Link Budgets

International Committee on GNSS

Working Group A

Torino, Italy

19 October 2010

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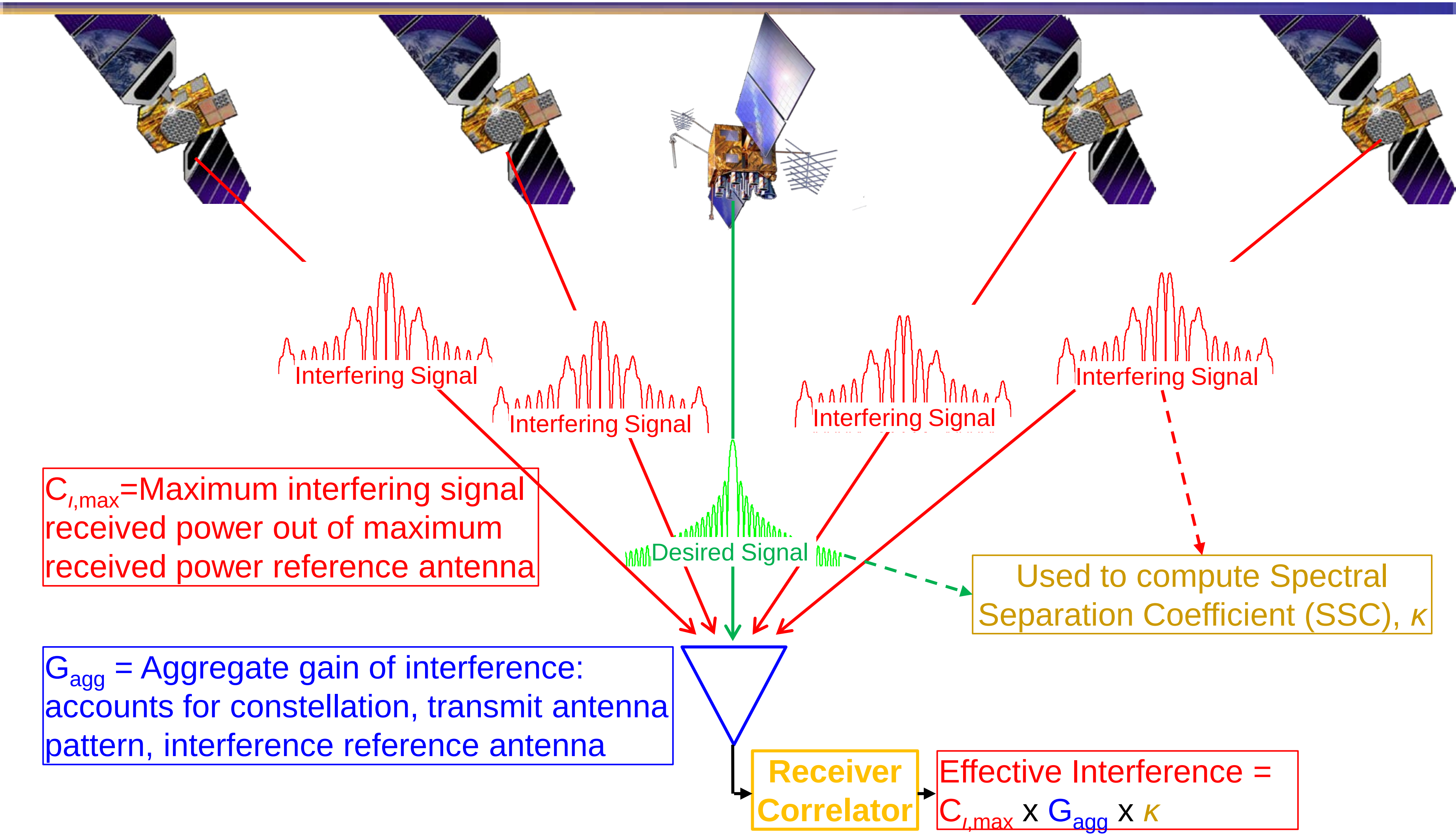
Background

- Each GNSS signal is a potential source of interference to other GNSS signals
- A GNSS signal's maximum received power is a critical parameter in quantifying the potential interference from that signal
- Previously, GPS and other GNSS providers have not always been explicit or consistent in defining the conventions and considerations associated with maximum received power
  - This presentation reflects recent experience, and represents GPS's proposal for the future
- It would be mutually beneficial for all GNSS providers to adopt explicit (<u>at least</u>) and consistent (<u>preferred</u>) conventions for defining maximum received power

Calculating Effective Interference to Reception of a GNSS Signal



- Aggregate effective interference = Σ (eff. interference from different signal types)

Maximum Received Power Link Budget Factors

- RF transmit power
- Transmit antenna gain toward receive antenna

} Equivalent Isotropic Radiated Power (EIRP)

- Free space propagation loss at a given angle off nadir
- Minimum possible atmospheric loss maximizes received power
- Minimum possible polarization loss maximizes received power
- Gain of maximum received power reference antenna

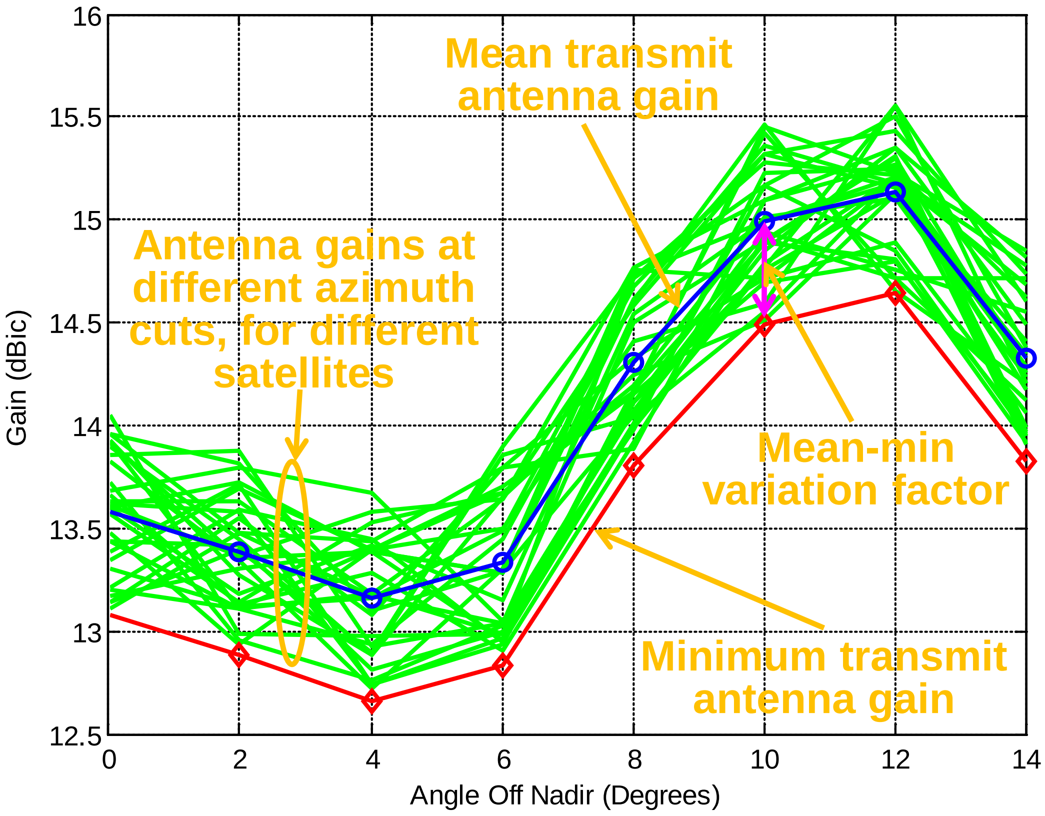
$$(C_{l,max})^{dbW} = \text{Max}\{(\text{RF transmit power})^{dbW} + (\text{Transmit antenna gain})^{db} - (\text{Free space propagation loss})^{db} - (\text{Atmospheric loss})^{db} - (\text{Polarization loss})^{db} + (\text{Receive antenna gain})^{db}\}$$

Compute max over surface of the earth

RF Transmit Power

- RF transmit power must be set so that received power exceeds minimum received power specification everywhere within service volume
- RF transmit power is independent of angle off nadir
- In establishing minimum and maximum received power levels, GPS includes operating margin above the theoretical minimum RF transmit power
  - "Operating margin" allows for RF transmit power set greater than theoretical minimum to allow for various practical factors:
    - Power setting granularity
    - Power measurement uncertainties
    - Delays in adjusting power
    - …

Transmit Antenna Gains Vary Over Different Azimuth Cuts and Satellites



Transmit Antenna Gain Versus Angle Off Nadir

- Nominal antenna gain pattern versus angle off nadir are normally provided during bilateral consultations

- In establishing minimum and maximum received power levels, GPS includes additional RF transmit power to account for variations in transmit antenna gain
  - “Transmit antenna gain margin” allows for RF transmit power set greater than theoretical minimum to allow for variations in transmit antenna gains at different angles off nadir or for different satellites

RF Transmit Power Margin

- GPS typically includes at least 1.5 dB of margin in establishing maximum received power levels, for given minimum received power level
  - Operating margin
  - Transmit antenna gain margin

Free Space Propagation Loss and Atmospheric Loss

- Free space propagation loss = $(4\pi r)^2/\lambda^2$
  - r = distance from satellite antenna to receive antenna on earth's surface at a given angle off nadir, at perigee if appropriate
  - λ = wavelength

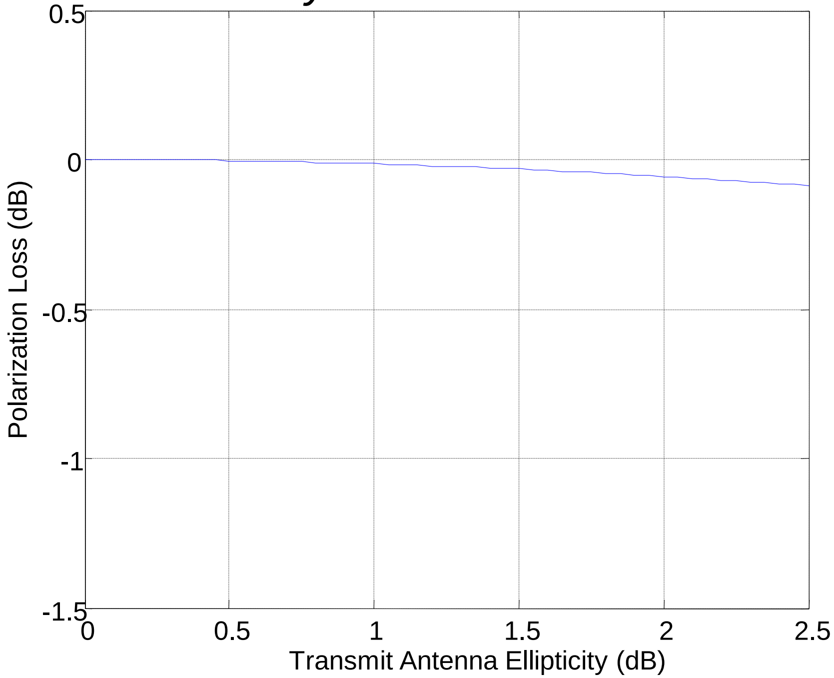
- Atmospheric loss considerations
  - Oxygen is the dominant source of attenuation at L band
  - Oxygen attenuation approaches 0.035 dB (rounding to 0.0 dB) for elevation angles exceeding 40 degrees
  - Other phenomena (turbulence, water vapor) may sometimes contribute additional losses, but do not always occur
  - Prudent to let atmospheric loss be 0.0 dB for maximum received power link budget

Reference: *Global Positioning System: Theory and Applications, Volume 1*, Parkinson and Spilker (Eds.), pp. 518-521

Proposed Receive Power Reference Antenna Polarization Loss

- GNSS signals are approximately circularly polarized
  - Specified ellipticities of GPS signals:
    - 1.8 dB (IS-GPS-800, IS-GPS-200 L1)
    - 2.2 dB (IS-GPS-200 L2, ICD-GPS-700 L2)
    - 2.4 dB (IS-GPS-705)
- Many receive antennas are approximately circularly polarized at higher elevation angles where maximum received power typically occurs

Polarization Loss at Worst Orientation into 0 dBic Circularly Polarized Receive Antenna



- Also, aggregate interference results from reception of multiple signals with received polarizations distributed in polarization orientation
- Prudent to use circularly polarized antenna with polarization loss of 0.0 dB for maximum received power link budget

Proposed Receive Power Reference Antenna Gain

- G_{agg} accounts for interference reference antenna's gain over angle

- Propose using 0 dBic reference antenna for specifying maximum received power

Summary of Proposed Link Budget Conventions for Maximum Received Power

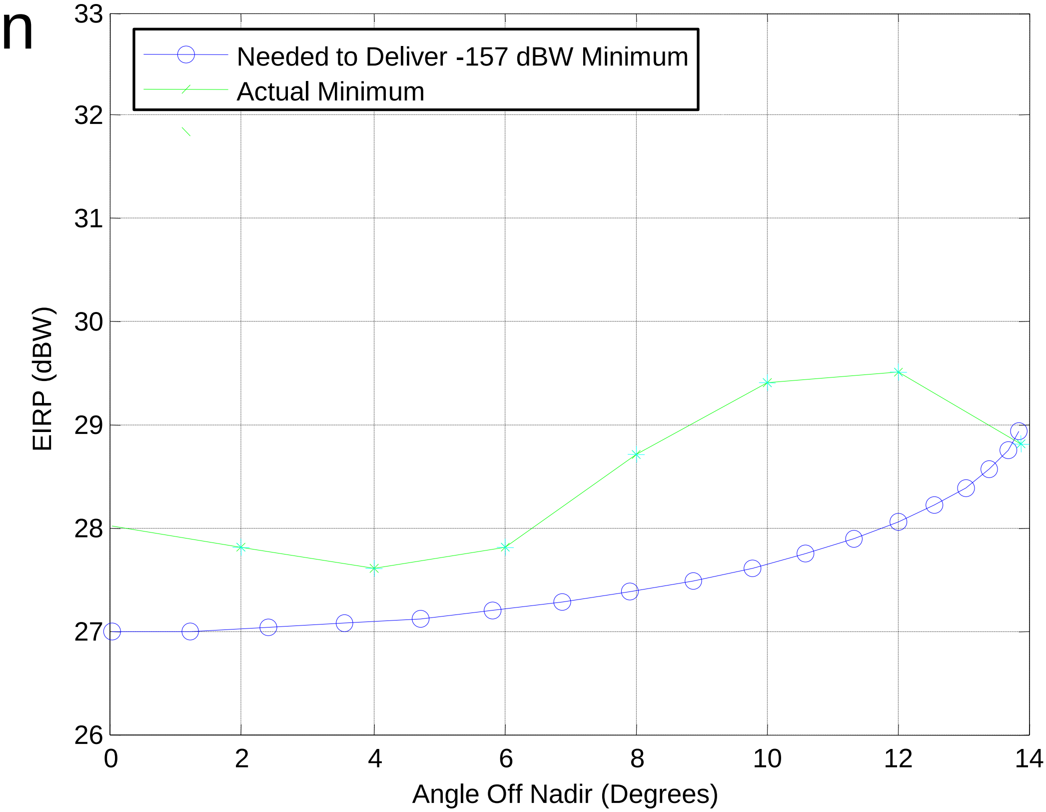
Description	Value	Notes
Elevation Angle to Satellite	≥ 0 degrees	Address all locations on surface of earth
Radius of Earth	6378.137 km	Free-space path loss calculated based on earth radius and orbital radius
Orbital Radius	Circular orbits: mean orbital radius Elliptical orbits: perigee	
Atmospheric Loss	0 dB	Lowest possible loss value, can occur at high elevation angles where max rx power typically occurs
Transmit Antenna Gain		Use average value over azimuth for each angle off nadir
Receive Antenna Gain	0 dBic	Many receive antennas are approximately circularly polarized at higher elevation angles where maximum received power typically occurs. Also, interference consists of signals from multiple signals with received polarizations randomly distributed in angle
Receive Antenna Polarization Loss	0 dB	Lowest possible loss value

$$(C_{I,max})^{dbW} = \text{Max}\{(\text{RF transmit power})^{dbW} + (\text{Transmit antenna gain})^{dbic} - (\text{Free space loss})^{db}\}$$

Example for GPS L1C—Minimum RF Transmit Power

- Mean transmit antenna gain

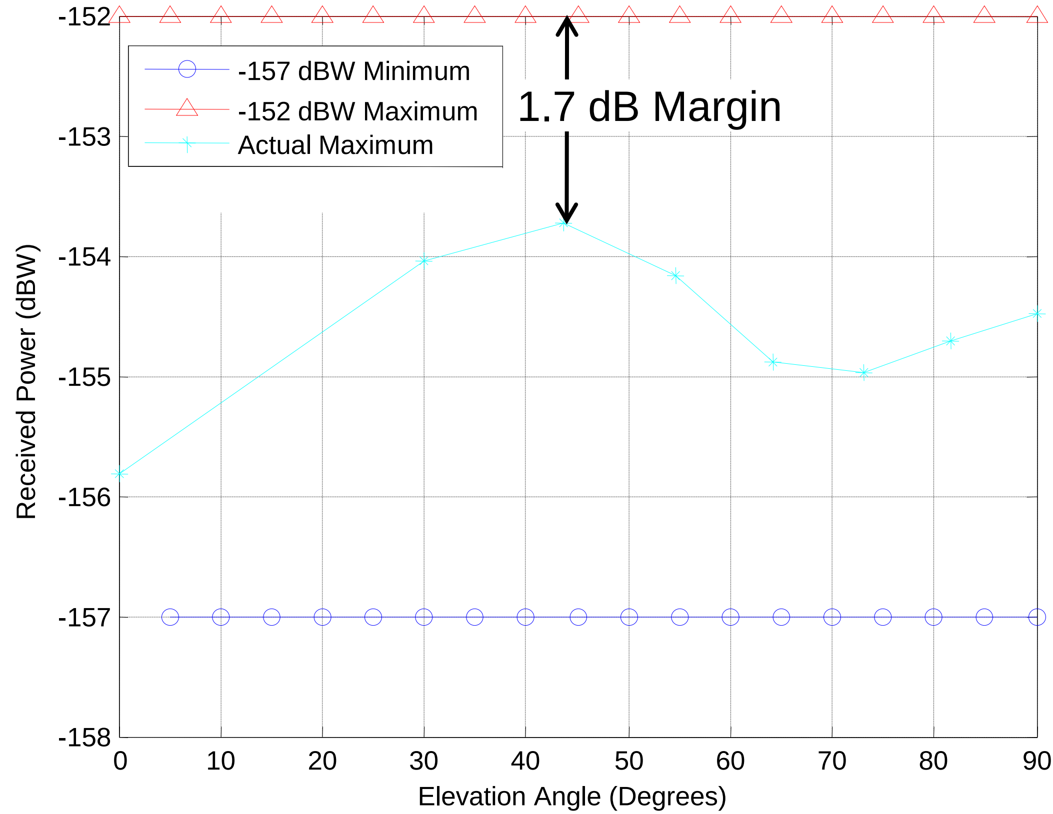
Angle Off Nadir (deg)	Gain (dBic)
0	13.6
2	13.4
4	13.2
6	13.4
8	14.3
10	15.0
12	15.1
14	14.4
16	12.7



- Minimum RF transmit power needed for specified minimum received power is 14.4 dBW
  - Provides minimum received power −157 dBW on surface of earth using GPS III antenna pattern and GPS conventions for minimum received power

Example for GPS L1C—Maximum Received Power

- Actual maximum received power calculated using 14.4 dBW RF power and conventions for maximum received power link budget
- Allows 1.7 dB of L1C margin for transmit antenna gain variation and operations
  - GPS uses slightly different margins for signals at different center frequencies, with different transmit antennas, and to accommodate multiple satellite blocks



Summary

- Proposed conventions for maximum received power link budgets involve only EIRP and free-space propagation loss

- If all providers adopt common conventions, all providers' numerical values for maximum received power can be interpreted and applied consistently