Antenna and RF FAQ

- Do I need an external antenna?
- What is the difference between dBi and dBd antenna gain?

Do I need an external antenna?

The stock antenna that comes with most LoRa boards is a rubber duck (flexible whip) antenna, typically 1-3 dBi gain (often a quarter-wave stubby around 2 dBi). For many use cases, this is adequate - but upgrading to an external antenna is one of the most cost-effective improvements you can make.

When the Stock Antenna is Fine

- Indoor portable use (office, home) within 200-500m of your nearest mesh node
- Temporary deployments where you're moving frequently
- Testing and development before a permanent installation
- Dense urban areas with many nearby nodes (short hop distances)

When You Should Upgrade

- **Fixed outdoor installation** - Any permanent outdoor node should use an external antenna rated for outdoor use. Stock rubber ducks are not weatherproof.
- **Coverage issues** - If you can't reach nodes you'd expect to reach, a better antenna is the first thing to try.
- **Backbone repeater** - Repeaters covering a neighborhood or city need the best possible antenna. A 5-8 dBi fiberglass omni provides several dB more gain than a stock whip, which can substantially extend range (roughly doubling it under line-of-sight conditions; the gain in cluttered terrain is smaller).
- **Point-to-point link** - If you're trying to bridge two specific locations, a directional yagi (commonly 6-10 dBi for compact 915 MHz models) extends range significantly. **FCC compliance:** on US 915 MHz, FCC 15.247(b)(4)(i) requires you to reduce conducted transmit power 1 dB for every dB of antenna gain above 6 dBi - and, unlike the 2.4 GHz band, the 902-928 MHz band has *no* point-to-point exception that relaxes this. For example, with a 12 dBi yagi you must drop conducted power roughly 6 dB below 1 W to stay within the EIRP limit. Most firmware lets you set TX power accordingly; do not run full power behind a high-gain antenna.

What External Antenna to Buy

For most fixed outdoor deployments, a 915 MHz fiberglass omnidirectional antenna is the right choice:

- **Taoglas TI.92.2113 (3 dBi)** - $15-20, compact, good for moderate ranges
- **Proxicast 5 dBi (ANT-DB5-5)** - $25-35, good all-around outdoor omni
- **Taoglas FXP73 (5 dBi, mag base)** - $25-40, great for vehicle or temporary mounts
- **L-com HG908U-PRO (8 dBi)** - $45-60, excellent for high-gain omni backbone nodes

Connector Adapters

Most LoRa boards use a standard SMA connector (male pin on the antenna/pigtail, female body on the board) or a u.FL connector. External antennas typically use an N-connector or SMA. **Watch out:** SMA and RP-SMA (reverse-polarity SMA) look almost identical but do not mate - RP-SMA swaps the center pin and socket, so an SMA antenna will not connect to an RP-SMA board (and vice versa). Check which gender and polarity your specific board revision uses before ordering a pigtail or antenna. Match your connectors:

- **Heltec V3, T-Beam:** SMA female on board - use SMA male on pigtail or antenna (verify your revision, as some units ship RP-SMA)
- **RAK4631:** u.FL (IPEX) connector - needs u.FL to SMA pigtail (~$5) to connect to any standard antenna
- **T-Deck, T-Echo:** SMA female - use SMA male pigtail or direct-connect SMA antenna

What is the difference between dBi and dBd antenna gain?

Antenna gain specifications use two different reference points - dBi and dBd - and confusing them leads to incorrect link budget calculations. Here's what each means and how to convert between them.

The Reference Antennas

- **dBi (decibels relative to isotropic)** - Compares gain to a theoretically perfect isotropic radiator (a point that radiates equally in all directions - a perfect sphere). This is a theoretical reference that doesn't exist in practice.
- **dBd (decibels relative to dipole)** - Compares gain to a half-wave dipole antenna, which is the most common practical antenna type and a natural reference for antenna engineers.

The Conversion

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dBi = dBd + 2.15


Examples:
0 dBd (dipole reference) = 2.15 dBi
3 dBd = 5.15 dBi (approximately 5 dBi)
5.85 dBd = 8 dBi
9 dBd = 11.15 dBi (approximately 11 dBi)
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Which is Used in Practice?

Most commercial antenna manufacturers use dBi because the numbers look higher (marketing benefit). For the 902-928 MHz ISM band that matters here, FCC Part 15 expresses its EIRP and antenna-gain limits using the isotropic (dBi) reference - so convert any dBd spec to dBi (add 2.15) before checking it against the 4 W (36 dBm) EIRP ceiling or the 6 dBi antenna-gain threshold. Most link budget calculators accept either unit, as long as you're consistent.

Rule of thumb: When comparing antennas, make sure you're comparing the same units. A "5 dBd" antenna and a "5 dBi" antenna are NOT equivalent - the dBd antenna is 2.15 dB better. This difference can mean the difference between a reliable link and a marginal one.

Practical Antenna Gain Reference

Antenna Type	Typical Gain (dBi)	Typical Gain (dBd)
Stock rubber duck	~0 to 2 dBi	~-2 to 0 dBd
Quarter-wave with ground plane	~5 dBi (ideal ground plane; less in practice)	~2.85 dBd
Half-wave dipole	2.15 dBi	0 dBd
5/8 wave vertical	4-5 dBi	2-3 dBd
3-element yagi	7-8 dBi	5-6 dBd
5-element yagi	10-11 dBi	8-9 dBd
Commercial 5 dBi fiberglass	5 dBi	2.85 dBd
Commercial 8 dBi fiberglass	8 dBi	5.85 dBd

Note: a quarter-wave monopole over an *ideal* (infinite, perfectly conducting) ground plane radiates into a half-space and so has roughly 3 dB more gain than a dipole - about 5 dBi. Real, finite ground planes deliver less than this, but it is not equal to a plain dipole. Use this table as the single canonical reference for stock-antenna gain figures across the wiki.

What Gain Actually Buys You

Every 3 dB of additional gain (all else equal) doubles the effective radiated power. Because free-space range scales with the square root of the power ratio (range $\propto \sqrt{\text{EIRP}}$), gain translates to range as:

- 3 dB gain improvement ≈ 41% range increase in free space ($\sqrt{2} = 1.41$x)
- 6 dB gain improvement ≈ 100% range increase / double in free space ($\sqrt{4} = 2$x)
- 10 dB gain improvement ≈ 216% range increase in free space ($\sqrt{10} = 3.16$x)

These are free-space figures. In practice real-world gains are lower due to terrain and building losses, and higher-gain antennas are also constrained by the 4 W (36 dBm) EIRP limit - you often cannot legally or usefully realize the full theoretical range gain. Still, the relative improvement from a better antenna (within the legal limit and with good siting) is significant.