Atmospheric Effects on Link Budget and their Interpretation

- Ionospheric effects:
  - Faraday rotation of linear polarization (first line of Table 2.2): This is most pronounced at L- and S-bands, with significant impact at C-band during the peak of sunspot activity. It is not a significant factor at Ku- and Ka bands.
  - Ionosphere scintillation (third and fourth lines of Table 2.2): This is most pronounced in the equatorial regions of the world (particularly along the geomagnetic equator). Like Faraday rotation, this source of fading decreases with increasing frequency, making it a factor for L-, S-, and C-band links.

Link Budget and their Interpretation

- Tropospheric (gaseous atmosphere) effects:
  - Absorption by air and water vapor (non-condensed): This is nearly constant for higher elevation angles, adding only a few tenths of decibels to the path loss. It generally can be ignored at frequencies below 15 GHz.
  - Refractive bending and scintillation (rapid fluctuations of carrier power) at low elevation angles: Earth stations that must point within 10° of the horizon to view the satellite are subject to wider variations in received or transmitted signal and therefore require more link margin. Tropospheric scintillation is time varying signal attenuation (and enhancement) caused by combining of the direct path with the refracted path signal in the receiving antenna.

Link Budget and their Interpretation

- Rain attenuation: This important factor increases with frequency and rain rate. Additional fade margin is required for Ku- and Ka-band links, based on the statistics of local rainfall. This will require careful study for services that demand high availability, as suggested in Figures 2.4 and 2.5. A standardized rain attenuation predictor, called the DAH model is available for this purpose [1]. Rain also introduces scintillation due to scattering of electromagnetic waves by raindrops, and in a later section we will see that the raindrops also radiate thermal noise—a factor that is easily modeled. In addition, rain beading on antenna surfaces scatters and in very heavy rains can puddle on feeds, temporarily providing high losses not accounted for in the DAH and thermal noise models.

Link Budget Example

- Satellite application engineers need to assess and allocate performance for each source of gain and loss.
- The link budget is the most effective means since it can address and display all of the components of the power balance equation, expressed in decibels.
- In the past, each engineer was free to create a personalized methodology and format for their own link budgets.
- This worked adequately as long as the same person continued to do the work.
- Problems arose, however, when link budgets were exchanged between engineers, as formats and assumptions can vary.
- A standardized link budget software tool should be used that performs all of the relevant calculations and presents the results in a clear and complete manner.

Link Budget Example

- We will now evaluate a specific example using a simplified link budget containing the primary contributors.
- This will provide a typical format and some guidelines for a practical approach.
- Separate uplink and downlink budgets are provided; our evaluation of the total end-to-end link presumes the use of a bent-pipe repeater.
- This is one that transfers both carrier and noise from the uplink to the downlink, with only a frequency translation and amplification.
- The three constituents are often shown in a single table, but dividing them should make the development of the process clearer for readers.
- The detailed engineering comes into play with the development of each entry of the table.
- Several of the entries are calculated using straightforward mathematical equations; others must be obtained through actual measurements or at least estimates thereof.

Link Budget Example

- This particular example is for a C-band digital video link at 40 Mbps, which is capable of transmitting 8 to 12 TV channels using the Motion Picture Experts Group 2 (MPEG 2) standard.

Link Budget Example: Downlink Budget

- The following Table 2.3 presents the downlink budget in a manner that identifies the characteristics of the satellite transmitter and antenna, the path, the receiving antenna, and the expected performance of the Earth station receiver.
- It contains the elements that select the desired radio signal (i.e., the carrier) and demodulates the useful information (i.e., the digital baseband containing the MPEG 2 "transport" bit stream).
- Once converted back to baseband, the transmission can be applied to other processes, such as de-multiplexing, decryption, and digital-to-analog conversion (D/A conversion).

Link Budget Example: Downlink Budget

Table 2.3 Link Budget Analysis for the Downlink (3.95 GHz, C-Band)

Item	*Link Parameter*	*Value*	*Unit*	*Computation*
1	Transmit power (10W)	10.0	dBW	Assumption
2	Transmit waveguide losses	1.5	dB	Assumption
3	Transmit antenna gain	27.0	dBi	U.S. Continental coverage
4	Satellite EIRP (toward LS)	35.5	dBW	1–2+3
5	Free-space loss	196.0	dB	(2.4)
6	Atmospheric absorption (clean air)	0.1	dB	Typical
7	Receive antenna gain(3.2m)	40.2	dBi	
8	Receive waveguide loss	0.5	dB	
9	Received carrier power	–121.7	dBW	4-5-6+7-8
10	System noise temperature (140K)	21.5	dBK	
11	Earth station *G/T*	18.2	dB/K	7–8–10
12	Boltzmann's constant	–228.6	dBW/Hz/K	
13	Bandwidth (25 MHz)	74.0	dB Hz	
14	Noise power	–133.1	dBW	10+12+13
15	Carrier-to-noise ratio	11.4	dB	9–14

Link Budget Example: Downlink Budget

- The following figure provides the horizontal downlink coverage of Telstar V, a typical C-band satellite that serves the United States.
- Each contour shows a constant level of saturated effective isotropic radiated power (EIRP) (the value at saturation of the transponder power amplifier).
- Assuming the receiving Earth station is in Los Angeles, it is possible to interpolate between the contours and estimate a value of 35.5 dBW.

Link Budget Example: Downlink Budget

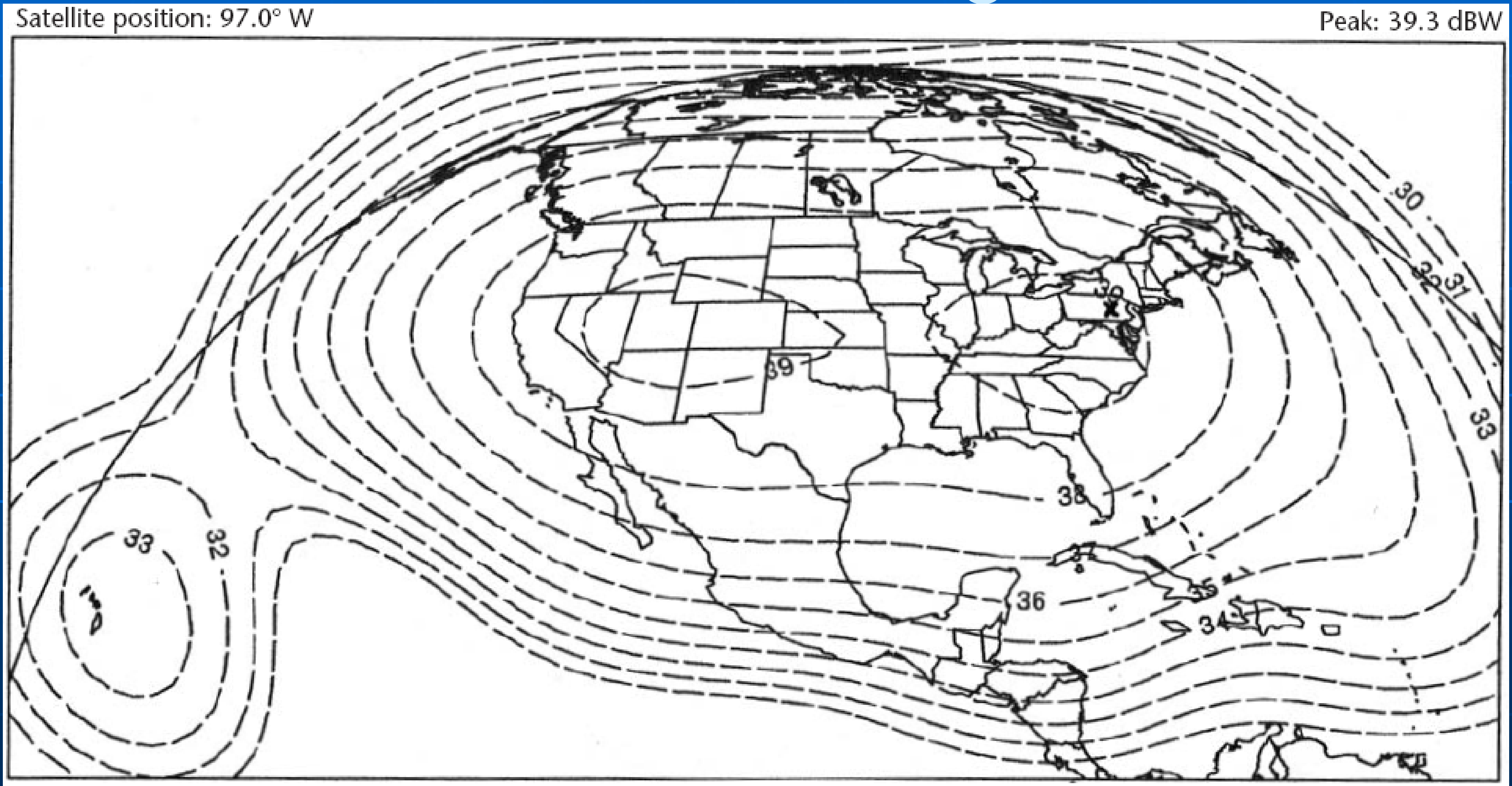


Figure 2.6: The downlink coverage footprint of the Telstar V satellite, located at 97° W. The contours are indicated with the saturated EIRP in decibels referred to 1W (0 dBW).

Link Budget Example: Downlink Budget

- The following parameters relate to the significant elements in the link (Figure 2.1) and the power balance equation, all expressed in decibels.
- Most are typically under the control of the satellite engineer:
  - Transmit power (P_t);
  - Antenna gain at the peak (G_t) and beam width at the −3-dB point (θ3dB);
  - Feeder waveguide losses (L_t);
  - EIRP in the direction of the Earth station;
  - Receiver noise temperature (T_0);
  - Noise figure (N_F).

Link Budget Example: Downlink Budget

- System noise temperature (T_{sys}) is the sum of T_0 and the noise contribution of the receive antenna (T_a).
- The overall Earth station figure of merit is defined as the ratio of receive gain to system noise temperature expressed in decibels per Kelvin—for example, *G/T*
- The same can be said of EIRP for the transmit case. Reception is improved if either the gain is increased or the noise temperature is decreased; hence the use of a ratio.

Link Budget Example: Downlink Budget

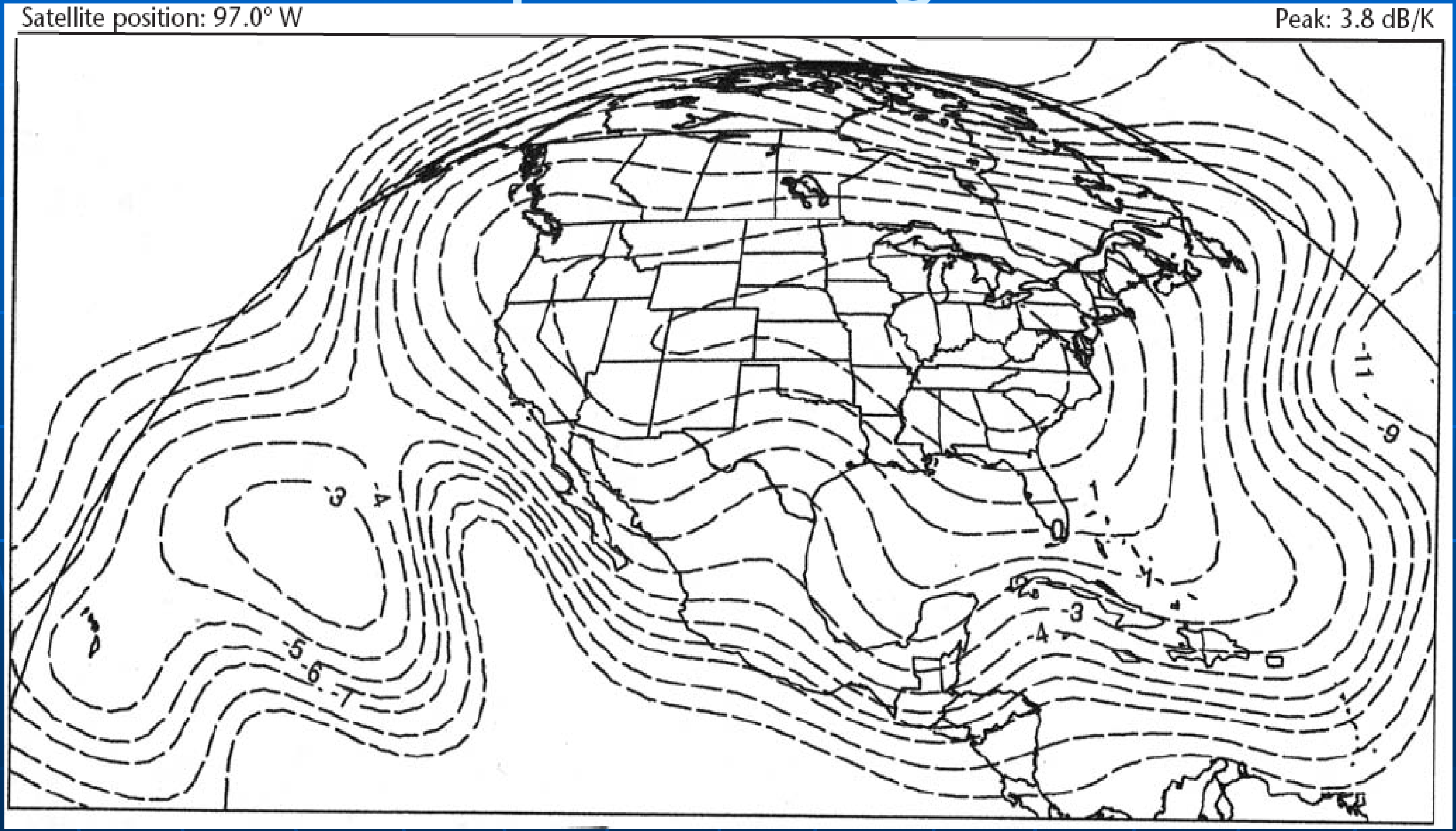
- Each of the link parameters relates to a specific piece of hardware or some property of the microwave path between space and ground.
- A good way to develop the link budget is to prepare it with a spreadsheet program.
- This permits the designer to include the various formulas directly in the budget, thus avoiding the problem of external calculation or the potential for arithmetic error (which still exists if the formulas are wrong or one adds losses instead of subtracting them).
- Commercial link budget software, such as SatMaster Pro from Arrowe Technical Services, does the same job but in a standardized fashion.

Link Budget Example: Uplink Budget

Table 2.4 Link Budget Analysis for the Uplink (6.175 GHz, C-band)

Item	*Link Parameter*	*Value*	*Units*	*Computation*
16	Transmit power (850W)	29.3	dBW	
17	Transmit waveguide losses	2.0	dB	
18	Transmit antenna gain (7m)	50.6	dBi	
19	Uplink EIRP from Boston	77.9	dBW	16 – 17 + 18
20	Spreading loss	162.2	dB(m^2)	
21	Atmospheric attenuation	0.1	dB	
22	Flux density at the spacecraft	–84.4	dBW/m^2	19 – 20 – 21
23	Free-space loss	200.4	dB	
24	Receive antenna gain	26.3	dBi	
25	Receive waveguide loss	0.5	dB	
26	System noise temperature (450K)	26.5	dB(K)	
27	Spacecraft *G/T*	–0.7	dB/K	24 – 25 – 26
28	Received *C/T*	–122.9	dBW/K	19 – 23 – 21 + 27
29	Boltmann's constant	–228.6	dBW/Hz/K	
30	Bandwidth (25 MHz)	74.0	dB Hz	
31	Carrier-to-noise ratio	31.7	dB	28 – 29 – 30

Link Budget Example: Uplink Budget



The uplink coverage footprint of the Telstar V satellite, located at 97° WL. The contours are indicated with the SFDM in the direction of the Earth station.

Link Budget Example: Uplink Budget

- The repeater in this design is a simple bent pipe that does not alter or recover data from the transmission from the uplink. The noise on the uplink (e.g., N in the denominator of C/N) will be transferred directly to the downlink and added to the downlink noise.
- In a baseband processing type of repeater, the uplink carrier is demodulated within the satellite and only the bits themselves are transferred to the downlink.
- In such case, the uplink noise only produces bit errors (and possibly frame errors, depending on the modulation and multiple access scheme) that transfer over the re-modulated carrier.
- This is a complex process and can only be assessed for the particular transmission system design in a digital processing satellite.

Link Budget Example: Overall Link Budget

- The last step in link budgeting for a bent-pipe repeater is to combine the two link performances and compare the result against a minimum requirement—also called the threshold. Table 2.5 presents a detailed evaluation of the overall link under the conditions of line-of-sight propagation in clear sky. We have included an allocation for interference coming from sources such as a cross-polarized transponder and adjacent satellites. This type of entry is necessary because all operating satellite networks are exposed to one or more sources of interference. The bottom line represents the margin that is available to counter rain attenuation and any other losses that were not included in the link budgets. Alternatively, rain margin can be allocated separately to the uplink and downlink, with the combined availability value being the arithmetic product of the two as a decimal value (e.g., if the uplink and downlink were each 99.9%, then the combined availability is $0.999 \times 0.999 = 0.998$ or 99.8%).

Link Budget Example: Overall Link Budget

Table 2.5 Combining the Uplink and the Downlink to Estimate Overall Link Performance

Item	*Link Parameter*	*Value*	*Units*	*Computation*
32	Uplink C/N (31.7 dB)	1,479.1	Ratio	31
33	N_u/C	0.000676	Ratio	
34	Downlink C/N (11.4 dB)	13.8	Ratio	15
35	N_d/C	0.0724	Ratio	
36	Total thermal noise (N_{th}/C)	0.0731	Ratio	33 + 35
37	Total thermal C/N_{th}	13.7	Ratio	
38	Total thermal C/N_{th}	11.4	dB	
39	Interference C/I (18.0 dB)	63.1	Ratio	Assumption
40	I/C	0.015848	Ratio	
41	Total noise $(N_{th} + I)/C$	0.0889	Ratio	36 + 40
42	Total $C/(N_{th} + I)$	11.2	Ratio	
43	Total $C/(N_{th} + I)$	10.5	dB	
44	Required C/N	8.0	dB	Equipment

Link Budget Summary

- Over estimate link specification
- Downlink Budget
- Uplink Budget
- Overall Link Budget

Multiple Access System

- Applications employ multiple-access systems to allow two or more Earth stations to simultaneously share the resources of the same transponder or frequency channel.
- These include the three familiar methods:
  - FDMA,
  - TDMA, and
  - CDMA.
- Another multiple access system called space division multiple access (SDMA) has been suggested in the past. In practice, SDMA is not really a multiple access method but rather a technique to reuse frequency spectrum through multiple spot beams on the satellite.
- Because every satellite provides some form of frequency reuse (cross-polarization being included), SDMA is an inherent feature in all applications.

Summary of Spectrum Options

- The frequency bands just reviewed have been treated differently in terms of their developmental timelines (C-band first, Ka-band last) and applications (L-band for MSS and Ku band for BSS and DTH).
- However, the properties of the microwave link that relate to the link budget are the same.
- Of course, properties of different types of atmospheric losses and other impairments may vary to a significant degree.
- This requires a careful review of each of the terms in the link budget prior to making any selection or attempting to implement particular applications.