

Link Budget Explained

Link Budget Explained

A link budget is an accounting of all the gains and losses in an RF communication link from transmitter to receiver. It tells you whether a link will work, by how much margin, and what changes would improve it. Every successful LoRa mesh deployment benefits from link budget analysis, even a rough one.

The Link Budget Equation

```
Received Signal Strength (dBm) =  
  TX Power (dBm)  
  + TX Antenna Gain (dBi)  
  - TX Feedline Loss (dB)  
  - Free-Space Path Loss (dB)  
  - RX Feedline Loss (dB)  
  + RX Antenna Gain (dBi)
```

To determine if a link closes, compare the received signal strength to the receiver sensitivity:

```
Link Margin (dB) = Received Signal Strength - Receiver Sensitivity  
  
Positive margin = link works  
Negative margin = link fails  
Margin > 10 dB = comfortable link (rule of thumb)  
Margin > 20 dB = robust link suitable for marginal terrain (rule of thumb)
```

These margin thresholds are engineering rules of thumb, not fixed standards. The fade margin you actually need depends on the propagation environment: roughly 10 dB may suffice for a stable urban or line-of-sight path, while non-line-of-sight, foliage, or rain-affected links require more.

Key Parameters Defined

EIRP (Effective Isotropic Radiated Power)

EIRP is the transmitter power plus the antenna gain, minus feedline losses. It represents the effective power that would need to be fed to an isotropic antenna to produce the same field strength in the direction of maximum radiation:

$$\text{EIRP (dBm)} = \text{TX Power (dBm)} + \text{Antenna Gain (dBi)} - \text{Feedline Loss (dB)}$$

FCC Part 15.247 limits **conducted** output power to 1 W (30 dBm) in the 902 - 928 MHz band, referenced to an antenna of up to 6 dBi gain. With a 6 dBi antenna this yields up to roughly +36 dBm (4 W) EIRP — so 30 dBm is the conducted-power ceiling, not the EIRP ceiling. For antenna gain above 6 dBi, the conducted output power must be reduced dB-for-dB for each dB of gain over 6 dBi (15.247(b)(4)(i)), holding EIRP at about 36 dBm. Unlike the 2.4 GHz band, the 902 - 928 MHz band has **no** relaxed point-to-point allowance that lets you add antenna gain in exchange for reduced power — the dB-for-dB reduction applies to point-to-point links too. Always confirm against current FCC rules and your specific module's certification.

Free-Space Path Loss (FSPL)

Free-space path loss is the reduction in signal power due to the spreading of the RF wavefront as it travels through space. It is a fundamental physical loss, not a deficiency of the system:

$$\begin{aligned}\text{FSPL (dB)} &= 20 \times \log_{10}(d) + 20 \times \log_{10}(f) + 20 \times \log_{10}(4\pi/c) \\ &= 20 \times \log_{10}(d) + 20 \times \log_{10}(f) - 147.55\end{aligned}$$

Where:

d = distance in meters

f = frequency in Hz

At 915 MHz, simplified:

$$\text{FSPL (dB)} = 20 \times \log_{10}(d_{\text{km}}) + 91.65$$

Examples:

100 m: FSPL $\approx$ 71.7 dB

1 km: FSPL $\approx$ 91.7 dB

5 km: FSPL $\approx$ 105.6 dB

20 km: FSPL $\approx$ 117.7 dB

Receiver Sensitivity

Receiver sensitivity is the minimum received signal power that the radio can successfully decode. It is determined by the modulation type, bandwidth, and noise figure of the receiver. LoRa sensitivity varies dramatically with spreading factor (SF). The figures below are typical values for the SX1262 /

community measurements; the SX1276 datasheet lists values about 1 - 1.5 dB less optimistic (e.g. SF11 $\approx$ -133 dBm, SF12 $\approx$ -136 dBm):

Spreading Factor	Bit Rate (approx.)	Typical Sensitivity (dBm)	Use Case
SF7	~5.5 kbps	-123 dBm	Short range, high throughput
SF9	~1.8 kbps	-129 dBm	Medium range, normal use
SF10	~0.98 kbps	-132 dBm	Extended range
SF11	~0.54 kbps	-134.5 dBm	Long range
SF12	~0.29 kbps	-137 dBm	Maximum range

Noise Floor

The thermal noise floor is the baseline noise level a receiver must overcome, set by thermodynamics:

Noise Floor = -174 dBm/Hz + 10 × log₁₀(BW_Hz) + Noise Figure (dB)

For LoRa with 125 kHz bandwidth and 6 dB noise figure:

Noise Floor $\approx$ -174 + 51.0 + 6 = -117 dBm

LoRa's processing gain (spreading factor) allows it to decode signals below this apparent noise floor, which is why SF12 achieves -137 dBm sensitivity.

Worked Example: Urban Mesh Node Link

Let's calculate whether a LoRa mesh link at SF11 will close between two residential nodes 2.5 km apart in a suburban environment.

Parameter	Value	Notes
TX power	+20 dBm	Meshtastic node at 100 mW
TX antenna gain	+5 dBi	5 dBi collinear, rooftop mount
TX feedline loss	-1.5 dB	10 ft LMR-200 + connectors
TX EIRP	+23.5 dBm	Well under the legal limit (1 W conducted with up to 6 dBi)
Free-space path loss	-99.6 dB	2.5 km at 915 MHz
Excess path loss (urban clutter)	-10 dB	Estimated additional suburban loss
RX feedline loss	-1.5 dB	Same installation as TX node

Parameter	Value	Notes
RX antenna gain	+5 dBi	Same 5 dBi antenna
Received signal level	−82.6 dBm	$23.5 - 99.6 - 10 - 1.5 + 5$
Receiver sensitivity (SF11)	−134.5 dBm	SX1262 typical (SX1276 datasheet: ≈ -133 dBm)
Link Margin	+51.9 dB	Excellent; link is robust

This link has roughly 52 dB of margin - it would still work with an additional 52 dB of path loss (about 160,000× more attenuation in power terms). This illustrates why LoRa is capable of penetrating buildings and covering large distances even with modest antenna installations.