PCB Trace vs External Antenna

The antenna is the component that most dramatically affects the range and reliability of a LoRa mesh node - more than spreading factor, transmit power, or even the radio chip. Yet it is also the most commonly overlooked hardware detail, especially by beginners who assume the built-in PCB trace antenna is adequate for outdoor use.

PCB Trace Antennas: What They Are

A PCB trace antenna (also called a PCB antenna or on-board antenna) is a specific pattern etched directly into the copper layers of the circuit board. No separate component - it is part of the PCB itself. You can identify one by looking at a corner of the board where the copper traces form a meandered or serpentine pattern, often with a small keepout area around it where no other copper is present.

PCB trace antennas are used because they cost essentially nothing to add during PCB manufacturing, they take up minimal volume, and they eliminate the need for an SMA/U.FL connector and cable. For products designed to be small and cheap - like the Heltec V3 or many ESP32 dev boards - they make sense as a baseline.

Why PCB Antennas Are Inadequate for Outdoor Use

The theoretical gain of a well-designed PCB trace antenna at 915 MHz is approximately 0 - 2 dBi - comparable to a short rubber duck. However, in practice, PCB antennas on development boards suffer from several additional problems:

- **Proximity effects:** A PCB trace antenna's tuning is affected by everything near it - your hand, a battery, the case material, the board itself. Moving the device changes the antenna's effective frequency and radiation pattern.
- **Orientation sensitivity:** PCB trace antennas typically have a highly directional radiation pattern. In a pocket or on a table, the null direction may be exactly toward the nodes you want to reach.
- **No replaceable component:** If the PCB trace antenna design is suboptimal (common on cheap dev boards), there is nothing to improve without adding an external connector.
- **Body shielding:** When carried in a pocket, the human body absorbs several dB of the already-weak signal from a PCB antenna. An external antenna on a cable can be positioned to avoid this.

Gain Comparison

Antenna Type	Typical Gain	Effective Range vs PCB	Notes
PCB trace antenna (dev board)	0 - 2 dBi	Baseline	Subject to proximity detuning
Small rubber duck (included)	1 - 2 dBi	~1.1 - 1.3x	Better than PCB in most orientations
Quality 915 MHz rubber duck	2 - 3 dBi	~1.3 - 1.5x	Taoglas, Linx brand options
Quarter-wave whip + ground plane	~2.15 dBi	~1.3x	Omnidirectional; DIY-constructable
Fiberglass 3 dBi (915 MHz)	3 dBi	~1.5 - 2x	Best for outdoor fixed nodes
Fiberglass 5 dBi	5 dBi	~2.5 - 3x	Narrower beam; use at elevation
Fiberglass 8 dBi	8 dBi	~4 - 5x	Very narrow beam; hilltop/tower only
Yagi 10 dBi	10 dBi	~6 - 8x	Highly directional; point-to-point only

Range multipliers are approximate in ideal line-of-sight conditions. Real-world gains depend on terrain, obstruction, and link margin.

Connector Types: SMA vs U.FL

SMA (SubMiniature version A)

SMA is a threaded RF connector found on most external antennas. Boards with an SMA connector (T-Beam, T-Echo, RAK WisBlock) can directly accept standard SMA-terminated antennas. There are two variants:

- **SMA:** Female connector on the antenna (outer thread, inner pin) plugs into the board's male SMA jack (inner socket, outer thread)
- **RP-SMA (Reverse Polarity SMA):** Used on WiFi routers and many US-market devices. The genders of the center conductor are swapped. A standard SMA antenna will NOT fit an RP-SMA connector without an adapter. Make sure your antenna matches your board's connector type.

U.FL (also called IPEX or MHF1)

U.FL is a tiny snap-fit coaxial connector used internally on boards when the antenna connector needs to be on a cable or module rather than soldered to the main PCB. The Heltec V3, some WisBlock modules, and many radio modules use U.FL.

A U.FL connector board requires a **U.FL to SMA pigtail cable** (typically 10 - 15 cm) to adapt to a standard SMA antenna. This cable introduces approximately 0.3 - 0.5 dB of loss, which is a worthwhile tradeoff for a proper external antenna.

When Is a PCB Antenna Acceptable?

PCB antennas are adequate in these specific scenarios:

- **Indoor testing at short range:** Verifying that firmware flashed correctly, testing basic connectivity between nodes in the same room
- **High-density indoor mesh:** In a building with many nodes at close range (under 50 meters), PCB antenna limitations are less relevant
- **Ultra-compact wearable or embedded device:** If physical size constraints prevent any external component, a PCB antenna may be the only option - but accept the range limitation

For any outdoor deployment, fixed repeater, or range-critical use, an external antenna is non-negotiable.

Antenna Selection for Common Boards

Board	Built-in Antenna	External Connector	Recommended Upgrade
Heltec WiFi LoRa 32 V3	PCB trace + spring wire	U.FL (under rubber cap)	U.FL - SMA pigtail + 3 dBi rubber duck
LilyGO T-Beam Supreme	None (SMA only)	SMA male	Quality 915 MHz 3 dBi rubber duck; fiberglass for fixed
LilyGO T-Echo	None (SMA only)	SMA male (small form)	Included rubber duck is adequate; upgrade for repeater use
RAK4631 (WisBlock)	None	IPEX (U.FL) on module	RAK base board provides SMA passthrough; use 3 - 5 dBi fiberglass for fixed nodes
Station G2	None	SMA male	3 dBi stubby for portable; fiberglass for fixed

Cable Loss Warning

If your antenna requires a coaxial cable run (for example, mounting an antenna on a roof while the radio is indoors), cable loss must be accounted for. At 915 MHz:

- RG-58: approximately 0.6 dB/meter - avoid runs over 3 meters
- RG-8X: approximately 0.35 dB/meter - usable up to ~10 meters
- LMR-400: approximately 0.14 dB/meter - suitable for long runs
- LMR-200: approximately 0.25 dB/meter - good for medium runs

A 10-meter run of RG-58 costs you 6 dB - equivalent to running at one quarter the transmit power and completely erasing any gain advantage from a high-gain antenna. Use the lowest-loss cable practical for your installation.

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