Professional Development Short Course On:

Satellite Communications Design & Engineering

Instructor:

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2. Transfer Orbit
3. Orbital Perturbations and Stationkeeping
4. The Spacecraft Environment
5. Earth-Satellite Geometry
6. Constellation Design

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7. Signals and Spectra
8. Analog Modulation
9. Digital Modulation
10. Coding
11. The Electromagnetic Spectrum
12. The RF Link
13. Earth Stations
14. Multiple Access
15. Antennas
16. System Temperature
17. Polarization
18. Rain Loss

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19. Link Budgets for Geostationary Satellites
20. Link Budgets for Nongeostationary Satellites
The RF Link
(Excerpt)
Antenna pattern, beamwidth, and gain

Beamwidth shows size of beam.

\[ \text{HPBW} = \alpha = k \frac{\lambda}{D} = 70^\circ \frac{\lambda}{D} \] where \( k = \text{antenna taper factor} \)

Gain shows relative strength of radiation. The maximum (boresight) gain is

\[ G = \eta^* \frac{4\pi}{\Omega_A} = \eta' \frac{4\pi}{\Omega} = 29,000 \frac{4\pi}{\alpha^2} = \eta \frac{4\pi}{\lambda^2} A = \eta \left( \frac{\pi D}{\lambda} \right)^2 \] where \( \eta^*, \eta', \eta = \text{measures of antenna efficiency} \)

Gain and beamwidth are linked: As the gain increases, the beamwidth decreases, and vice versa.
Example: Earth terminal antenna

Ku band downlink frequency

\[ f = 12 \text{ GHz} \]

\[
\lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{ m/s}}{12 \times 10^9 \text{ Hz}} = 0.025 \text{ m}
\]

\[
\text{HPBW} = \alpha = 70^\circ \frac{\lambda}{D} = 70^\circ \frac{0.025 \text{ m}}{5.0 \text{ m}} = 0.35^\circ
\]

\[
G = \eta \left( \frac{\pi D}{\lambda} \right)^2 = 0.60 \left( \frac{\pi \text{ 5.0 m}}{0.025 \text{ m}} \right)^2 = 237,000
\]

\[ [G] = 10 \log_{10} (237,000) = 53.7 \text{ dB} \]

Prime Focus Feed; 5 meter reflector; Tx and Rx
C-Band gain 46 dB; Beamwidth = 1°
Ku-Band gain 54 dB; Beamwidth = 0.4°
Equivalent isotropic radiated power (EIRP)

The equivalent isotropic radiated power (EIRP) is the transmit power of a hypothetical antenna radiating equally in all directions (like a light bulb) so as to have the same power flux density over the coverage area as the actual antenna.

The power flux density of the actual antenna is

\[ \Phi = \frac{P}{S} = \frac{\eta^* P_{in}}{\Omega_A d^2} = \eta^* \frac{4\pi}{\Omega_A} \frac{P_{in}}{4\pi d^2} = G_t \frac{P_{in}}{4\pi d^2} \]

where \( \eta^* \) is the antenna power loss efficiency, \( P = \eta^* P_{in} \) is the transmitted power, \( S \) is the total coverage area at distance \( d \), \( \Omega_A \) is the antenna beam solid angle, and \( G_t = \eta^* (4\pi / \Omega_A) \) is the transmit gain.

By the definition of EIRP

\[ \Phi = \frac{\text{EIRP}}{4\pi d^2} \]

Therefore,

\[ \text{EIRP} = G_t P_{in} \]

The EIRP is the product of the antenna transmit gain and the power applied to the input terminals of the antenna. The antenna efficiency \( \eta^* \) is absorbed in the definition of gain.
## Example 1

<table>
<thead>
<tr>
<th>numeric form</th>
<th>logarithmic (dB) form</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G_t = 100$</td>
<td>$[G_t] = 10 \log_{10}(100) = 20.0 \text{ dB}$</td>
</tr>
<tr>
<td>$P_{in} = 50 \text{ W}$</td>
<td>$[P_{in}] = 10 \log_{10}(50 \text{ W}) = 17.0 \text{ dBW}$</td>
</tr>
<tr>
<td>$EIRP = G_t P_{in}$</td>
<td>$[EIRP] = [G_t] + [P_{in}]$</td>
</tr>
<tr>
<td>= (100)(50 W)</td>
<td>= 20.0 dB + 17.0 dBW</td>
</tr>
<tr>
<td>= 5000 W</td>
<td>= 37.0 dBW</td>
</tr>
</tbody>
</table>

$10 \log_{10}(5000 \text{ W}) = 37.0 \text{ dBW}$
Example 2

\[ P_{\text{HPA}} = 10 \log_{10}(100 \text{ W}) = 20 \text{ dBW} \]

\[ P_{\text{in}} = P_{\text{HPA}} - L = 20 \text{ dBW} - 1 \text{ dB} = 19 \text{ dBW} \]

\[ \text{EIRP} = G_t + P_{\text{in}} = 60 \text{ dB} + 19 \text{ dBW} = 79 \text{ dBW} \]
Figure of Merit ($\frac{G}{T}$)

The ratio of the receive antenna gain $G$ to the total system temperature $T$ is called the “figure of merit.”

\[
\frac{G}{T} = G - T \quad \text{(dB/K)}
\]

where

- $[G]$ = receive antenna gain (dB)
- $[T]$ = total system temperature (dBK)

The figure of merit is independent of the point where it is calculated. However, the gain and system temperature must be specified at the same point.

Example: Suppose the antenna gain is 53.7 dB and the system temperature is 150 K. Then

\[
[T] = 10 \log_{10}(150 \text{ K}) = 21.7 \text{ dBK}
\]

\[
\frac{G}{T} = G - T = 53.7 \text{ dB} - 21.7 \text{ dBK} = 32.0 \text{ dB/K}
\]
Satellite communications payload architecture
Transponder

11 dB reference level
1 input filter
2 wideband receiver
3 3 dB coupler
4 demultiplexer
5 attenuator (lower position)
6 amplifier
7 multiplexer

Satellite Engineering Research Corporation
Satellite transponder frequency plan (C-band)
Typical satellite data

Telstar 5  97º W  C/Ku band

Began service: 7/97
Station-keeping ± 0.05 degrees
Mission Life 12 years

Transponders: 24 C-band  @ 36 MHz
4 Ku-band  @ 54 MHz
24 Ku-band  @ 27 MHz

Coverage: Continental US, Alaska, Hawaii, Puerto Rico, the Caribbean, and into Canada and Latin America.

Markets: Strong broadcast and syndication neighborhood anchored by ABC and FOX; host to SNG, data, business television, Internet, direct-to-home programming and digital data applications

<table>
<thead>
<tr>
<th>Orbital Location</th>
<th>Transponders</th>
<th>Useable Bandwidth</th>
<th>Power</th>
<th>EIRP (dBW)</th>
<th>G/T (dB/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>97 degrees W</td>
<td>24 C-band</td>
<td>36 MHz</td>
<td>20 W nominal</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 Ku-band</td>
<td>54 MHz</td>
<td>100 W nominal</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>24 Ku-band</td>
<td>27 MHz</td>
<td>100 W nominal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Saturation Flux Density - Typical CONUS
-71 to -92 (dBW/m²) at C-band adjustable in 1 dB steps
-75 to -96 (dBW/m²) at Ku-band adjustable in 1 dB steps

Polarization
Orthogonal linear polarization at C-band and Ku-band.

Frequency Band
4/6 GHz and 12/14 GHz

Ku-band Optional "Automatic Level Control" Mode
Mitigates the effects of uplink rain fade by maintaining the transponder at a specific fixed operating point between saturation and 8 dB input backoff.
Satellite EIRP footprint

\[ P = 100 \text{ W} \quad [P] = 20 \text{ dBW} \quad [G] = 30 \text{ dB} \]

\[ [\text{EIRP}] = [G] + [P] = 30 \text{ dB} + 20 \text{ dBW} = 50 \text{ dBW (COC)} \]
Satellite Figure of Merit $G / T$

$T = 630$ K \hspace{1cm} \left[ T \right] = 28$ dBK \hspace{1cm} \left[ G \right] = 30$ dB

\[ \left[ G / T \right] = \left[ G \right] - \left[ T \right] = 30$ dB $- 28$ dBK $= 2$ dB/K (COC)
# Earth-satellite geometry

## Telstar 5 97° W C / Ku band

<table>
<thead>
<tr>
<th>City/Country</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Azimuth</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchorage, AK/USA</td>
<td>61.22</td>
<td>149.90</td>
<td>123.52</td>
<td>8.3</td>
</tr>
<tr>
<td>Boston, MA/USA</td>
<td>42.21</td>
<td>71.03</td>
<td>215.82</td>
<td>34.6</td>
</tr>
<tr>
<td>Calgary/Canada</td>
<td>51.08</td>
<td>114.08</td>
<td>158.45</td>
<td>29.3</td>
</tr>
<tr>
<td>Dallas, TX/USA</td>
<td>32.46</td>
<td>96.47</td>
<td>180.37</td>
<td>52.2</td>
</tr>
<tr>
<td>Guatemala City/Guatemala</td>
<td>14.63</td>
<td>90.52</td>
<td>204.71</td>
<td>71.2</td>
</tr>
<tr>
<td>Halifax/Canada</td>
<td>44.65</td>
<td>63.60</td>
<td>223.21</td>
<td>28.8</td>
</tr>
<tr>
<td>Havana/Cuba</td>
<td>23.12</td>
<td>82.42</td>
<td>213.52</td>
<td>58.3</td>
</tr>
<tr>
<td>Honolulu, HI/USA</td>
<td>21.32</td>
<td>157.83</td>
<td>101.44</td>
<td>18.8</td>
</tr>
<tr>
<td>Houston, TX/USA</td>
<td>29.45</td>
<td>95.21</td>
<td>183.28</td>
<td>55.6</td>
</tr>
<tr>
<td>Jacksonville, FL/USA</td>
<td>30.19</td>
<td>81.39</td>
<td>208.53</td>
<td>50.9</td>
</tr>
<tr>
<td>Los Angeles, CA/USA</td>
<td>34.03</td>
<td>118.14</td>
<td>145.36</td>
<td>44.4</td>
</tr>
<tr>
<td>Merida/Mexico</td>
<td>20.97</td>
<td>89.62</td>
<td>199.81</td>
<td>64.0</td>
</tr>
<tr>
<td>Mexico City/Mexico</td>
<td>19.42</td>
<td>99.17</td>
<td>173.65</td>
<td>67.1</td>
</tr>
<tr>
<td>Miami, FL/USA</td>
<td>25.46</td>
<td>80.11</td>
<td>214.78</td>
<td>54.8</td>
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<tr>
<td>Nassau/Bahamas</td>
<td>25.08</td>
<td>77.33</td>
<td>220.17</td>
<td>53.3</td>
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<tr>
<td>New York, NY/USA</td>
<td>40.43</td>
<td>74.01</td>
<td>213.10</td>
<td>37.6</td>
</tr>
<tr>
<td>Reno, NV/USA</td>
<td>39.53</td>
<td>119.82</td>
<td>146.53</td>
<td>38.5</td>
</tr>
<tr>
<td>San Francisco, CA/USA</td>
<td>37.46</td>
<td>122.25</td>
<td>142.19</td>
<td>39.1</td>
</tr>
<tr>
<td>San Juan/Puerto Rico</td>
<td>18.48</td>
<td>66.13</td>
<td>242.07</td>
<td>48.8</td>
</tr>
<tr>
<td>Seattle, WA/USA</td>
<td>47.60</td>
<td>122.33</td>
<td>147.34</td>
<td>30</td>
</tr>
<tr>
<td>Toronto/Canada</td>
<td>43.70</td>
<td>79.42</td>
<td>204.71</td>
<td>36.6</td>
</tr>
<tr>
<td>Vancouver/Canada</td>
<td>49.22</td>
<td>123.10</td>
<td>147.10</td>
<td>28.3</td>
</tr>
<tr>
<td>Washington, DC/USA</td>
<td>38.53</td>
<td>77.02</td>
<td>210.99</td>
<td>40.7</td>
</tr>
</tbody>
</table>

Example: Earth terminal in Los Angeles

\[
\cos \gamma = \cos \phi \cos \Delta \lambda \\
= \cos(34.03°) \cos(118.14° - 97.0°) \\
= 0.7730
\]

\[
\gamma = 39.38°
\]

\[
\sin \Delta \lambda = \sin \gamma = \frac{\sin(118.14° - 97.0°)}{\sin(39.38°)} \\
= 0.5685
\]

\[
\Delta \lambda = 180° - 34.64° = 145.36°
\]

\[
\tan \theta = \frac{\cos \gamma - R_E / r}{\sin \gamma} \\
= \frac{\cos(39.38°) - (6378 \text{ km})/(42,164 \text{ km})}{\sin(39.38°)} \\
= 0.9799
\]

\[
\theta = 44.42°
\]
Free space loss

The free space loss takes into account that electromagnetic waves spread out into spherical wavefronts as they propagate through space due to diffraction.

$$L_s = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2$$

$$[L_s] = 10 \log_{10} \left(\frac{4\pi d}{\lambda}\right)^2 = 20 \log_{10} \left(\frac{4\pi d}{\lambda}\right)$$

For a geostationary satellite, the free space loss is on the order of 200 dB (or a factor of $10^{20}$).

The received power at the earth terminal is typically on the order of tens of picowatts.
Example

Problem: Determine the free space loss for a Ku band downlink between Telstar 5 at 97° W Longitude and Los Angeles if the frequency is 12 GHz and the angle of elevation is 44.4°.

Solution: The wavelength is

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{ m/s}}{12 \times 10^9 \text{ Hz}} = 0.025 \text{ m}$$

The slant range is

$$d = \sqrt{r^2 - (R_E \cos \theta)^2 - R_E \sin \theta}$$

$$= \sqrt{(42,164 \text{ km})^2 - (6378 \text{ km} \times \cos 44.4^\circ)^2 - 6378 \text{ km} \times \sin 44.4^\circ}$$

$$= 37,453 \text{ km}$$

Thus

$$L_s = \left( \frac{4\pi d}{\lambda} \right)^2 = \left( \frac{4\pi \times 37,453,000 \text{ m}}{0.025 \text{ m}} \right)^2 = 3.544 \times 10^{20}$$

$$[L_s] = 10 \log_{10} (3.544 \times 10^{20}) = 205.5 \text{ dB}$$
Received carrier power

\[ C = \frac{A_e}{S} \frac{P}{L} = \Phi A_e \]

Transmit gain

\[ G_t = \eta^* \frac{4\pi}{\Omega_A} = \eta^* \frac{4\pi d^2}{S} \]

Receive gain

\[ G_r = \frac{4\pi}{\lambda^2} A_e \]

Footprint area

\[ S = \eta^* \frac{4\pi d^2}{G_t} \]

Receiver equivalent area

\[ A_e = G_r \frac{\lambda^2}{4\pi} \]

Received carrier power

\[ C = \frac{G_r \left( \frac{\lambda^2}{4\pi} \right)}{4\pi d^2 / G_t} \frac{P}{\eta^*} \frac{1}{L} = \frac{(G_t P_{in}) G_r}{(4\pi d / \lambda)^2 L} = \frac{\text{EIRP}}{L_s L} \]

Equivalent isotropic radiated power

\[ \text{EIRP} = G_t P_{in} \]

Free space loss

\[ L_s = \left( \frac{4\pi d}{\lambda} \right)^2 \]
Example

Problem: Determine the received carrier power for the Ku band downlink between Telstar 5 and an Earth terminal in Los Angeles if the frequency is 12 GHz and the antenna has an efficiency of 0.60 and a diameter of 5.0 m. Allow a rain attenuation loss of 1.9 dB, a gaseous atmospheric loss of 0.1 dB, and a pointing loss of 0.2 dB.

Solution: The satellite EIRP in Los Angeles is 49.2 dBW. At 12 GHz, the antenna gain is 53.7 dB and the free space loss is 205.5 dB. Therefore, the received carrier power is

\[
[C] = [EIRP] + [G_r] - [L_s] - [L_r] - [L_a] - [L_p]
\]

\[
= 49.2 \text{ dBW} + 53.7 \text{ dB} - 205.5 \text{ dB} - 1.9 \text{ dB} - 0.1 \text{ dB} - 0.2 \text{ dB}
\]

\[
= -104.8 \text{ dBW}
\]

Therefore,

\[
C = 10^{-10.48} \text{ W} = 3.3 \times 10^{-11} \text{ W} = 33 \text{ pW}
\]
Noise power

Thermal noise power in bandwidth $B$

$$N = N_0 B = k_B T B$$

where the spectral noise density is

$$N_0 = k_B T$$

for system temperature $T$ and Boltzmann’s constant is

$$k_B = 1.381 \times 10^{-23} \text{ W} / \text{K Hz} \quad [k_B] = -228.6 \text{ dBW} / \text{K Hz}$$
Link budget equation

Carrier power

\[ C = \frac{\text{EIRP} \; G_r}{L_s \; L_r \; L_o} \]

Noise power

\[ N = k_B \; T \; B = N_0 \; B \]

Carrier to noise ratio

\[ \frac{C}{N} = \frac{\text{EIRP} \; G}{T \; L_s \; L_r \; L_o \; k_B \; B} \]

Carrier to noise density ratio

\[ \frac{C}{N_0} = \frac{C}{N} \; B = \frac{\text{EIRP} \; G}{T \; L_s \; L_r \; L_o \; k_B} \]
The link budget equation is expressed in logarithmic (dB) form as follows (dB values indicated by brackets):

**Uplink**

\[
\left[ \frac{C}{N_0} \right] = [\text{EIRP}] + [G/T] - [L_s] - [L_r] - [L_o] - [k_B]
\]

at satellite E/S satellite at uplink frequency

**Downlink**

\[
\left[ \frac{C}{N_0} \right] = [\text{EIRP}] + [G/T] - [L_s] - [L_r] - [L_o] - [k_B]
\]

at E/S satellite E/S at downlink frequency
Combined uplink and downlink

Only thermal noise (Average White Gaussian Noise)

\[
\left( \frac{C}{N} \right)_{\text{net}}^{-1} = \left( \frac{C}{N} \right)_{\text{up}}^{-1} + \left( \frac{C}{N} \right)_{\text{down}}^{-1}
\]

(include numeric)

Include interference

\[
\left( \frac{C}{N} \right)_{\text{net}}^{-1} = \left( \frac{C}{N} \right)_{\text{up}}^{-1} + \left( \frac{C}{N} \right)_{\text{down}}^{-1} + \left( \frac{C}{I} \right)^{-1}
\]

Noise power

\[
N = N_0 B
\]

\[
\frac{C}{N} = \frac{C}{N_0} \frac{1}{B}
\]
Power flux density

The EIRP of the uplink Earth station antenna must be adjusted to match an acceptable power flux density (PFD) at the satellite.

\[
PFD = \Phi = \frac{\text{EIRP}}{4\pi d^2} \frac{1}{L_r} \frac{1}{L} = \frac{\text{EIRP}}{L_s \left( \frac{\lambda^2}{4\pi} \right)} \frac{1}{L_r} \frac{1}{L}
\]

\[
[\Phi] = [\text{EIRP}] - [4\pi d^2] - [L_r] - [L]
\]

or

\[
[\Phi] = [\text{EIRP}] - [L_s] - \left[ \frac{\lambda^2}{4\pi} \right] - [L_r] - [L]
\]
Example

**Problem:** For an uplink between an Earth station in Washington, DC and Telstar 5, the EIRP is 79.0 dBW, the slant range is 37,722 km, the rain attenuation is 5.9 dB, and the antenna pointing loss is 0.2 dB. Determine the power flux density incident on the satellite.

**Solution:**

\[
[\Phi] = [\text{EIRP}] - [4\pi d^2] - [L_r] - [L]
\]

\[
= 79.0 \text{ dBW} - 10 \log_{10} \left\{ 4\pi (37,722,000 \text{ m})^2 \right\} - 5.9 \text{ dB} - 0.2 \text{ dB}
\]

\[
= -89.6 \text{ dBW} / \text{m}^2
\]

This PFD is within the specifications for Telstar 5.

**Saturation Flux Density - Typical CONUS**

-75 to -96 (dBW/m²) at Ku-band adjustable in 1 dB steps

**Ku-band Optional "Automatic Level Control" Mode**

Mitigates the effects of uplink rain fade by maintaining the transponder at a specific fixed operating point between saturation and 8 dB input backoff.
## Example link budget

### Signal architecture

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information bit rate</td>
<td>22.5 Mbps</td>
</tr>
<tr>
<td>dBHz</td>
<td>73.5 dBHz</td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK</td>
</tr>
<tr>
<td>Coding</td>
<td>V(7,1/2)</td>
</tr>
<tr>
<td>Bits per symbol</td>
<td>2</td>
</tr>
<tr>
<td>Code rate</td>
<td>1/2</td>
</tr>
<tr>
<td>Percentage of raised cosine filtering</td>
<td>20</td>
</tr>
<tr>
<td>Noise bandwidth</td>
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</tr>
<tr>
<td>Occupied bandwidth</td>
<td>27.0 MHz</td>
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<tr>
<td>BER</td>
<td>0.00001</td>
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<tr>
<td>Eb/No (uncoded)</td>
<td>9.6 dB</td>
</tr>
<tr>
<td>Coding gain</td>
<td>5.1 dB</td>
</tr>
<tr>
<td>Eb/No (ideal)</td>
<td>4.5 dB</td>
</tr>
<tr>
<td>Modem implementation loss</td>
<td>0.5 dB</td>
</tr>
<tr>
<td>Eb/No (required)</td>
<td>5.0 dB</td>
</tr>
<tr>
<td>C/No (required)</td>
<td>78.5 dBHz</td>
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### Satellite

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Telstar 5</td>
</tr>
<tr>
<td>Longitude</td>
<td>deg 97.0</td>
</tr>
<tr>
<td>Transponder bandwidth</td>
<td>MHz 27.0</td>
</tr>
<tr>
<td>EIRP</td>
<td>dBW 49.2</td>
</tr>
<tr>
<td>G/T</td>
<td>dB/K 2.0</td>
</tr>
<tr>
<td>Signal architecture</td>
<td></td>
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Example link budget (continued)

**Uplink**

**Earth station transmit terminal**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>City</td>
<td>Washington</td>
</tr>
<tr>
<td>Longitude</td>
<td>deg 77.0</td>
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<tr>
<td>Latitude</td>
<td>deg 38.5</td>
</tr>
<tr>
<td>Earth central angle</td>
<td>deg 42.7</td>
</tr>
<tr>
<td>Elevation angle</td>
<td>deg 40.8</td>
</tr>
<tr>
<td>Slant range</td>
<td>km 37722</td>
</tr>
<tr>
<td>HPA Power</td>
<td>W 100.0</td>
</tr>
<tr>
<td></td>
<td>dBW 20.0</td>
</tr>
<tr>
<td>Antenna diameter</td>
<td>m 9.2</td>
</tr>
<tr>
<td>Antenna half power beamwidth</td>
<td>deg 0.16</td>
</tr>
<tr>
<td>Antenna efficiency</td>
<td>0.55</td>
</tr>
<tr>
<td>Antenna transmit gain</td>
<td>dBW 60.0</td>
</tr>
<tr>
<td>Line loss</td>
<td>dB 1.0</td>
</tr>
<tr>
<td>EIRP</td>
<td>dBW 79.0</td>
</tr>
</tbody>
</table>

**Link calculation**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>GHz 14.0</td>
</tr>
<tr>
<td>Wavelength</td>
<td>m 0.0214</td>
</tr>
<tr>
<td>Earth station EIRP</td>
<td>dBW 79.0</td>
</tr>
<tr>
<td>Satellite G/T</td>
<td>dB/K 2.0</td>
</tr>
<tr>
<td>Free space loss</td>
<td>dB 206.9</td>
</tr>
<tr>
<td>Rain region</td>
<td>D2</td>
</tr>
<tr>
<td>Availability</td>
<td>percent 99.95</td>
</tr>
<tr>
<td>Rain attenuation</td>
<td>dB 5.9</td>
</tr>
<tr>
<td>Antenna pointing error</td>
<td>deg 0.02</td>
</tr>
<tr>
<td>Antenna pointing loss</td>
<td>dB 0.2</td>
</tr>
<tr>
<td>Boltzmann's constant</td>
<td>dBW/K Hz -228.6</td>
</tr>
<tr>
<td>C/No (uplink)</td>
<td>dBHz 96.6</td>
</tr>
<tr>
<td>Noise bandwidth</td>
<td>dBHz 73.5</td>
</tr>
<tr>
<td>C/N (uplink)</td>
<td>dB 23.1</td>
</tr>
<tr>
<td>Power flux density</td>
<td>dBW/m² -89.6</td>
</tr>
</tbody>
</table>
**Example link budget (continued)**

*Downlink*

**Earth station receive terminal**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>City</td>
<td>Los Angeles</td>
</tr>
<tr>
<td>Longitude</td>
<td>deg 118.1</td>
</tr>
<tr>
<td>Latitude</td>
<td>deg 34.0</td>
</tr>
<tr>
<td>Earth central angle</td>
<td>deg 39.4</td>
</tr>
<tr>
<td>Elevation angle</td>
<td>deg 44.4</td>
</tr>
<tr>
<td>Slant range</td>
<td>km 37453</td>
</tr>
<tr>
<td>Antenna diameter</td>
<td>m 5.0</td>
</tr>
<tr>
<td>Antenna half power beamwidth</td>
<td>deg 0.35</td>
</tr>
<tr>
<td>Antenna efficiency</td>
<td>0.60</td>
</tr>
<tr>
<td>Antenna receive gain</td>
<td>dB 53.7</td>
</tr>
<tr>
<td>Clear sky antenna noise temperature</td>
<td>K 25</td>
</tr>
<tr>
<td>Receiver equivalent temperature</td>
<td>K 125</td>
</tr>
<tr>
<td>System temperature</td>
<td>K 150</td>
</tr>
<tr>
<td>G/T (clear sky)</td>
<td>dB/K 21.8</td>
</tr>
<tr>
<td>C/N (downlink)</td>
<td>dB 26.3</td>
</tr>
</tbody>
</table>

**Link calculation**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>GHz 12.0</td>
</tr>
<tr>
<td>Wavelength</td>
<td>m 0.025</td>
</tr>
<tr>
<td>Satellite EIRP</td>
<td>dBW 49.2</td>
</tr>
<tr>
<td>Earth station G/T (clear sky)</td>
<td>dB/K 32.0</td>
</tr>
<tr>
<td>Free space loss</td>
<td>dB 205.5</td>
</tr>
<tr>
<td>Rain region</td>
<td>F</td>
</tr>
<tr>
<td>Availability</td>
<td>percent 99.95</td>
</tr>
<tr>
<td>Rain attenuation</td>
<td>dB 1.9</td>
</tr>
<tr>
<td>Degradation in G/T</td>
<td>dB 2.2</td>
</tr>
<tr>
<td>Gaseous atmospheric loss</td>
<td>dB 0.1</td>
</tr>
<tr>
<td>Antenna pointing error</td>
<td>deg 0.05</td>
</tr>
<tr>
<td>Antenna pointing loss</td>
<td>dB 0.2</td>
</tr>
<tr>
<td>Boltzmann's constant</td>
<td>dBW/K Hz -228.6</td>
</tr>
<tr>
<td>C/No (downlink)</td>
<td>dBHz 99.9</td>
</tr>
<tr>
<td>Noise bandwidth</td>
<td>dBHz 73.5</td>
</tr>
<tr>
<td>C/N (downlink)</td>
<td>dB 26.3</td>
</tr>
</tbody>
</table>
Example link budget (continued)

*Combined uplink and downlink*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C/N (uplink)</td>
<td>dB</td>
<td>23.1</td>
</tr>
<tr>
<td>C/N (downlink)</td>
<td>dB</td>
<td>26.3</td>
</tr>
<tr>
<td>C/I (adjacent satellite)</td>
<td>dB</td>
<td>20.0</td>
</tr>
<tr>
<td>C/I (cross polarization)</td>
<td>dB</td>
<td>24.0</td>
</tr>
<tr>
<td>C/N (net)</td>
<td>dB</td>
<td>16.7</td>
</tr>
<tr>
<td>Noise bandwidth</td>
<td>dB/Hz</td>
<td>73.5</td>
</tr>
<tr>
<td>C/No (net)</td>
<td>dB/Hz</td>
<td>90.3</td>
</tr>
<tr>
<td>Information bit rate</td>
<td>dB/Hz</td>
<td>73.5</td>
</tr>
<tr>
<td>Eb/No (available)</td>
<td>dB</td>
<td>16.7</td>
</tr>
<tr>
<td>Eb/No (required)</td>
<td>dB</td>
<td>5.0</td>
</tr>
<tr>
<td>C/No (required)</td>
<td>dB/Hz</td>
<td>78.5</td>
</tr>
<tr>
<td>Margin</td>
<td>dB</td>
<td>11.7</td>
</tr>
</tbody>
</table>
### Power levels in satellite link

**Uplink path**
- 30.0 dB Driver gain
- 20.0 dB Earth station HPA gain
- 1.0 dB Line loss
- 60.0 dB Earth station antenna gain
- 6.1 dB Rain attenuation + other losses
- 206.9 dB Free space loss

**Satellite**
- 30.0 dB Satellite receive antenna gain
- 69.0 dB Receiver amplifier gain
- 57.0 dB Satellite TWTA saturated gain
- 2.0 dB Output losses
- 29.2 dB Satellite transmit antenna gain

**Downlink path**
- 205.5 dB Free space loss
- 2.2 dB Rain attenuation + other losses
- 53.7 dB Earth station antenna gain
- 0.2 dB Line loss
- 40.0 dB LNA gain
- 35.0 dB Downconverter and IF amplifier gain

**-30.0 dBW** Input to demodulator

---

**Graph**

```
Earth Station EIRP = 79.0
Satellite EIRP = 49.2
```

```
Transmit earth station  Uplink  Satellite  Downlink  Receive terminal
```

---

**Legend**
- **Uplink**
- **Downlink**

---

**Satellite Engineering Research Corporation**
RF link (summary)

**Antenna half power beamwidth**

\[ \text{HPBW} = \alpha = k \frac{\lambda}{D} = k \frac{c}{f D} \]

**Antenna gain**

\[ G = \eta^* \frac{4\pi}{\Omega_A} = \eta' \frac{4\pi}{\Omega} = \eta \frac{4\pi}{\lambda^2} A = \eta \left( \frac{\pi D}{\lambda} \right)^2 \]

**Free space loss**

\[ L_s = \left( \frac{4\pi d}{\lambda} \right)^2 = \left( \frac{4\pi d f}{c} \right)^2 \]

**Carrier to noise density ratio**

\[ \frac{C}{N_0} = R_b \frac{E_b}{N_0} = G_t \frac{G_r}{L_s L} \frac{P_{in}}{k_B T} = \frac{\text{EIRP} (G_r / T)}{L_s L k_B} \]

- \(\alpha\) = half power beamwidth
- \(\lambda\) = wavelength
- \(f\) = frequency
- \(c\) = speed of light
- \(D\) = antenna diameter
- \(k\) = antenna taper factor
- \(\eta^*, \eta', \eta\) = antenna efficiency factors
- \(\Omega_A\) = antenna beam solid angle
- \(d\) = slant range
- \(S\) = footprint area
- \(A\) = antenna area
- \(C\) = carrier power
- \(N_0\) = noise density
- \(R_b\) = information bit rate
- \(E_b\) = energy per information bit
- \(\text{EIRP}\) = equivalent isotropic radiated power
- \(G_t\) = transmit antenna gain
- \(G_r\) = receive antenna gain
- \(P_{in}\) = input power
- \(L_s\) = free space loss
- \(L\) = net attenuative loss
- \(T\) = system noise temperature
- \(k_B\) = Boltzmann’s constant
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