GNSS Introduction

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Part IV

Link Budget

The link budget concept

- All the positioning procedures are based on the measurement performed by a user receiver of a signal transmitted by a reference source
- In the GPS system the reference source is a satellite at about 20200 Km from a user on the ground
- The estimation of the received power is usually performed through a link budget calculation

The link budget concept

- The "budget" takes into account all the phenomena affecting the power of the signal as it travels from the satellite towards the ground
  - power propagation laws
  - attenuation phenomena due to the atmosphere
  - capability of the receiver to capture the signal power

Power propagation laws

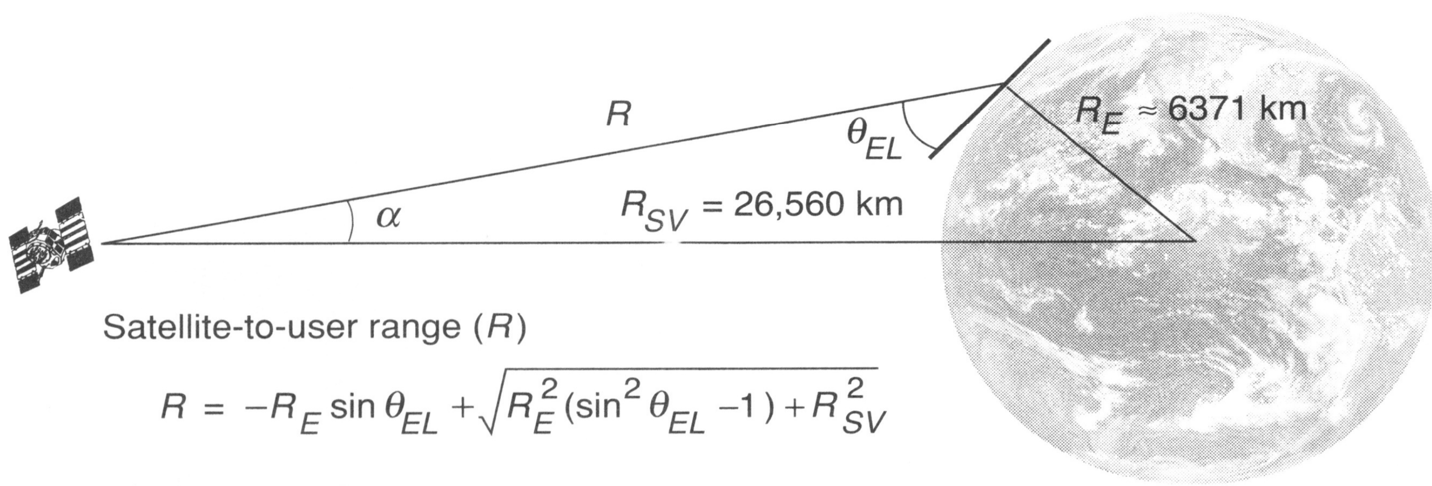
- Considering a uniform transmission of the signal power P_T by the satellite (isotropic antenna) at a distance R the power density is

$$PD_S = \frac{P_T}{4\pi R^2} \, watts / m^2$$

$$\frac{1}{4\pi R^2}$$ *path loss (spreading loss)*

The user elevation

- The distance from the satellite to the user depends on the user location on the Earth



Satellite-to-user range (R)

$$R = -R_E \sin\theta_{EL} + \sqrt{R_E^2(\sin^2\theta_{EL} - 1) + R_{SV}^2}$$

Nadir angle (α)

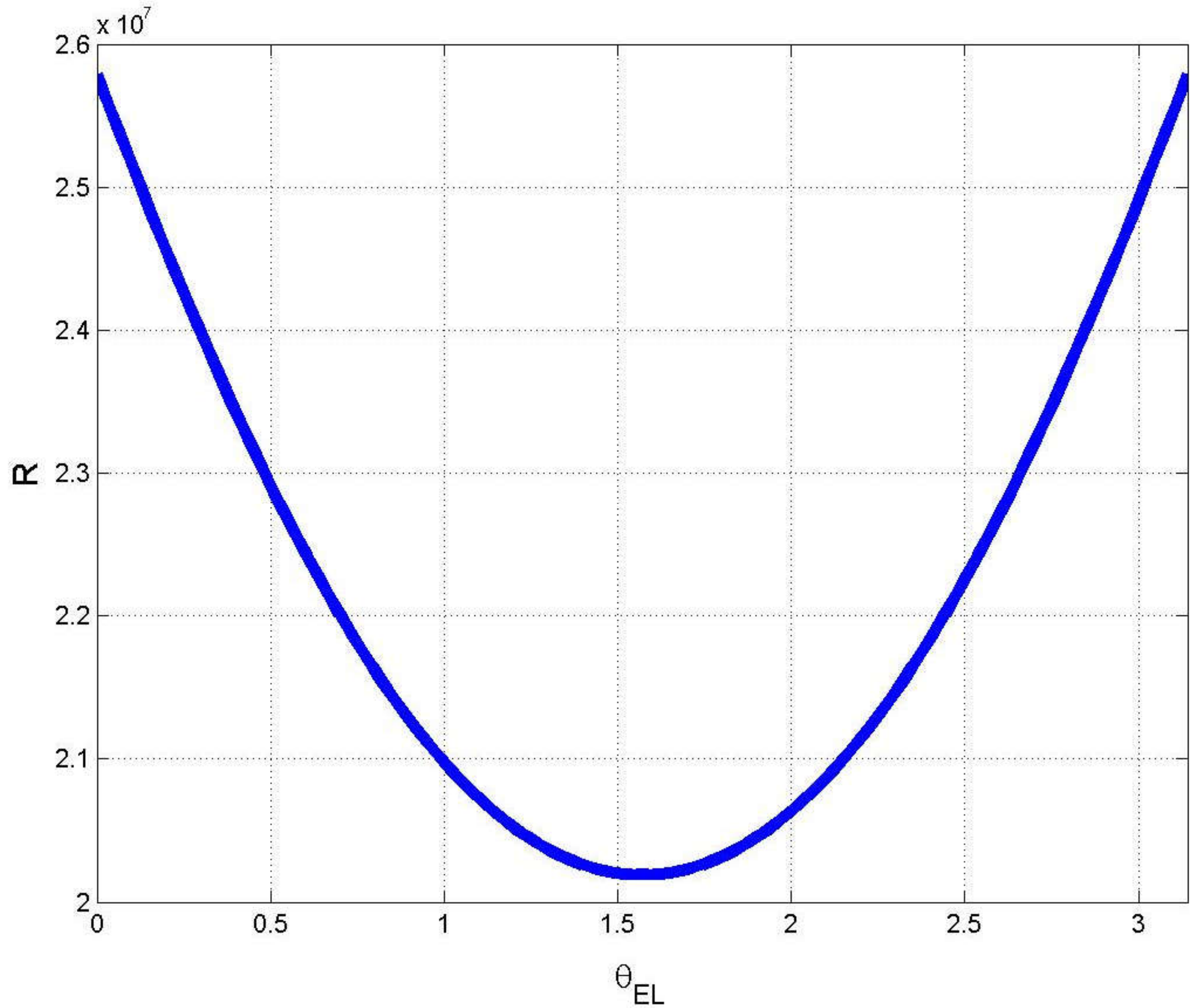
$$\alpha = \sin^{-1}\left[\frac{R_E \sin(\theta_{EL} + 90°)}{R_{SV}}\right]$$

The user elevation

$$R = -R_E \sin \vartheta_{EL} + \sqrt{R_E^2 \left(\sin^2 \vartheta_{EL} - 1\right) + R_{SV}}$$

- The actual distance depends on
- R_E=6371 10^3 m (*Earth radius*)
- R_{SV}=26560 10^3 m
- θ_{EL}= satellite elevation angle at the user

The user distance



The antenna gain

- Transmission of power towards outer space is a waste of resources
- Some antenna gain is obtained giving it some directivity
- Power is focused towards the Earth in a solid angle 2α

$$G_T(\alpha) = \frac{2}{1-\cos(\alpha)}$$

Antenna footprint

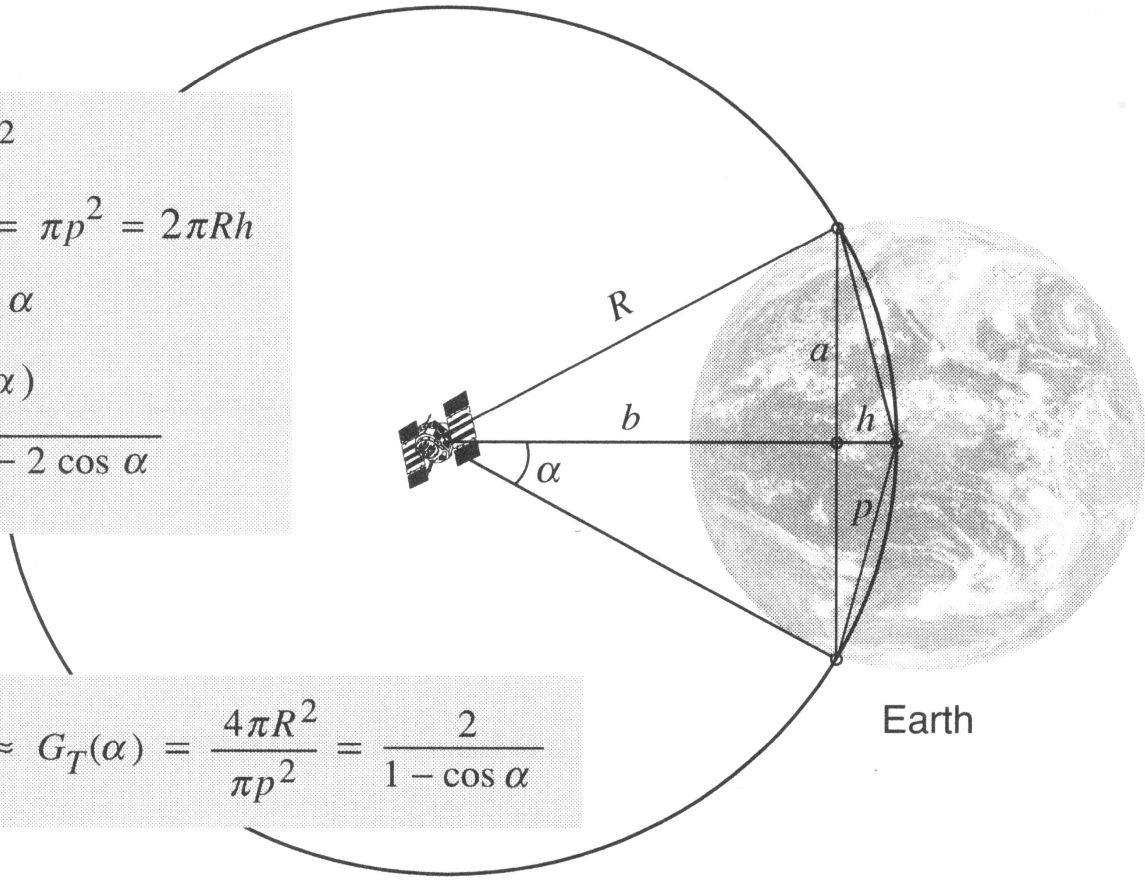
Area of sphere $= 4\pi R^2$

Area of spherical cap $= \pi p^2 = 2\pi R h$

$a = R \sin\alpha, \quad b = R\cos\alpha$

$h = R - b = R(1 - \cos\alpha)$

$p = \sqrt{h^2 + a^2} = R\sqrt{2 - 2\cos\alpha}$



Transmit antenna gain $\approx G_T(\alpha) = \dfrac{4\pi R^2}{\pi p^2} = \dfrac{2}{1 - \cos\alpha}$

Antenna footprint

- The Earth subtends an angle of ± 13.9° as seen from the GPS satellite
- The satellite antenna beam is somewhat wider ± 21.3°, giving a gain

$$G_T(\alpha)\Big|_{dB} = 10Log_{10}\left[G_T(21.3°)\right] = 14.7dB$$

Antenna footprint

- The actual gain is smaller
- additional loss in the antenna
- the gain is tailored to compensate for greater distances (about 2 dB more at the edge of the footprint)

Link budget calculation (1)

- Combining all the factors, the power density received by the user is given by

$$PD_S = \frac{P_T G_T}{4\pi R^2 L_A} \; watts/m^2$$

$$PD_S\big|_{dB} = P_T\big|_{\mathrm{dB}} + G_T\big|_{\mathrm{dB}} \underbrace{-20\log_{10} R - 11}_{\text{path loss}} \quad \underbrace{-L_A\big|_{\mathrm{dB}}}_{\text{atmosphere power loss}} \quad \mathrm{W/m^2}$$

Link budget calculation (1)

	SV at low elevation	SV at moderate elevation	SV at Zenith
	θ_{EL}= 5° α= ±13.9°	θ_{EL}= 40° α= ±10.6°	θ_{EL}= 90° α= ±0°
Power TX	14.3 dBW	14.3 dBW	14.3 dBW
SV antenna gain	12.1 dB	12.9 dB	10.2 dB
Path loss	-159 dB	-157.8 dB	-157.1 dB
Atmospheric loss	-2 dB	-2 dB	-2 dB
RX PD_S	-134.6 dBW/m^2	-132.6 dBW/m^2	-134.6 dBW/m^2

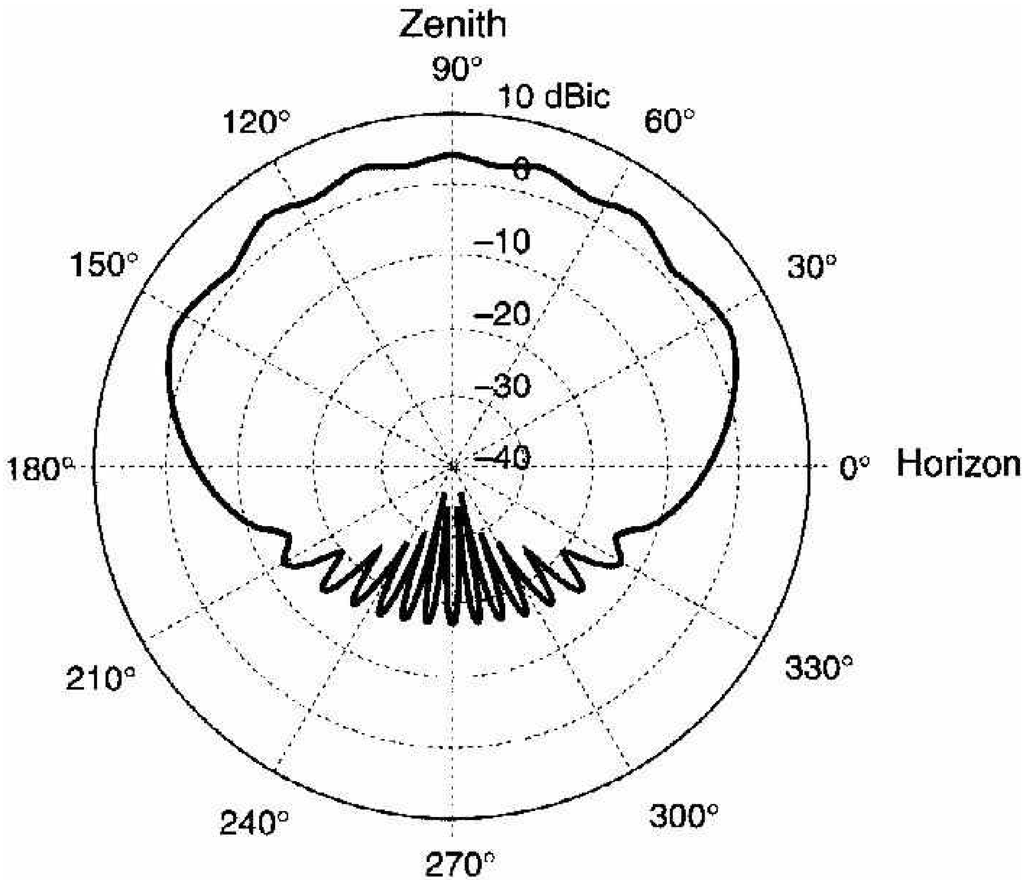
The antenna

- The ability of the antenna of capturing the incident signal field is measured by its gain G_R or by its effective area

$$A_E = G_R \frac{\lambda^2}{4\pi}$$

- Typical GPS antennas are isotropic in azimuth and gain varies in elevation
- Directional antennas are not suitable (DOP issues)
- Several solutions for harsh environments (multipath, interference,…)

The antenna

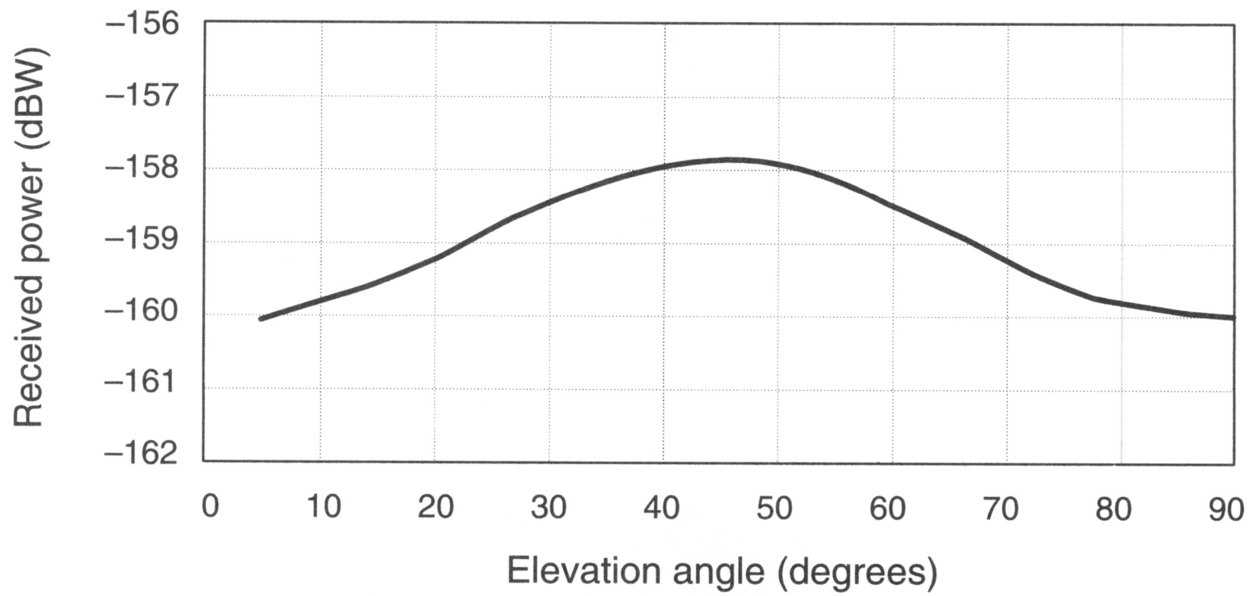


Elevation pattern for a typical commercial L1 antenna

Link budget calculation (2)

	SV at low elevation	SV at moderate elevation	SV at Zenith
	θ_{EL}= 5° α= ±13.9°	θ_{EL}= 40° α= ±10.6°	θ_{EL}= 90° α= ±0°
RX PD_S	-134.6 dBW/m^2	-132.6 dBW/m^2	-134.6 dBW/m^2
Effective area of an isotropic antenna	-25.4 dBm^2	-25.4 dBm^2	-25.4 dBm^2
Gain of a *typical* patch antenna	-4 dBic	+2 dBic	+4 dBic
CA code received power	-164 dBW	-156 dBW	-156 dBW

Typical C/A code RX power



- Typically the power level is up to 8 dB higher
  - more power transmitted
  - atmospheric losses are smaller
  - depend on the RX antenna gain

End of Part IV