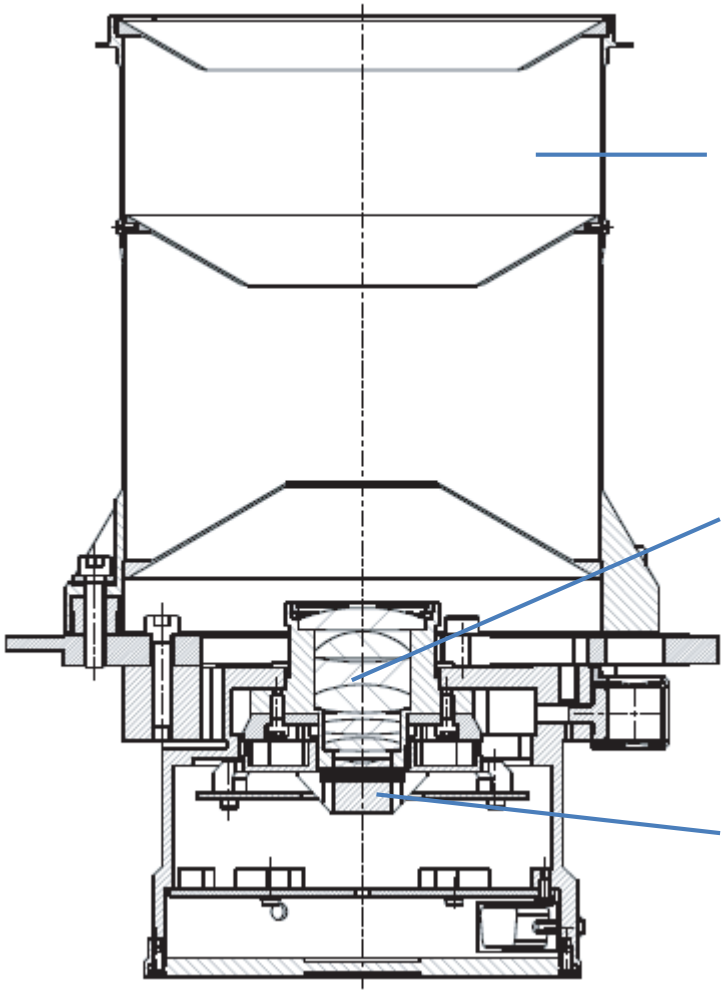


Sensing the attitude – Star sensors

- Identification of star patterns
  - camera (sensor head)
  - electronics for image processing and attitude determination

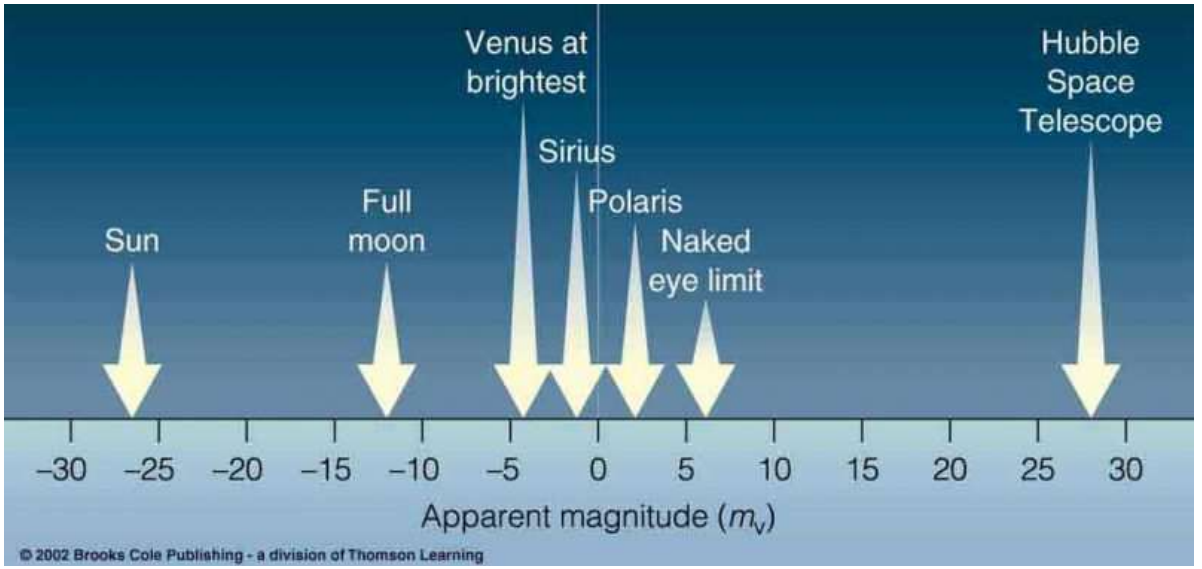
- Parameters:
  - accuracy (1-5”)
  - signal strength
  - # of processed stars





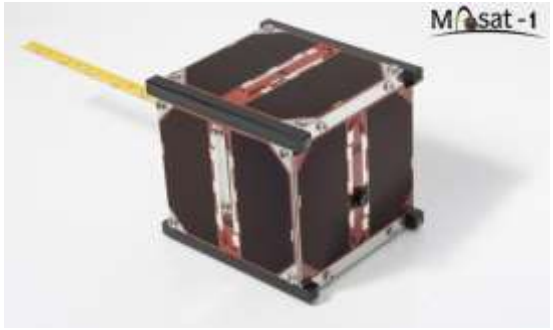
Alphasat TDP#6: Star tracker

- Determine the location and attitude of a satellite
- Analyse the placement of the surrounding stars relative to the payload
- Operating conditions: -30°C / 60°C
- View: 20°; min. magnitude: 5.8; accuracy: 4.3/26 arcsec for the xy/z axes; 1024*1024
- A catalogue of over 3000 stars for guiding purposes
- Active pixel detector system (ASTRO APS) the most advanced radiation-resistant detection technology for long-term missions.

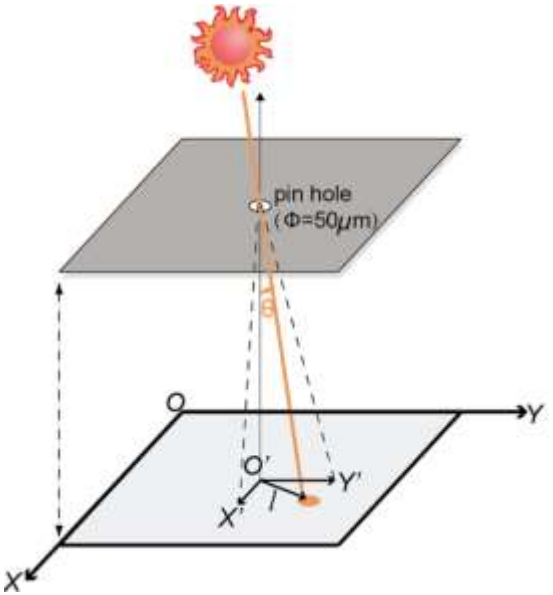


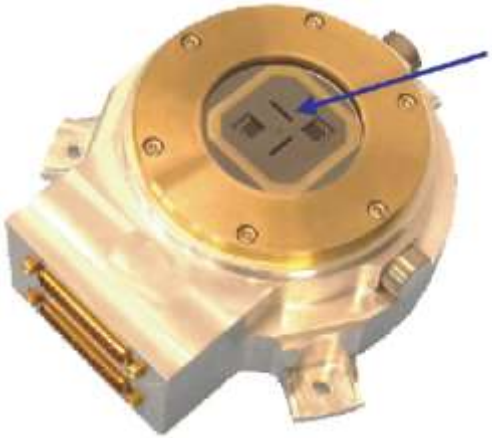
Sensing the attitude – Sun sensors

- Two-axis direction information
  - coarse (10-20°): comparison of the currents generated by the different cells

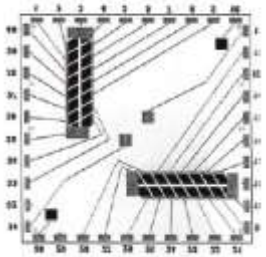


  - fine sensors (0.01°): baffles/slots + photocells or CCD chips





Slots to avoid diffuse light

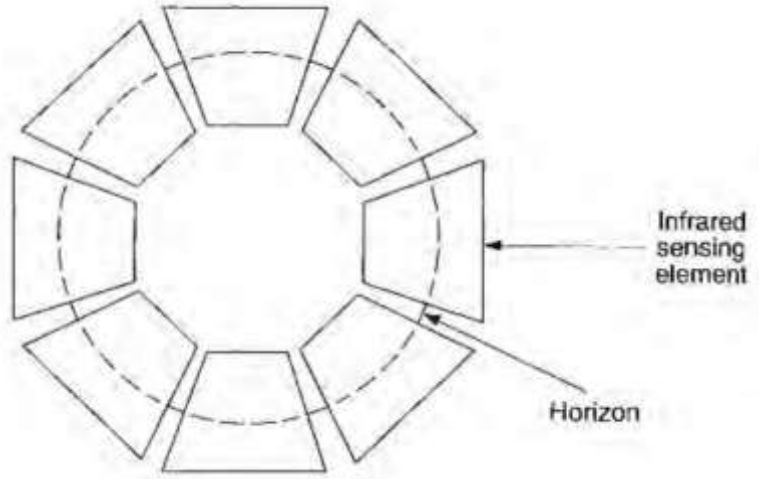


Detector

Sensing the attitude – Earth sensors

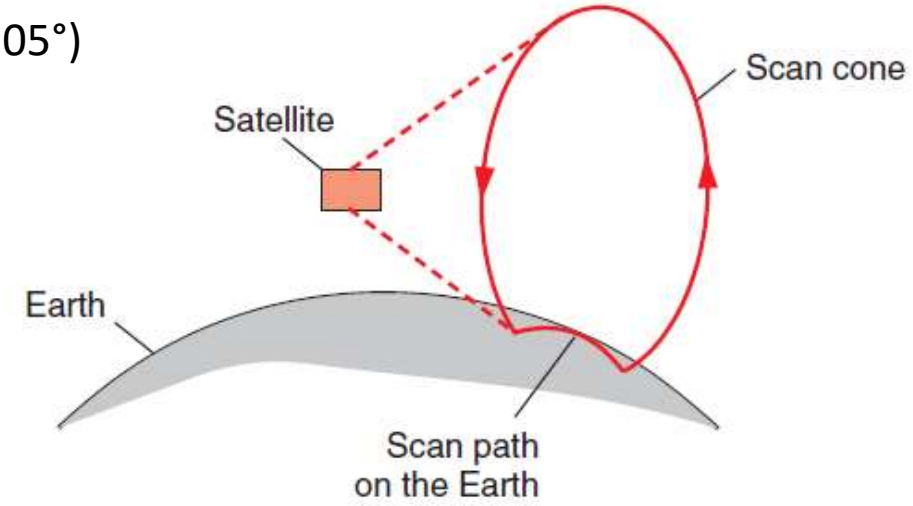
- They detect the Earth's horizon based on thermal infrared spectrum sensing: temperature dependency exists!
  - static (1°)

Germanium lenses



(thermopiles)

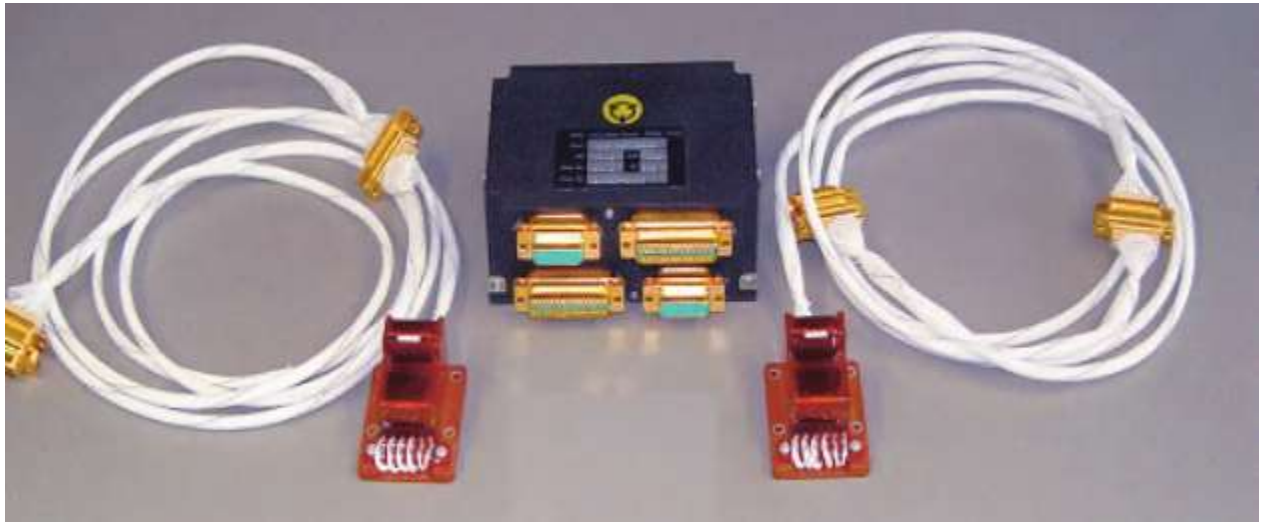
  - scanning (rotating mirror), (0.05°)



Sensing the attitude – Magnetometers

- Measurement of the Earth's magnetic field (0.1-1°direction precision)
- Coil-magnetic field-torque

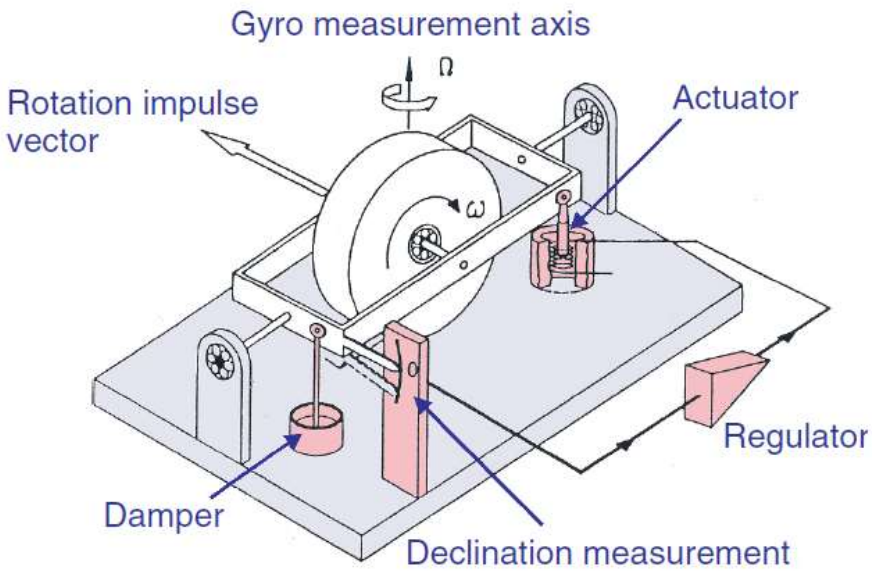
electronics



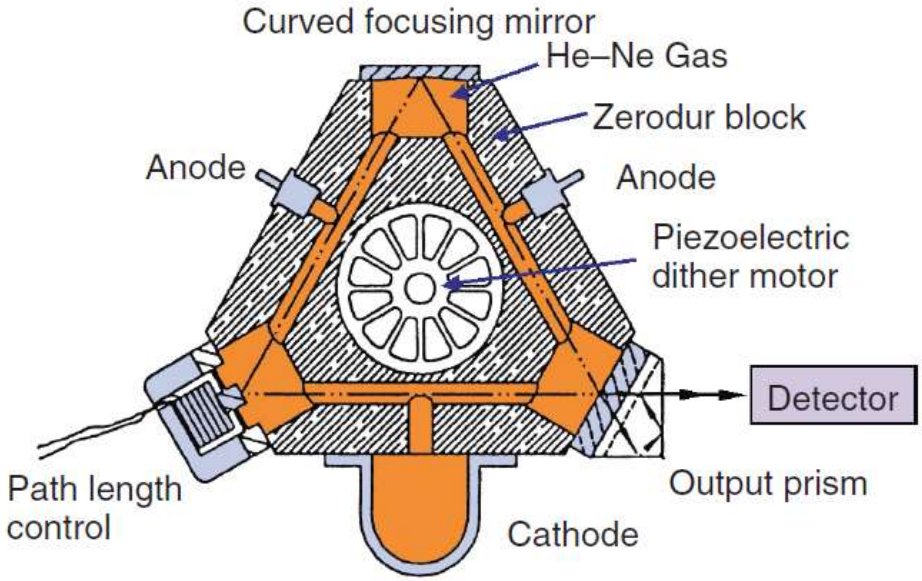
sensor heads

Sensing the attitude – Gyroscopes

- Measure rotations in an inertial reference frame
- Independence from external sources
- Useful also for stabilizing spacecraft rotation
- Types:
  - Mechanical
  - Hemispheric resonator (deformation due rotation)
  - Ring laser
  - Fiber optic



Mechanical gyro

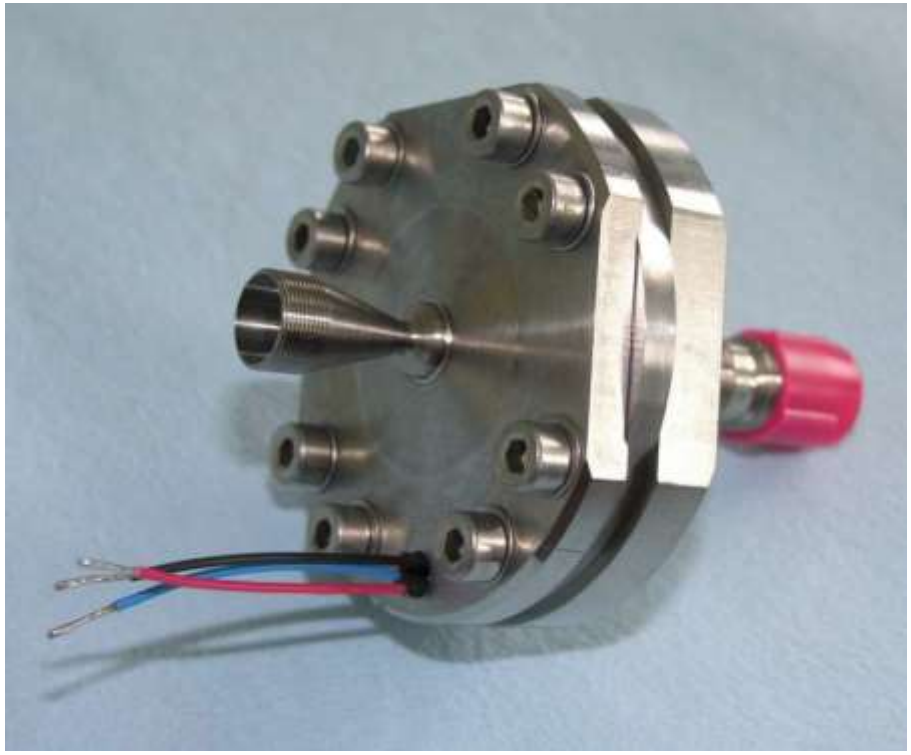


Ring laser gyro (interference; relativistic)

Actuators for attitude control 1.

- ❑ The spacecraft can be moved only by torque
- ❑ A torques changes the angular momentum

- ❑ External torque: cold gas thruster



- 0.1-10Nm torque level

Actuators for attitude control 2.

- External torque: magnetic torquer
- A strong magnetic dipole that interacts with the Earth's magnetic field
- Weak: 75-10000μNm

Actuators for attitude control 3.

- Internal torque:
  - Rotational acceleration or deceleration of a flywheel
  - Rotation is driven by an electric motor which allows a variable torque
  - 0.1-250Nm

  - reaction wheel
  - Designed for high torque provided at low rotation speeds
  - bidirectional

  - **momentum wheel**
  - running constantly at high speed
  - single direction

Actuators for attitude control 4.

- Internal torque:
  - Control Momentum Gyro (CMG; a gimbaled wheel)

- 100 times higher than the usual reaction torques of a reaction wheel
- CMG technology requires more volume and mass: preferably used in large satellites

- For complete three-axis attitude control at least three single-gimbal GMGs are needed

Sources:

- Gary D. Gordon, Walter L. Morgan:
  Principles of Communications Satellites
  Wiley, ISBN: 978-0-471-55796-8
- Wilfried Ley, Klaus Wittmann and Willi Hallmann (ed):
  Handbook of Space Technology
  Wiley, ISBN: 978-0-470-69739-9

Main topics / questions

- The role of the attitude control system
- Disturbance sources
- Attitude sensor types
- Actuators for attitude control