Antenna Fundamentals

- Understanding Gain and dBi
- Connector Types & Coax Cable

Understanding Gain and dBi

Understanding Gain and dBi

Antenna gain is one of the most misunderstood topics in practical LoRa deployment. More gain is not always better - understanding what gain actually does will help you choose the right antenna for each deployment scenario.

What dBi Means

dBi (decibels relative to an isotropic radiator) measures how much an antenna concentrates radio energy in a particular direction compared to a theoretical antenna that radiates equally in all directions. An antenna with 0 dBi is a theoretical perfect sphere of radiation. An antenna with 5 dBi concentrates the same total energy into a narrower pattern.

The key insight: antennas do not add power. They redistribute it. Higher gain means more energy focused in the desired direction and less energy wasted in other directions.

Gain vs. Beam Angle

The figures below are approximate vertical (elevation) beamwidths for typical vertical omni antennas. They are illustrative, not exact: gain and beamwidth are always inversely proportional, but the actual beamwidth of a given antenna depends on its specific design. Use them to understand the trend, not as precise specifications.

Gain	Approx. Vertical (Elevation) Beamwidth — illustrative	Best Use Case
0 dBi	~80°	Indoor, short range, omnidirectional coverage needed in 3D
2 - 3 dBi	~60°	Handheld portable, varied terrain
5 dBi	~40°	Standard outdoor omni, modest height, moderate terrain
8 dBi	~20°	High-site omni with flat terrain and long-range targets
12+ dBi	<15°	Directional point-to-point links only

The High-Gain Trap in Hilly Terrain

An 8 dBi antenna on a rooftop in hilly terrain will have a dead zone directly below and nearby because its beam is concentrated nearly horizontally. Nodes at ground level within a few hundred metres may receive a worse signal than they would from a 5 dBi antenna at the same height. For community mesh networks with nodes at varying elevations, 5 - 6 dBi is typically optimal for omni antennas at medium-height fixed sites.

Practical dB Math

The range rules below assume free-space (inverse-square) propagation. In free space, range scales as 10^(gain_dB/20), so +6 dB doubles range and +3 dB adds about 40%. In real terrain — with obstructions, vegetation, and buildings — propagation is worse than inverse-square, so the actual range gain is smaller (often only 30 - 60% for +6 dB).

- **+3 dB** = doubles effective radiated power (≈ +40% range in free space; less in real terrain)
- **+6 dB** = 4× effective radiated power (≈ doubles range in free space; typically only +30 - 60% in real terrain)
- **+10 dB** = 10× effective radiated power

Range does not scale linearly with power because signal propagation follows an inverse square law (or worse in real-world conditions with obstructions). Going from 22 dBm to 28 dBm is +6 dB - 4× the power - which in free space would roughly double range, but in real terrain typically yields only 30 - 60% more range.

Placement vs. Gain

Moving an antenna from ground level to a rooftop 10 metres up provides far more range improvement than switching from a 3 dBi to an 8 dBi antenna at ground level. Elevation eliminates obstructions and increases radio horizon. Always optimise placement before spending money on higher-gain antennas.

Free Space Path Loss at 915 MHz

Free space path loss (FSPL) increases with distance. At 915 MHz:

Distance	Free Space Path Loss
1 km	~91 dB
5 km	~105 dB

Distance	Free Space Path Loss
10 km	~111 dB
20 km	~117 dB

LoRa with SF12 has a link budget of roughly 150 - 160 dB (note: a link budget is a difference of two dBm values, so it is expressed in dB, not dBm — the exact figure depends on transmit power and antenna gain). Under ideal, fully clear line-of-sight conditions, SF12 links can reach tens of kilometres; record links far exceed this. However, real-world terrain, vegetation, building losses, and Fresnel-zone obstruction reduce achievable range dramatically, and typical installations achieve far less. See the Fresnel Zones and Link Budget pages for how to estimate realistic range for your site.

Connector Types & Coax Cable

Connector Types & Coax Cable

Using the wrong connector or cable is one of the most common and frustrating mistakes when setting up LoRa hardware. This page covers everything you need to know to buy and connect antennas correctly.

SMA vs. RP-SMA

SMA (SubMiniature version A) and RP-SMA (Reverse Polarity SMA) look nearly identical but are **not interchangeable**. Connecting a mismatched pair results in no signal or very poor signal even though the connectors physically engage.

Connector	Male	Female	Common Devices
SMA	Pin in centre, external thread	Socket in centre, internal thread	Heltec V3/V4, RAK WisBlock, many antennas
RP-SMA	Socket in centre, external thread	Pin in centre, internal thread	Some LilyGo devices, Wi-Fi routers, some Meshtastic builds

RP-SMA originates from an FCC convention for consumer Wi-Fi antenna couplings (it is an industry convention, not an FCC mandate for LoRa). It sometimes appears on LoRa boards - notably some LilyGo and inexpensive units - and is not "wrong," but it must be matched to the antenna.

Before buying an antenna: check your device datasheet or photos to confirm whether it uses SMA or RP-SMA. The Heltec V3 and V4 are generally reported to use SMA Male on the board (the antenna plugs SMA Female onto the board connector); verify against the official Heltec datasheet for your exact board revision, since some clones and variants differ.

N-Connector

N-connectors are larger, more weatherproof, and lower-loss than SMA. Used on outdoor base station antennas and feedlines. The ALFA 5 dBi Mini uses N-Male. For base station builds with

significant coax runs, N-connector systems are preferred over SMA.

Coax Cable Selection

Coax cable introduces loss that subtracts directly from your effective radiated power and receive sensitivity. At 915 MHz, cable loss is significant for runs over 3 metres. The figures below are the canonical 915 MHz loss values used across this book (sourced from manufacturer datasheets, e.g. Times Microwave for LMR cable). The reference length is **100 ft (≈30.5 m)**; the dB/m column is the same value divided to a per-metre basis (per metre = dB/100 ft × 0.0328).

Cable Type	Loss at 915 MHz (dB/100 ft)	Loss at 915 MHz (dB/m)	Use Case
RG174	~28 dB/100 ft	~0.92 dB/m	Short pigtails only (<30cm); avoid for longer runs
RG316	~26 dB/100 ft	~0.85 dB/m	Short internal pigtails; better than RG174 but still lossy
RG58	~20 dB/100 ft	~0.66 dB/m	Acceptable for runs up to 3 - 5m
LMR-200	~9.9 dB/100 ft	~0.32 dB/m	Good for runs 3 - 10m; flexible
LMR-400	~3.9 dB/100 ft	~0.13 dB/m	Long runs (>10m) or base stations; less flexible

For a DIY solar repeater with the node inside the enclosure and the antenna immediately outside, a 30cm RG316 pigtail is fine. For a base station where the coax runs 10 metres from the node to the roof antenna, use LMR-200 or LMR-400.

SWR and Cable Quality

Poor-quality connectors and cables produce poor SWR readings even with a good antenna. If your NanoVNA shows unexpectedly high SWR, suspect the cable and connectors before the antenna itself. Wiggle the connector while monitoring - if SWR changes, the connector is the problem.

Weatherproofing Outdoor Connections

Outdoor N-connector and SMA connections must be weatherproofed. Water intrusion corrodes the connector and increases loss. Use self-amalgamating (self-fusing) tape: stretch it over the connector and cable and overlap each wrap by half. It bonds to itself and forms a watertight seal without adhesive. Cover with UV-resistant electrical tape for UV protection.