

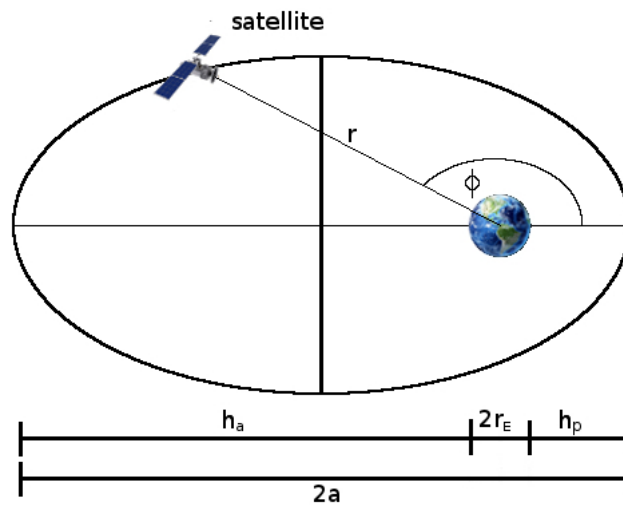
Formeln SSD

Bahn- und Orbitdinge

3. Keplersches Gesetz (Quadrate der Umlaufdauern proportional zu den Kuben der großen Halbachsen)

$$T = 2\pi\sqrt{\frac{a^3}{\mu}}$$

Ellipsendinge:



$$2a = h_a + h_p + 2r_E$$

$$r_p = h_p + r_E \quad r_a = h_a + r_E$$

$$r_p = a(1 - \varepsilon) \quad r_a = a(1 + \varepsilon)$$

$$\varepsilon = \frac{r_p - r_a}{r_p + r_a}$$

Vis-Viva-Gleichung/Binet-Gleichung:

$$v = \sqrt{\mu \left(\frac{2}{r} - \frac{1}{a} \right)}$$

Vis-Viva-Gleichung für Kreis:

$$r = a \Rightarrow v = \sqrt{\frac{\mu}{r}}$$

für Erde:

$$v = \sqrt{\frac{\mu}{r_E}} = 7.905 \frac{km}{s}$$

(= erste kosmische Geschwindigkeit = minimale Geschwindigkeit, die ein Objekt haben muss, um in einen Erdorbit zu gelangen)

Vis-Viva-Gleichung für Pabel:

$$a \rightarrow \infty \Rightarrow v = \sqrt{\frac{2\mu}{r}}$$

für Erde:

$$v = \sqrt{\frac{2\mu}{r_E}} = 11.179 \frac{km}{s}$$

(= zweite kosmische Geschwindigkeit = minimale Geschwindigkeit, die ein Objekt haben muss, um das Gravitationsfeld der Erde zu verlassen)

Geschwindigkeitsdinge für Ellipse:

average angular velocity:

$$\frac{2\pi \text{ rad}}{T \text{ min}} \quad \frac{360^\circ \text{ deg}}{T \text{ min}}$$

maximale Geschwindigkeit (Periapsis):

$$v_{max} = \sqrt{\mu \left(\frac{2}{h_p + r} - \frac{1}{a} \right)}$$

minimale Geschwindigkeit (Apoapsis):

$$v_{min} = \sqrt{\mu \left(\frac{2}{h_a + r} - \frac{1}{a} \right)}$$

wahre Anomalie (Φ , ν , ...)

$$r = a \frac{1 - \varepsilon^2}{r \cdot \varepsilon \cdot \cos(\nu)} \Rightarrow \nu = \arccos \left(a \frac{1 - \varepsilon^2}{r^2 \cdot \varepsilon} \right)$$

wahre Anomalie ist auch über die exzentrische Anomalie berechenbar:

$$\tan \left(\frac{\nu}{2} \right) = \sqrt{\frac{1 + \varepsilon}{1 - \varepsilon}} \cdot \tan \left(\frac{E}{2} \right)$$

$$E - \varepsilon \cdot \sin(E) = \frac{2\pi}{T} (t - t_{perigee})$$

right ascension of the ascending node:

$$\Delta\Omega_{rev} = -\frac{3\pi J_2 r_E^2}{a^2 (1 - \varepsilon^2)^2} \cos(i) \quad \text{in } \left[\frac{\text{rad}}{\text{rev}} \right]$$

$$\Delta\Omega_{rev} = -\frac{3\pi J_2 r_E^2}{a^2 (1 - \varepsilon^2)^2} \cos(i) \cdot \frac{360^\circ}{2\pi} \quad \text{in } \left[\frac{\text{deg}}{\text{rev}} \right]$$

$$\Delta\Omega_{day} = -\frac{3\pi J_2 r_E^2}{a^2 (1 - \varepsilon^2)^2} \cos(i) \cdot \frac{\tau_E}{T} \quad \text{in } \left[\frac{\text{rad}}{\text{day}} \right]$$

$$\Delta\Omega_{rev} = -\frac{3\pi J_2 r_E^2}{a^2 (1 - \varepsilon^2)^2} \cos(i) \cdot \frac{360^\circ}{2\pi} \cdot \frac{\tau_E}{T} \quad \text{in } \left[\frac{\text{deg}}{\text{day}} \right]$$

argument of perigee:

$$\Delta\omega = \frac{3\pi J_2 r_E^2}{2a^2 (1 - \varepsilon^2)^2} (4 - 5\sin^2(i)) \quad \text{in } \left[\frac{\text{rad}}{\text{rev}} \right]$$

angular displacement after n siderial days:

$$\Delta\Omega_n = \frac{n}{T} [\text{rev}] \cdot \Delta\Omega \left[\frac{\text{deg}}{\text{rev}} \right]$$

Subsatellitenpunkt

latitude of SSP:

$$\Theta = \arcsin(\sin(i) \cdot \sin(\omega + \nu))$$

longitude of SSP:

$$\lambda = \arccos \left(\frac{\cos(\omega + \nu)}{\cos(\Theta)} \right) + \Omega + \lambda_{greenwich}$$

swath-width:

$$D_{\text{foot}} = 2 \cdot \lambda_{\text{max}} = 2 \cdot (90^\circ - \arcsin\left(\frac{r_E}{r_E + h}\right))$$

Hohmann-Transfer:

große Halbachse der Transferellipse:

$$a_{\text{transfer}} = \frac{r_A + r_B}{2}$$

Transferdauer:

$$T_{\text{transfer}} = \pi \sqrt{\frac{a_{\text{transfer}}^3}{\mu}}$$

Geschwindigkeitsänderung, um ersten Orbit zu verlassen (beschleunigen):

$$\Delta v_1 = \sqrt{\frac{\mu}{r_A}} \left(\sqrt{\frac{2r_B}{r_A + r_B}} - 1 \right)$$

Geschwindigkeitsänderung, um auf zweiten Orbit zu kommen (abbremsen):

$$\Delta v_2 = \sqrt{\frac{\mu}{r_B}} \left(1 - \sqrt{\frac{2r_A}{r_A + r_B}} \right)$$

noch mehr Bahnparameterdinge:

earth angular radius:

$$\rho = \arcsin\left(\frac{r_E}{r_E + h}\right)$$

maximum nadir angle:

$$\eta_{\text{max}} = \arcsin(\sin(\rho) \cdot \cos(\varepsilon_{\text{min}}))$$

maximum earth central angle:

$$\lambda_{\text{max}} = 90^\circ - \varepsilon_{\text{min}} - \eta_{\text{max}}$$

maximum distance:

$$D_{\text{max}} = r_E \left(\frac{\sin(\lambda_{\text{max}})}{\sin(\eta_{\text{max}})} \right)$$

minimum earth central angle:

$$\lambda_{\text{min}} = \arcsin(\sin(90^\circ - i) \cdot \sin(\text{lat}_{gs}) + \cos(90^\circ - i) \cdot \cos(\text{lat}_{gs}) \cdot \cos(\text{long}_{gs} - L_{\text{node}} + 90^\circ))$$

minimum nadir angle:

$$\eta_{\text{min}} = \arctan\left(\frac{\sin(\rho) \cdot \sin(\lambda_{\text{min}})}{1 - \sin(\rho) \cdot \cos(\lambda_{\text{min}})}\right)$$

maximum elevation angle:

$$\varepsilon_{\text{max}} = 90^\circ - \lambda_{\text{min}} - \eta_{\text{min}}$$

minimum distance:

$$D_{\text{min}} = r_E \left(\frac{\sin(\lambda_{\text{min}})}{\sin(\eta_{\text{min}})} \right)$$

maximum angular rate:

$$\dot{\Theta}_{\text{max}} = \frac{2\pi(r_E + h)}{T \cdot D_{\text{min}}}$$

azimuth range:

$$\Delta\Phi = 2 \cdot \arccos\left(\frac{\tan(\lambda_{\text{min}})}{\tan(\lambda_{\text{max}})}\right)$$

time in view:

$$T_{\text{view}} = \frac{T}{180^\circ} \cdot \arccos\left(\frac{\cos(\lambda_{\text{max}})}{\cos(\lambda_{\text{min}})}\right)$$

time in view (Galileo Example):

$$T_{\text{view}} = \frac{T}{180^\circ} \cdot \lambda_{\text{max}}$$

street of coverage width:

$$\lambda_{\text{street}} = \arccos\left(\frac{\cos \lambda_{\max}}{\cos\left(\frac{\Delta\nu}{2}\right)}\right) \text{ mit } \Delta\nu = \frac{360^\circ}{\#\text{satellites/plane}}$$

Eclipsedinge:

$$\beta = \arcsin\left(\frac{r_E}{r_E + h}\right)$$

eclipsed fraction of a circular orbit:

$$F_e = \frac{1}{\pi} \left(\frac{\sqrt{h^2 + 2r_E \cdot h}}{(r_E + h) \cdot \cos(\beta)} \right)$$

Dezibeldinge:

$$P[W] = 1W \cdot 10^{\frac{P[dBW]}{10}}$$

$$P[dBW] = 10 \cdot \log_{10} \left(\frac{P[W]}{1W} \right)$$

$$P[W] = \frac{1}{1000} W \cdot 10^{\frac{P[dBm]}{10}}$$

$$P[dBm] = 10 \cdot \log_{10}(1000 \cdot P[W])$$

gain:

$$G = 10 \cdot \log_{10} \left(\frac{P_1}{P_2} \right)$$

EIRP:

$$\text{EIRP} = G + P$$

Thermalldinge:

$$Q = A_r \cdot \varepsilon_{IR} \cdot \sigma \cdot T^4$$

$$\dot{Q} = \lambda \cdot a \cdot b \cdot \frac{T_1 - T_2}{c} \quad \text{oder auch} \quad \dot{Q} = K \cdot A \cdot \frac{T_1 - T_2}{L}$$

series conduction:

$$\sigma_{tot} = \frac{1}{\frac{1}{\sigma_1} + \frac{1}{\sigma_2} + \frac{1}{\sigma_3} + \dots} \quad \text{und } Q = \sigma_{tot}(T_{box} - T_2)$$

$$\sigma = \frac{L}{K \cdot A} \quad \text{oder} \quad \sigma = \frac{1}{\alpha \cdot A}$$

Free Space Path Loss:

$$L = \left(\frac{4\pi \cdot d}{\lambda} \right)^2 = \left(\frac{4\pi \cdot d \cdot f}{c} \right)^2$$

oder auch (ungenauer)

$$L = 92.4dB + 20 \cdot \log_{10}(F[GHz]) + 20 \cdot \log_{10}(d[km])$$

thermal noise:

B...bandwidth, R...resistor, T...temperature, k...Boltzmann constant ($1.38 \cdot 10^{-23} \frac{J}{K}$)

$$V_n = \sqrt{4kTBR}$$

Noise Power:

T_e = system receiver noise temperature

$$N[dBW] = 10 \cdot \log_{10}(kT_e B)$$

Noise Figure:

$$NF[dB] = 10 \cdot \log_{10} \left(1 + \frac{T_e}{290^\circ} \right) = 10 \cdot \log_{10}(F)$$

Noise Factor:

$$F = \frac{\left(\frac{S}{N}\right)_{in}}{\left(\frac{S}{N}\right)_{out}} = 1 + \left(\frac{T_e}{290^\circ} \right)$$

Doppler shift:

$$\Delta f_{up} = -\frac{f \cdot v}{c} \quad \text{und} \quad \Delta f_{down} = -\frac{(f + \Delta f_{up}) \cdot v \cdot r}{c}$$

Effective area of dish antenna:

$$A_{eff,1} = \eta \pi \frac{d_1^2}{4}$$

dish antenna gain:

$$G_t = A_{eff,t} \frac{4\pi}{\lambda^2} \quad \lambda = \text{wavelength}$$

reciever power:

$$P_{rec} = P_{tr} \cdot G_{tr} \cdot \frac{A_{eff,rec}}{4\pi R^2}$$

Fermienergie:

Wahrscheinlichkeit, dass ein Teilchen mit Energie E

$$f(E) = \frac{1}{1 + e^{\frac{E-E_F}{k \cdot T}}}$$

Power System Dinge:

solar array power during daylight:

$$P_{sa} = \frac{\frac{P_e \cdot T_e}{X_e} + \frac{P_d \cdot T_d}{X_d}}{T_d}$$

P_e ...power in eclipse, T_e ...time in eclipse, P_d ...power in daylight, T_d ...time in daylight, X_e ...path efficiency during eclipse, X_d ...path efficiency during daylight

spacecraft power budget:

$$P_{sg} = \frac{\frac{P_e \cdot T_e}{\eta_L \cdot \eta_b} + \frac{P_s \cdot T_s}{\eta_L}}{T_s}$$

P_{sg} ...total power from solar array, η_L ...losses between solar array and loads, η_b ...losses of battery, P_s ...available power in sunlight, P_e ...power demand in eclipse

wichtige Parameter für BOL/EOL-Berechnungen:

- η ... production efficiency of solar cells (14-22%)
- X ... path efficiency from solar array through batteries to loads (eclipse and daytime): $X_e = 0.65$, $X_d = 0.85$ (direct energy transfer), $X_e = 0.60$, $X_d = 0.80$ (peak power tracking)
- I_d ...inherent degradation (≈ 0.77 , ranges from 0.49 – 0.88)
- Θ ...angle between array normal and sun vector; typically use worst-case sun-angle
- L_d ...life degradation: micrometeorites, radiation, etc. (2-4% per year)

$$L_d = (1 - \text{degradation per year})^{\text{satellite life}}$$

From Begin of Life to End of Life

$$P_o = \eta \cdot 1358 \frac{W}{m^2} \quad (\text{output power})$$

$$P_{BOL} = P_o \cdot I_d \cdot \cos(\Theta)$$

$$P_{EOL} = L_d \cdot P_{BOL}$$

solar array size to meet power requirement:

$$A_{sa} = \frac{P_{sa}}{P_{EOL}}$$

mass of solar array ranges from 14 to $47 \frac{W}{kg}$:

$$M_{sa} = 0.04 \cdot P_{sa} \quad \left(\text{for } 25 \frac{W}{kg}\right)$$

Battery Sizing

Power need:

$$P_{avg} = V_{bus} \cdot I$$

$$Ah_{avg} = \frac{T_e}{1h} \cdot I$$

$$Ah_{total} = \frac{Ah_{avg}}{DoD}$$

Capacity:

$$C_r = \frac{P_{avg} \cdot T_e}{DoD \cdot N_{bat} \cdot \eta}$$

charge power in eclipse:

$$P_{charge} = \frac{P_{ecl}}{\eta \cdot U}$$