ICG SSV - Simulation Phase 2
Link budget setup

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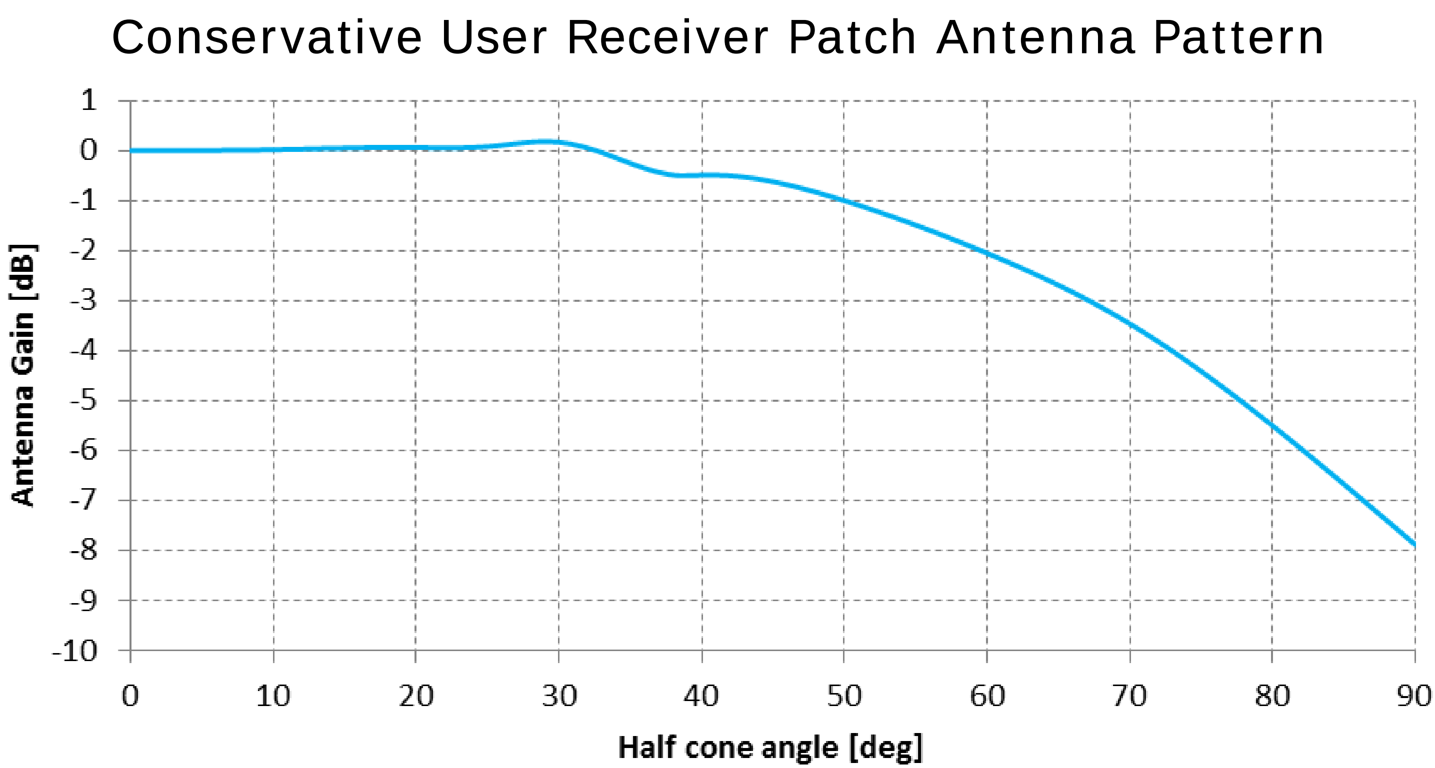
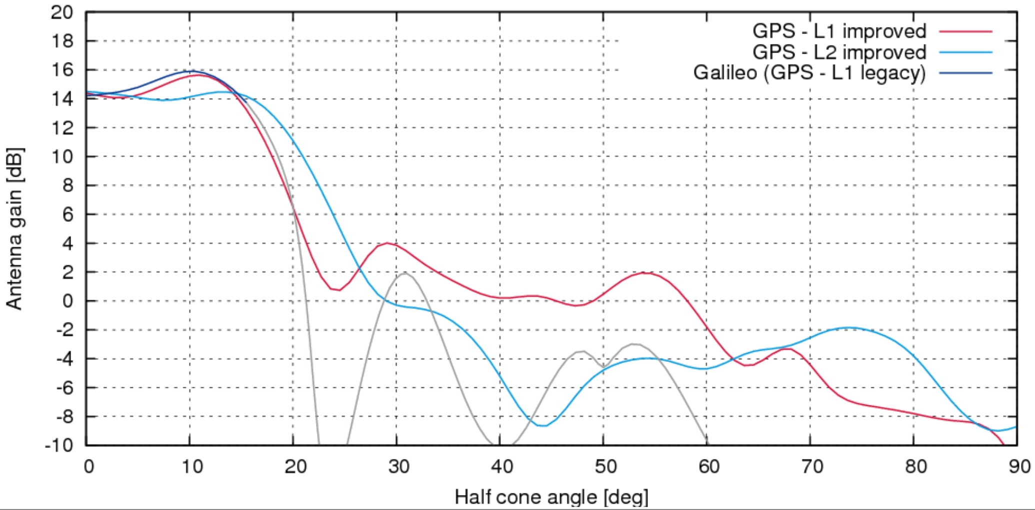
Space User Receiver antenna pattern – Example



To be defined:

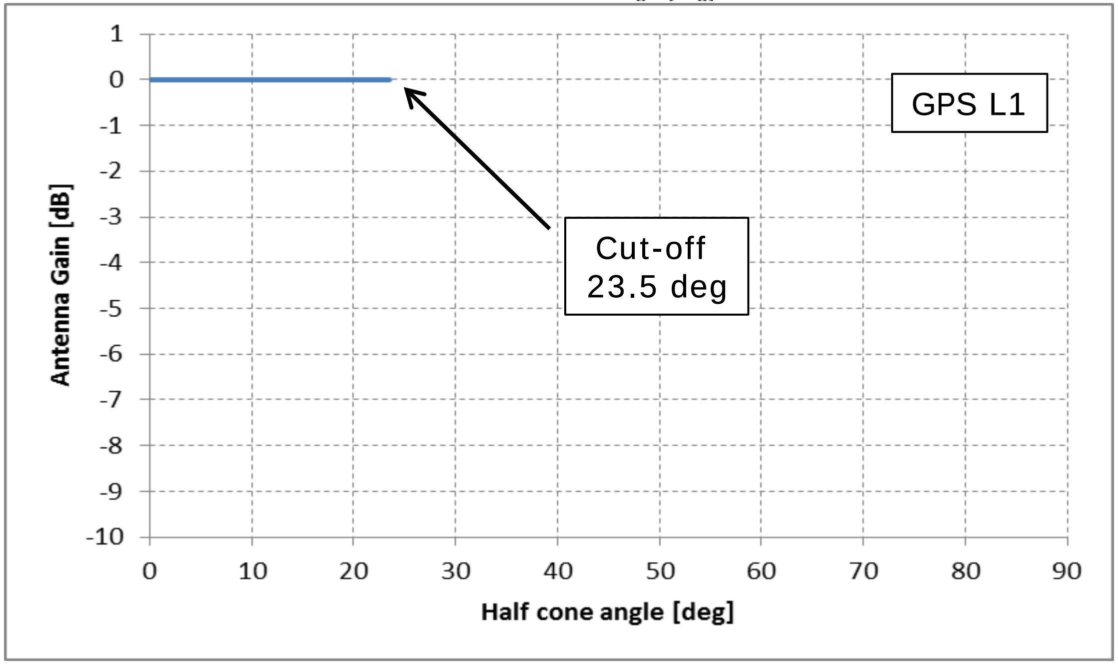
- Antenna pointing direction (nadir, zenith, ...) or
- Antenna location and Attitude law

GNSS antenna pattern



Realistic GPS IIR-M antenna pattern

GPS L1 & L2 reference:
The GPS Block IIR/IIR-M Antenna Panel Pattern, LMOC, Iss. Rev. 1.0, Feb. 2014



Simple GPS (L1) antenna pattern (normalized)

No signal is considered as emitted outside the off-boresight cut-off angle

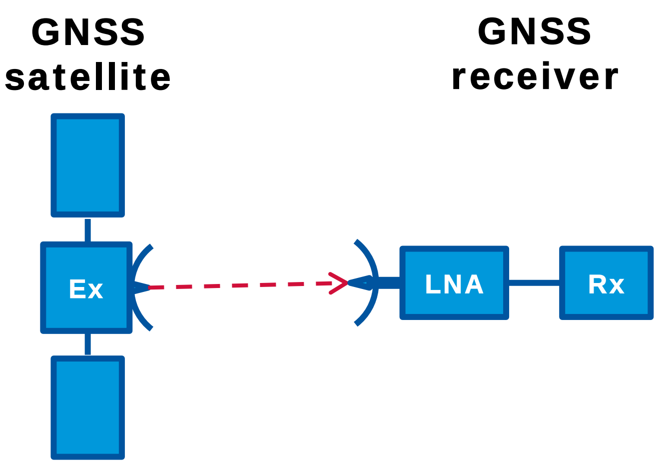
Link budget figures

Received Power

$$P_r = EIRP + L_t + L_S + G_r + L_A + G_A + L_C + L_{sys}$$

Received Signal to noise

$$C/N_0 = EIRP + L_t + L_S + G_r + L_A + L_C + L_{sys} - 10\log_{10} T_{sys} - 10\log_{10} k$$



Parameter	Description
EIRP	Effective Isotropic Radiated Power
L_t	Emitter antenna off-boresight power loss
L_S	Free path free-space loss
G_r	Receiver antenna gain
L_A	Receiver antenna off-boresight power loss
G_A	Low Noise Amplifier gain
L_c	Cable losses
L_{sys}	System losses
T_{sys}	System temperature
k	Boltzmann constant

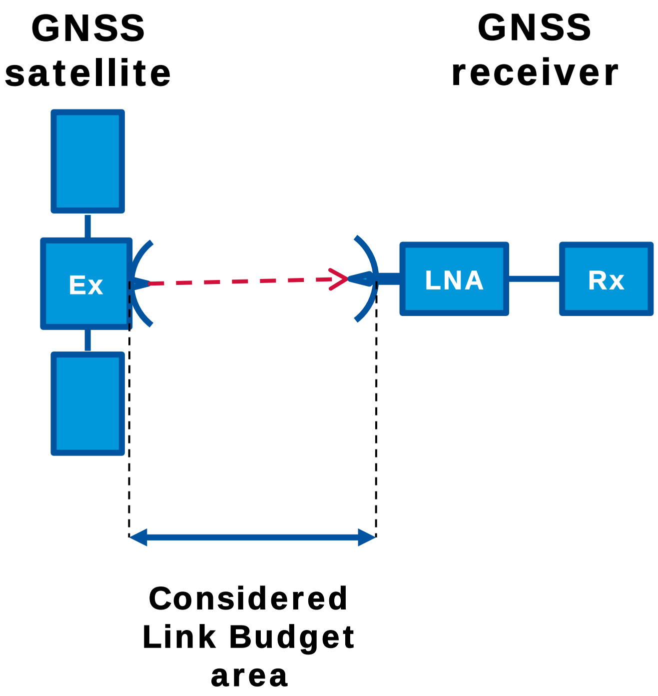
Link budget figures

Received Power

$$P_r = EIRP + L_t + L_S + G_r + \cancel{L_A} + \cancel{G_A} + \cancel{L_C} + \cancel{L_{sys}}$$

Received Signal to noise

$$C/N_0 = EIRP + L_t + L_S + G_r + \cancel{L_A} + \cancel{L_C} + \cancel{L_{sys}} - 10\,log_{10}\,T_{sys} - 10log_{10}k$$

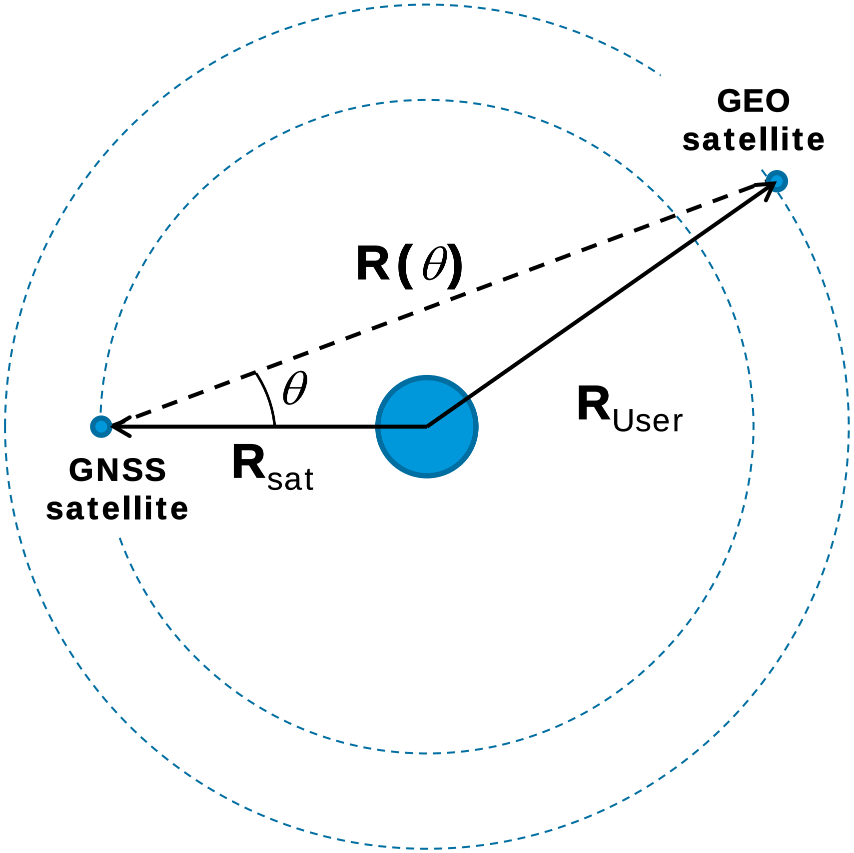


Parameter	Considered	Description
EIRP	✓	Effective Isotropic Radiated Power
L_t	✓	Emitter antenna off-boresight power loss
L_S	✓	Free path free-space loss
G_r	✓	Receiver antenna gain
L_A	✗	Receiver antenna off-boresight power loss
G_A	✗	Low Noise Amplifier gain
L_c	✗	Cable losses
L_{sys}	✗	System losses
T_{sys}	✓	System Noise temperature
k	✓	Boltzmann constant

Link budget figures

Parameter	Proposed for usage	Value	Reference	Comments
EIRP	✓	To be calculated	SSV Booklet	Constellation-wise specific
L_t	✓	0 dB within off-boresight cut-off angle	Assumption	Within the off-boresight cut-off angle the gain is constant, outside there is no signal
L_S	✓	$FPSL(dB) = 20\, log_{10}\left(\frac{\lambda}{4\pi r}\right)$	By definition. Wavelength λ will be included in the booklet	Free path free-space loss, function of GNSS-user distance r and the signal wavelength λ
G_r	✓	Patch antenna	We should use the values from an agreed data sheet	Receiver antenna gain, as per data sheet
L_A	✗	N/A	Assumption	Not considered
G_A	✗	N/A	Assumption	Not considered
L_c	✗	0 dB	Assumption	Not considered
L_{sys}	✗	0 dB	Assumption	Not considered
T_{sys}	✓	To be agreed within the project	Assumption	System Temperature
P_r acq.	(✓)	See following tables	Agreed figures for GEO	Acquisition Received Power threshold
P_r track.	(✓)	See following tables	Agreed figures for GEO	Tracking Received Power threshold
C/N_0 acq.	✓	20/25/30 dBHz	Values to be agreed	Acquisition Received SNR threshold
C/N_0 track.	(✓)	N/A	Values to be agreed	Tracking Received SNR threshold

Satellite-User range computation as a function of θ



$\mathbf{R}_{sat}$ = instantaneous GNSS position vector

$\mathbf{R}_{user}$ = instantaneous User position vector

$\mathbf{R}(\theta)$ = instantaneous GNSS-User range

θ = GNSS off-boresight angle

$R_{sat} = |\mathbf{R}_{sat}|$

$R_{user} = |\mathbf{R}_{user}|$

Given $\boldsymbol{R}_{user}$, $\boldsymbol{R}_{sat}$ and θ,
based on the Law of cosines:

$$R_{user}{}^2 = R_{sat}{}^2 + R(\theta)^2 - 2\, R_{sat}\, R_{user} \cos(\theta)$$

And solving for $R(\theta)$:

$$R(\theta) = R_{SAT} \cdot \cos(\theta) + \sqrt{R_{User}^2 - R_{SAT}^2 \cdot \sin^2(\theta)}$$

Range and FSL Equation

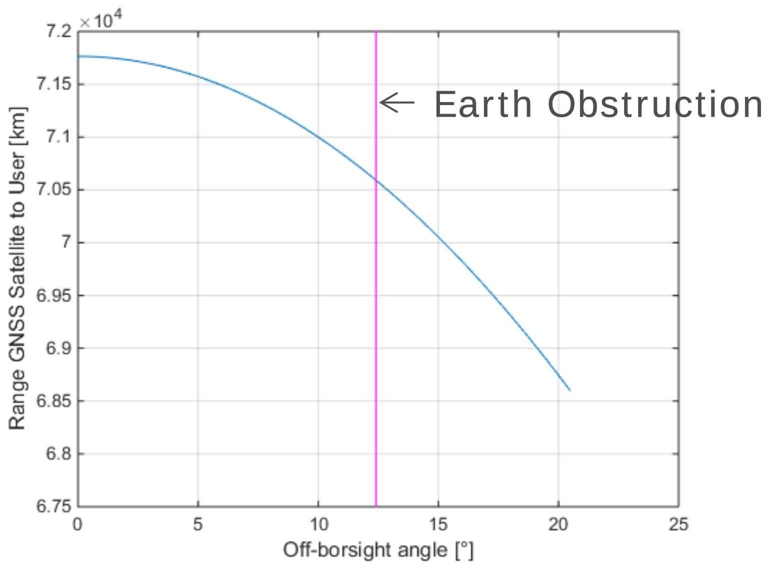
Range between GNSS satellite and user satellite

$$R(\theta) = R_{SAT} \cdot \cos(\theta) + \sqrt{R_{User}^2 - R_{SAT}^2 \cdot \sin^2(\theta)}$$

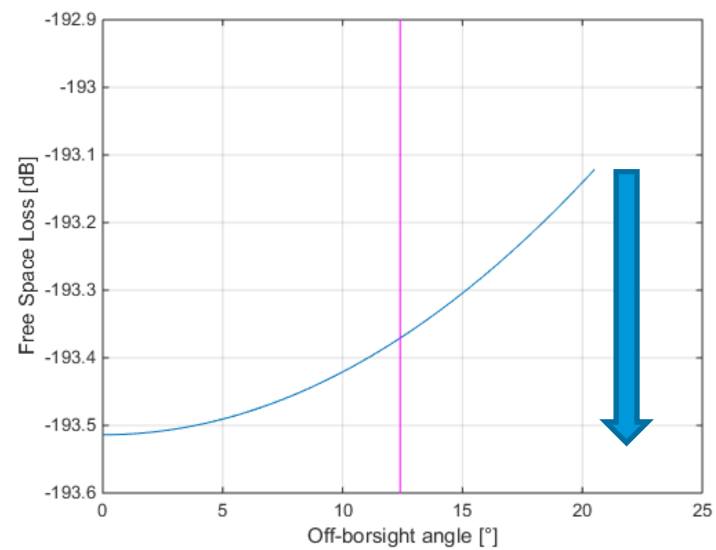
Derived Free Space Loss

$$FSL(\theta) = -20\log_{10}\left(\frac{4\pi R(\theta) f}{c}\right) = 20\log_{10}\left(\frac{\lambda}{4\pi R(\theta)}\right)$$

Range Example for Galileo



FSL Example for Galileo in E1



Additional FSL requires Compensation!

User Received Power threshold

GPS signals	Minimum Received Civilian Signal Power (GEO)
L1 C/A	-184.0 dBW
L1C	-182.5 dBW
L2 (L2C or C/A)	-183.0 dBW
L5 (I5 or Q5)	-182.0 dBW

Galileo signals	Minimum Received Civilian Signal Power (GEO)
E1B/C	-182.5 dBW
E6B/C	-182.5 dBW
E5b	-182.5 dBW
E5ABOC	-182.5 dBW
E5a	-182.5 dBW

Glonass signals	Minimum Received Civilian Signal Power (GEO)
L1	-180 ÷ -185 dBW
L2	-177 ÷ -184.4 dBW
L3	-176 ÷ -184 dBW

BeiDou signals	Minimum Received Civilian Signal Power (GEO)
B1 (MEO)	-183.1 dBW
B1 (GEO/IGSO)	-183.3 dBW
B2 (MEO)	-182.0 dBW
B2(GEO/IGSO)	-182.4 dBW
B3 (MEO)	-183.8 dBW
B3 (GEO/IGSO)	-184.3 dBW

QZSS signals	Minimum Received Civilian Signal Power (GEO)
L1 C/A	-185.3 dBW
L1C	-185.3 dBW
L2 C	-188.7 dBW
L5 (I5 or Q5)	-180.7 dBW

IRNSS signals	Minimum Received Civilian Signal Power (GEO)
L5	-186.51 dBW
S	-189.78 dBW

Agreed figures for GEO, as per ICG SSV Booklet

Conclusions for Phase 2

1. The proposed, simplified Link Budget calculation and in particular the calculation of the EIRP values for each constellation must be discussed and agreed between all parties involved.
2. The Link budget parameters must be discussed and agreed in particular the acquisition and tracking SNR values.
3. User-antenna pointing direction, location and satellite attitude needs to be discussed and agreed for specific missions.

To be defined:

- User-Antenna pointing direction (nadir, zenith, …) or
- User-Antenna location and attitude law

ESOC Proposal:

- Attitude: Nadir pointing GNSS satellite
- Antenna location: always using 2 antennas (1 nadir and 1 zenith pointing)

Initial thoughts for Phase 3

1. Some basic principles should be agreed:
   - User-antenna pointing direction, location of antenna on satellite and satellite attitude needs to be discussed and agreed for specific missions

   ESOC Proposal:

   - User satellite attitude: Nadir pointing
   - User antenna location: always using 2 antennas (1 nadir and 1 zenith pointing)
   - Realistic space user antenna pattern

   ESOC Proposal:

   - Use of batch antenna data sheet, because of conservative approach
2. Reference missions should cover wide range of applications
   - Scientific missions
   - Weather satellites
   - Earth observation missions
   - ...

Initial thoughts for Phase 3

1. Definition of 4-5 general KPIs and a set of mission drivers for the reference missions

ID	Mission	Mission drivers	GNSS KPIs
1	Scientific mission	• Orbit accuracy • Quality of GNSS data • Availability of GNSS data at specific mission phases…	• Number of visible GNSS sv • Time where 1 GNSS sv is visible • Time where 4 or more GNSS sv are visible • Quality of relative geometry
2	Weather satellite	• Availability of service • On-board autonomy – GNSS is used in user sat AOCS • …	• Max outage time of 1 sv • Number of visible GNSS sv • Min time of 4 visible GNSS sv • …

ESOC mission proposal for phase 3: Proba-3

Proba-3 Orbital parameters	
Apogee altitude	60,530 km
Perigee altitude	600 km
Semi-major axis	36943 km
Eccentricity	0.8111
Inclination	59 deg
Argument of perigee	188 deg
Right ascension of ascending node	152 deg
Orbital period	19.6 hours