Fundamentals of Satellite Communications
Part 2
Link Analysis, Transmission, Path Loss, & Reception

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Link Analysis, Transmission, Path Loss, & Reception

Communications Link Objectives
- Design Factors to Consider in Signal Transmission
- Transmitter Sub-System
- Transmitted Power
- Common Digital Modulation Techniques
- Path Loss to the Satellite
- Atmospheric Effects
- Receiving System – Carrier to Noise
- Gain over Noise Temperature
- Satellite Link Example
- Bandwidth Economics
- Satellite Tracking
- Uplink Power Controller
- Summary

-
Communications Link Objectives

Recover Information

- Received Signal must be
  - Above noise
  - Above spurious signals
  - Undistorted

- Transmitters live in a community
  - Don’t interfere with your neighbor

- Cost effective so someone will use your link
Design Factors to Consider in Signal Transmission

- Distance between users
  - Fixed Satellites are ≈ 25,000 miles above Earth
- Weather effects
  - Adjusting the Signal for Adverse Weather
- Availability of the communication link
  - Some Transmissions can wait for weather to clear
    - Internet users are use to waiting
    - Satellite TV needs a high level of availability
- Maintaining Signal Quality
- Using Minimum Bandwidth
- Antenna Tracking -
Satellite Communications Design Considerations

- Satellite signals cover a wide area
- Many users
- Independent Operations
  - One site has no idea what another site is doing
- Coexist by following the rules – Don’t interfere with your neighbor -
Multiple Carrier Transmission

- Many Users - Multiple signals can be transmitted simultaneously or interleaved
  - FDM - Each Carrier has an assigned Frequencies
  - TDM - Each Carrier has an assigned Time to Transmit
  - CDM - Each Carrier has an assigned Transmit Code
- Many systems use a combination of techniques
- Independent carriers to a satellite are assigned a center frequency and a bandwidth (FDM) -
Transmitter Sub-System

- Modulator
- Frequency Converter
- Power Amplifier
- Antenna

Data → Modulator → Frequency Converter → Power Amplifier → Antenna Ass’y

Carrier
Spurious
Multiple Signal Transmission

Two most expensive components in a Transmitter
- Antenna & High Power Amplifier
- Signals are combined prior to High Power Amplification

- Block Conversion
  - Multiple modulator outputs at their assigned frequencies are summed into a Block Up Converter (BUC)

Diagram:
- Modulator #1
- Data In N Carriers
- Carrier Summing Network
- Modulator #N
- Satellite Carriers (FDM)
- Frequency Converter
- Power Amp

Notes:
- Many carriers occupy the same frequency (FDM)
- Orthogonal polarizations
- Block Conversion
- Two most expensive components
Satellite Communications Signal Path

- Satellite (Bent Pipe) -
- Frequency Converter
- Power Amplifier
- Antenna
- Modulator
- Data In
- Earth Station Up Link
- LNA
- Path
- Freq Conv
- HPA
- Path
- Antenna
- Low Noise Amplifier
- Frequency Converter
- De-Modulator
- Data Out
- Earth Station Down Link
Transmitted Power

EIRP - Effective Isotropic Radiated Power

- Isotropic Radiated Power is the power emitted from a point source
  - Three dimensions
- Directional antenna emits radiation in a solid angle
- EIRP is the power radiated in the solid angle as if it were isotropic
  - EIRP = Power in Solid Angle x the number of solid angles in a sphere
- Antenna Gain (dB) = 10*Log₁₀

  (surface of the sphere/ surface of the solid angle)

- Gain_{dB} = 10*\log_{10} (60*F^2 * D^2)
  - F = Frequency in GHz
  - D = diameter of Parabolic dish in Meters
EIRP - Effective Isotropic Radiated Power

- EIRP = Transmitter Output Power + Antenna Gain
- EIRP includes the effects of:
  - Antenna Gain
  - Antenna Efficiencies
  - Transmitter Output Power
  - Coupling and Wave guide Losses, Etc.
- Once the EIRP is known, no additional information about the transmitter is required.
  - EIRP information assumes the transmitter is pointed directly at the receiver.
Calculating Earth Station Transmitted Power

Typical Required EIRP = 42 dBW / 4kHz (Clear Sky)
- Determined by the satellite operator
- Assume Signal Bandwidth = 8MHz \( \Rightarrow \) + 33 dB (with respect to 4kHz) i.e 10\( \log(8\text{MHz}/4\text{kHz}) \)
- For 8MHz the required EIRP = + 75 dBW
  - +75 dBW \( \Rightarrow \) 3 Billion Watts
- Antenna size
  - 10 Meter antenna @ 6 GHz \( \Rightarrow \) 53.3 dB of Gain
- Misc Loss = 4 dB
- \( P_{\text{out}} = +75 \text{ dBW} - 53.3 \text{ dB} + 4 \text{ dB} = +25.7 \text{dBW} \)
- Required transmitter \( P_{\text{out}} = 372 \text{ Watts} \)
Analog vs Digital TV
Transmission - Power Requirements

\[ P_{out} = 25.7 \text{ dBW in an 8 MHz BW (Digital TV Bandwidth)} \]
- \[ P_{out} = 372 \text{ Watts} \]
- Bandwidth of 36 MHz (Analog TV Bandwidth)
  - \[ P_{out} = +25.7 \text{ dBW} + 10 \times \log_{10} (36 MHz/8 MHz) \]
  - \[ P_{out} = +25.7 \text{ dBW} + 6.5 \text{ dB} = 32.2 \text{ dBW} = 1.66 \text{ KW} \]
- DTV has 4 to 8 MHz BW
- HDTV 8 to 36 MHz BW
  - BW always improving
  - Better coding technology
    - Saves power
    - Increases the spectral efficiency -
Common Digital Modulation Techniques

Constant Envelope Modulation
- BPSK – Bi-Phase Shift Keying
- QPSK – Quadrature Phase Shift Keying
- 8PSK – Phase Shift Keying with 8 phase states
- 16QAM – Quadrature Amplitude Modulation with 16 vector locations -
Digital Modulation: Design Trade Offs

Previously calculated $P_{out} = 372W$ for an 8MHz BW

- Required IF bandwidth ($\approx 1.3 \times$ Symbol Rate)
  - Housekeeping & Error Correcting Codes
- Bit Rate of 26MBits/Sec
  - BPSK Modulation (1 Bit/Symbol) $\approx 26$MBits/Sec$ \times 1.3 \Rightarrow 33.8$ MHz
    - $P_{out} = 1572$ Watts
  - QPSK Modulation (2 Bit/Symbol) $\approx 16.9$ MHz
    - $P_{out} = 786$ Watts
  - 8PSK Modulation (3 Bit/Symbol) $\approx 11.3$ MHz
    - $P_{out} = 524$ Watts
- 16QAM Modulation (4 Bit/Symbol) $\approx 8.65$ MHz
  - $P_{out}$ does not correlate because of the AM Modulation

More complex modulation requires less bandwidth & Less Power

- Minimum S/N is increased to maintain an acceptable BER -
C/N vs. Eb/No

Eb/No = C/N + 10\log(\text{Symbol Rate}/\text{Bit Rate})

- Eb is the Energy in a bit - Determines Bit Error Rate (BER)
- Bit Rates \(\geq\) Symbol Rates
- Eb/No \(\leq\) C/N

- For C/N = 14.49 dB
  - BPSK Modulation (1 Bit/Symbol)
    - Eb/No \(\approx\) C/N = 14.49 dB
    - Approximation is due different Forward Error Correcting (FEC) used to correct bit errors
  - QPSK Modulation (2 Bit/Symbol)
    - Eb/No \(\approx\) C/N – 3dB = 11.49 dB
  - 8PSK Modulation (3 Bit/Symbol)
    - Eb/No \(\approx\) C/N – 5dB = 9.49 dB
Symbol Error in M-ary PSK Systems

Note: More Complex Modulations Require higher Eb/No for the same Error

Higher Modulation Complexity ➔ Higher BER for same C/N
Limiting Factor in Digital Modulation

Shannon’s Theorem (1950’s)
- Relates Bit Rate, Bandwidth, & Signal to Noise
  - Bit Rate = BW * log₂(1 + SNR)
    - Bit Rate (Bits/Sec.) = BR
    - Signal bandwidth = BW
    - SNR = Signal to Noise Ratio
- Bit Rate is limited by S/N
- Symbol rate is a function of Bandwidth
  - Bit Rate / Symbol Rate is a function of signal complexity
- Complex modulations optimize Bit Rates/BW
- Higher BR/BW requires higher Signal to Noise
- In a noiseless system
  - Infinite complexity and Bit Rate is theoretically attainable
- Shannon Theoretical limit has never been reached -
Path Loss to the Satellite

- Signal Radiates out from a point Source
- Flux Density is less at receiving antenna as the distance increases
- Path Loss is actually a dispersion of the transmitted signal

\[
\Psi_m = \frac{EIRP}{4\pi r^2}
\]

surface area of the sphere
\[= 4\pi r^2\]

Isotropic Transmitter

Receiving antenna sees less of the wave front as the distance increases.
Path Loss Calculations

\[ P_L = \left( \frac{4\pi D}{\lambda} \right)^2 \]

Path Loss in dB = 10 \log(P_L)

- Note: Path Loss is related to Number of Wave Lengths Traversed:
  - Path Loss proportional to \( (D / \lambda)^2 \)
- Example
  - Frequency: 14GHz
    - Lambda (\( \lambda \)) = 0.021429 Meters
  - Distance: 22,300 Miles (35,888 kM)
  - Path Loss: 206.46 dB
- This why EIRP is 3 Billion Watts -
Atmospheric Effects

- 1st 5 miles of the 22,300 mile trip is the most detrimental
  - Potential interference from terrestrial sources
  - Increased atmospheric absorption
  - Partially depolarizes signal

- Low Elevation Angles traverse more atmosphere than high elevation angles

- Minimum Elevation Angles
- C-Band Elevations ≥ 5°
- Ku-Band Elevations ≥ 10°
Atmospheric Attenuation vs. Frequency (Horizontal Polarization)

Ka Band Frequencies are above & below the water absorption peak

- Oxygen Peaks at 60GHz
- Satellite to Satellite communication is usually in the 50 to 80 GHz range, because the signals do not interfere with terrestrial communications.
Adverse Weather

Satellite operators demand that the signal entering the satellite have a fixed Power Spectral density

- Prevents signals from interfering with each other

Satellite users expectation of signal availability varies

- Internet users have been conditioned to wait
- Super bowl viewers must see pictures without a lapse

Rain is the most common adverse effect on signal transmissions -
Rain Fade Margins

- Adverse weather is usually localized
- MUST have power to spare to burn through adverse weather
- C-Band: 2 to 3 dB
- Ku-Band: 5 to 15 dB
- Ka-Band: 20 to 50 dB

- Actual rain fade margins depend on
  - Location of the earth station
  - Rain fall model for the respective area
  - Weather effects only the first 5 miles
Rain Attenuation

- Droplets absorb and depolarize the microwaves
- Rain effects depend on Rain Rates which are classified by region
- Note the significant difference in Ka Band Attenuation
- C-Band rain fade is a minor problem

- 5kM @ 25mm/Hr Rain
- C-Band Loss: .35dB
- Ku Band Loss: 5dB
- Ka Band Loss: 25dB

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Atten (dB/kM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C Band</td>
<td>0.07dB/kM</td>
</tr>
<tr>
<td>Ku Band</td>
<td>1dB/kM</td>
</tr>
<tr>
<td>Ka Band</td>
<td>5dB/kM</td>
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</table>

Droplets absorb and de-polarize the microwaves. Rain effects depend on Rain Rates which are classified by region. Note the significant difference in Ka Band Attenuation. C-Band rain fade is a minor problem.
## CCIR Rain Zone Rain Rates in mm/h

<table>
<thead>
<tr>
<th>Rainzone</th>
<th>1%</th>
<th>0.30%</th>
<th>0.10%</th>
<th>0.03%</th>
<th>0.01%</th>
<th>0.003%</th>
<th>0.001%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>8</td>
<td>14</td>
<td>22</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>6</td>
<td>12</td>
<td>21</td>
<td>32</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>3</td>
<td>5</td>
<td>9</td>
<td>15</td>
<td>26</td>
<td>42</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>5</td>
<td>8</td>
<td>13</td>
<td>19</td>
<td>29</td>
<td>42</td>
</tr>
<tr>
<td>E</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>12</td>
<td>22</td>
<td>41</td>
<td>70</td>
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<tr>
<td>F</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>15</td>
<td>28</td>
<td>54</td>
<td>78</td>
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<tr>
<td>G</td>
<td>0</td>
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<td>12</td>
<td>20</td>
<td>30</td>
<td>45</td>
<td>65</td>
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<tr>
<td>H</td>
<td>0</td>
<td>4</td>
<td>10</td>
<td>18</td>
<td>32</td>
<td>55</td>
<td>83</td>
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<tr>
<td>J</td>
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<td>13</td>
<td>20</td>
<td>28</td>
<td>35</td>
<td>45</td>
<td>55</td>
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<tr>
<td>K</td>
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<td>6</td>
<td>12</td>
<td>23</td>
<td>42</td>
<td>70</td>
<td>100</td>
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<tr>
<td>L</td>
<td>0</td>
<td>7</td>
<td>15</td>
<td>33</td>
<td>60</td>
<td>105</td>
<td>150</td>
</tr>
<tr>
<td>M</td>
<td>4</td>
<td>11</td>
<td>22</td>
<td>40</td>
<td>63</td>
<td>95</td>
<td>120</td>
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<tr>
<td>N</td>
<td>5</td>
<td>15</td>
<td>35</td>
<td>65</td>
<td>95</td>
<td>140</td>
<td>180</td>
</tr>
<tr>
<td>P</td>
<td>12</td>
<td>34</td>
<td>65</td>
<td>105</td>
<td>145</td>
<td>200</td>
<td>250</td>
</tr>
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</table>

### % Time at Rate

<table>
<thead>
<tr>
<th>Hr/Yr</th>
<th>87.6</th>
<th>26.28</th>
<th>8.76</th>
<th>2.628</th>
<th>0.876</th>
<th>0.2628</th>
<th>0.0876</th>
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</thead>
<tbody>
<tr>
<td>Availability</td>
<td>99%</td>
<td>99.7%</td>
<td>99.9%</td>
<td>99.97%</td>
<td>99.99%</td>
<td>99.997%</td>
<td>99.999%</td>
</tr>
</tbody>
</table>

99.9% availability in rain zone “P” requires sufficient dB margin to overcome 65 mm/hr rain rates.
Rain Rates at Various Locations

IP Star Satellite is in a P Region at Ka Band -
Approaches to Rain Fade

- Larger ground station antennas
  - Difficult to Point
- Higher available power
  - Up-Link Power Controller adjusts the transmitted power
  - Average rain time is short (< 10%)
  - Added margin is wasted 90% of the time.
- Site diversity
  - Parallel operation several kilometers apart
  - “expensive”
- Adaptive Coding
  - Increase in Forward Error Correction Coding
  - Flexible Bandwidths maintain constant data rates
  - Difficult to Implement
Atmospheric Attenuation Measured with the ACTS satellite systems over an 8 hour period in Tampa, FL. On Jan 1, 1996

Rain Fade at 27.5 GHz & 20.2 GHz

Transmission loss during the peak attenuations -

Rain Rate vs Time (Hours)

- Change in attenuation vs. time
Noise is a random motion of electrons
At 0 °K there is no electron motion
Noise is referenced in terms of Noise Temperature (°K)
- System Noise (T_{sys}) is temperature above 0 °K
- Antenna & Receiving system adds noise to the input signal -
- System noise temperature $T_{sys} = T_A + T_e$
- Antenna Noise Temperature $= T_A$
- $T_A = \text{sky noise + antenna losses}$
  - sky noise is background microwave radiation
- Receiver Noise ($T_e$) is the added to the signal
- Receiver Noise Temperature relates to Noise Figure
- $T_e = (F_n - 1) T_o$ ($T_o = 290^\circ K$)
- $F_n$ is the receiver noise factor
- Noise Factor $F_n = 10^{NF/10}$
  - $NF = \text{Noise Figure in dB}$
Antenna Noise is a function of Elevation Angle and Frequency.
Antenna Noise vs. Angle off Perpendicular

Noise temperatures can get high at low angles of elevation.
Table of Noise Temperature (Te), Noise Factor (F) and Noise Figure (NF)

<table>
<thead>
<tr>
<th>Te (Deg K)</th>
<th>F</th>
<th>NF (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.03</td>
<td>0.15</td>
</tr>
<tr>
<td>20</td>
<td>1.07</td>
<td>0.29</td>
</tr>
<tr>
<td>40</td>
<td>1.14</td>
<td>0.56</td>
</tr>
<tr>
<td>70</td>
<td>1.24</td>
<td>0.94</td>
</tr>
<tr>
<td>100</td>
<td>1.34</td>
<td>1.29</td>
</tr>
<tr>
<td>150</td>
<td>1.52</td>
<td>1.81</td>
</tr>
<tr>
<td>200</td>
<td>1.69</td>
<td>2.28</td>
</tr>
<tr>
<td>250</td>
<td>1.86</td>
<td>2.70</td>
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<tr>
<td>298</td>
<td>2.03</td>
<td>3.07</td>
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<tr>
<td>400</td>
<td>2.38</td>
<td>3.76</td>
</tr>
<tr>
<td>500</td>
<td>2.72</td>
<td>4.35</td>
</tr>
<tr>
<td>700</td>
<td>3.41</td>
<td>5.33</td>
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</table>

<table>
<thead>
<tr>
<th>NF (dB)</th>
<th>F</th>
<th>Te (Deg K)</th>
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</thead>
<tbody>
<tr>
<td>0.1</td>
<td>1.02</td>
<td>6.75</td>
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<tr>
<td>0.2</td>
<td>1.05</td>
<td>13.67</td>
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<td>0.3</td>
<td>1.07</td>
<td>20.74</td>
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<td>0.4</td>
<td>1.10</td>
<td>27.98</td>
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<td>0.5</td>
<td>1.12</td>
<td>35.39</td>
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<td>0.6</td>
<td>1.15</td>
<td>42.96</td>
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<td>0.7</td>
<td>1.17</td>
<td>50.72</td>
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<td>0.8</td>
<td>1.20</td>
<td>58.66</td>
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<td>0.9</td>
<td>1.23</td>
<td>66.78</td>
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<td>1.0</td>
<td>1.26</td>
<td>75.09</td>
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<td>1.1</td>
<td>1.29</td>
<td>83.59</td>
</tr>
<tr>
<td>1.2</td>
<td>1.32</td>
<td>92.29</td>
</tr>
</tbody>
</table>

- Standard Temperature = To=290°K
- Noise Factor (Fn) = 1+ (Teff/To)
- NF is the noise Figure (dB)

\[
NF = 10 \times \log_{10} \left[ 1 + \frac{T_{\text{eff}}}{T_o} \right] = 10 \log (Fn)
\]
Calculating System Noise Temperature

\[ TSYS = TA + TLNA \]

- TA is the antenna noise temperature
  - TLNA is the LNA noise temperature (Receiver Noise)
- Example:
  - Antenna Sky Noise: \( T_{sky} = 5° \) K
  - Losses: 0.5 dB \( \Rightarrow T_{loss} = 38° \) K
  - \( TA = T_{sky} + T_{loss} = 43° \) K
  - LNA: NF = 0.7dB \( \Rightarrow TLNA = 51° \) K
  - \( TSYS = 43° + 51° = 94° \) K
Gain Over Noise Temperature (G/T)

- G/T is Gain / Noise Temperature
- \( G/T = \text{Antenna Gain (dB)} - \text{System Noise Temperature (dB)} \ [10 \ \log(T_{sys}/1^\circ\text{K})] \)
  - Signal at the receiving antenna is increased by the antenna gain
  - Subtract out the System Noise Temperature
  - Result is signal level with respect to Thermal noise

\[ \text{Signal In (dBm)} + G/T \ (\text{dB}) = \text{Signal with respect to Thermal Noise} \]
Calculating G/T

- \( TSYS = TA + TLNA \)
  - TA is the antenna noise temperature
  - TLNA is the LNA noise temperature (Receiver Noise)

Antenna: \( TA = 43^\circ K, \text{ Gain} = 38 \text{ dB} \)

LNA: \( TLNA = 51^\circ K \)

\[
TSYS = 43^\circ + 51^\circ = 94^\circ K
\]

\[
G/T = \text{Antenna Gain (dB)} - 10 \log(Tsys/1^\circ K)
\]

\[
G/T = 38dB - 19.7dB = 18.3 \text{ dB}
\]
Importance of G/T Parameter

- Signal into the antenna is increased by G/T (dB) = \( S_A \text{(dBm)} \)
  \[ C/N = S_A \text{(dBm)} / \text{Thermal Noise (dBm)} \]
- \( C/N = \) Carrier at the Antenna (dBm) + G/T(dB) – (-174dBm/Hz) - 10Log(BW(Hz))
- Signal Level at the Antenna & G/T of a receiver is all the information necessary to determine the C/N
- Communication Link C/N can be determined knowing only EIRP, Path Loss, G/T, & Bandwidth

\[ C/N = \text{EIRP(dBm)} - \text{Path Loss(dB)} + \text{G/T(dB)} - 10\log_{10}(kTB) \]

- \( k = \) Boltzman’s Constant
- \( T = \) Temperature (°K)
- \( B = \) Bandwidth in Hz
- Bit Error Rate is a function of C/N
Satellite Link Example
Transmission System  Antenna Gain & EIRP

**Antenna Gain**
- Diameter: 2.5 Meters
- Frequency: 14 GHz
- Lambda: 0.021429 Meters
- Ideal Gain: 48.66 dB
- Ant Effic.: 2 dB
- Ant Gain: 46.66 dB

**EIRP Analysis**
- Antenna Gain: 46.7 dBi
- HPA Output: 24.77 dBW
- Feed Loss: 0.4 dB
- Xmit Path Loss: 0.6 dB
- System EIRP: 70.47 dBW

- EIRP is 70.47 dBW
- Total Necessary information about the Transmit system -
Path Loss & Received Signal Level

<table>
<thead>
<tr>
<th>Path Loss</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>22300</td>
</tr>
<tr>
<td></td>
<td>35888.37</td>
</tr>
<tr>
<td>Path Loss</td>
<td>206.46</td>
</tr>
<tr>
<td>Fade Margin</td>
<td>10</td>
</tr>
<tr>
<td>Worst Path Loss</td>
<td>216.46</td>
</tr>
</tbody>
</table>

- Path Loss is under Clear Sky Conditions
- Worst Path Loss is during adverse weather conditions

Received Signal Level

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear Sky</td>
<td>-105.99 dBm</td>
</tr>
<tr>
<td>Adverse Weather</td>
<td>-115.99 dBm</td>
</tr>
</tbody>
</table>
Receiver (G/T)

Antenna Gain
Diameter 1.5 Meters
Frequency 14 GHz
Ideal Gain 44.23 dB
Ant Effic. 2 dB
Ant Gain 42.23 dB

G/T Analysis
Antenna Noise 11 Deg K
at 20 Deg Elevation Angle
W/G Loss 14 Deg K
LNA Noise Temp 50 Deg K
System Noise Temp 75 Deg K
Antenna Gain 42.23 dBi
G/T 23.48 dB/°K

- Loss in a passive device is the devices noise figure
- Waveguide loss is converted to Noise Temperature -
## Link Analysis

<table>
<thead>
<tr>
<th></th>
<th>Clear Sky</th>
<th>Adverse Weather</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. EIRP</td>
<td>70.47 dBW</td>
<td>70.47 dBW</td>
</tr>
<tr>
<td>Power Back-Off</td>
<td>10.00 dB</td>
<td>0.00 dB</td>
</tr>
<tr>
<td>EIRP</td>
<td>60.47 dBW</td>
<td>70.47 dBW</td>
</tr>
<tr>
<td>Path Loss</td>
<td>206.46 dB</td>
<td>216.46 dB</td>
</tr>
<tr>
<td>Signal at Receiver</td>
<td>-115.99 dBm</td>
<td>-115.99 dBm</td>
</tr>
<tr>
<td>G/T</td>
<td>23.48 dB</td>
<td>23.48 dB</td>
</tr>
<tr>
<td>Effective Signal at RCVR</td>
<td>-92.52 dBm</td>
<td>-92.52 dBm</td>
</tr>
<tr>
<td>Thermal Noise</td>
<td>-174 dm/Hz</td>
<td>-174 dm/Hz</td>
</tr>
<tr>
<td>C/N (1Hz)</td>
<td>81.48 dB/Hz</td>
<td>81.48 dB/Hz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>5.00 MHz</td>
<td>5.00 MHz</td>
</tr>
<tr>
<td>C/N</td>
<td>14.49 dB</td>
<td>14.49 dB</td>
</tr>
</tbody>
</table>

• Note the back-Off under clear sky conditions -
Typical Link Parameters

- Uplink Frequency: 5.925 to 6.425GHz
- Down Link Frequency: 3.7 to 4.2 GHz
- Up Link is always the higher Frequency (Higher Path Loss)
- Higher Power Amplifiers and lower noise amplifiers are more available on the Ground Segment

Uplink Path Loss at 6GHz: 199.1dB
Downlink Path Loss at 4GHz: 195.6dB
Bandwidth Economics

- Bandwidth is expensive
  - Bandwidth is a Limited Natural Resource
  - There is a limited bandwidth availability
  - More Bandwidth requires greater EIRP
  - Power Amplifiers are expensive
  - Larger Antennas are expensive
  - Pointing Large Antennas can be a problem
  - A 3 Meter Antenna at 14 GHz has a 1.5° Beam width -

Beam width is a solid angle
- Beam width ≈ 21 / (F*D) in degrees
  (Parabolic dish)
- F = Frequency in GHz
- D = diameter of the dish in Meters
Satellite Tracking
Antenna Pointing

- Satellite locations are relatively fixed in the sky
- Small antenna can be set manually
- Large Antenna require some satellite tracking mechanism
- A sensitive receiver locks on to a satellite beacon
- Earth Station antenna searches for maximum beacon power to focus the antenna on the satellite
Beacon Receiver

Beacon Signals are buried between the data transponders
- Beacon can be as much as 50dB below the composite carriers
- Beacon Receiver must locate the beacon and measure its power level
- Beacon Signals change from CW to Spread Spectrum Telemetry Data Carriers
- Locking on a Beacon Signal is difficult -
Antenna Step Tracking

- Used for Low Relative Motion
- Beacon Receiver Monitors Signal Strength
- Moves Antenna in Small Az/El Increments
- Compares Signal Strength with Previous Values to Determine Direction & Size of Next Step
- Once Signal Strength is “Peaked” Waits for Next Scheduled Step Track Cycle -
Uplink Power Control

Spectral Densities at the satellite MUST be constant (dBm/Hz)
- Prevent adjacent channel interference
- Constant within 0.5 dB under clear sky conditions
- Within 1dB under adverse weather conditions
- Beacon Receiver monitors down link signal strength
- Algorithm converters down link signal strength to expected uplink path loss
- Up Link Power Controller adjusts transmitter power to compensate for path loss variations -
Up & Down Link Correlation

Note the correlation of down link and up link attenuation

- Uplink controller corrects uplink power
  - Uses down link beacon power and a correlation algorithm -

Rain Rate vs Time (Hours)

Rain Fade at 27.5 GHz Up Link
Rain Fade at 20.2 GHz Down Link
Summary

- A Satellite Communication system was used as an example
  - Principals hold for all communication systems
- Terrestrial Communications Systems other issues:
  - Shorter paths
  - Multi-paths
  - Terrestrial interference
- Fundamentals of Satellite Communications
  - Part 3 Modulation Techniques
  - Part 4 Effect of Sub-System Specifications on Signal Recovery