# SWR, VSWR, and Return Loss Explained

Before deploying an antenna on your mesh node, understanding how to measure and interpret antenna performance can save you from poor coverage or potential hardware damage.

## What is SWR?

Standing Wave Ratio (SWR) - more precisely Voltage Standing Wave Ratio (VSWR) - measures how well an antenna is impedance-matched to your transmission line and radio. A perfect match is 1:1. Most radios are designed for 50-ohm impedance.

- **SWR 1.0:1** - Perfect match. 100% of power transferred to antenna.
- **SWR 1.5:1** - Excellent. ~96% power transferred. Imperceptible in practice.
- **SWR 2.0:1** - Good. ~89% power transferred. Acceptable for most deployments.
- **SWR 3.0:1** - Poor. ~75% power transferred. Antenna should be investigated.
- **SWR 5.0:1+** - Bad. Significant reflected power. Can stress or damage some unprotected transmitters over time (many modern radios fold back power at high SWR to protect the power amplifier, but don't rely on it).

*Note: these labels are a simple rule of thumb. Other pages in this book (NanoVNA Antenna Testing, SWR & Antenna Analyzers) use slightly different band boundaries for the same SWR values; treat any single SWR figure near a boundary as approximate and prefer the lowest SWR you can achieve.*

At LoRa power levels (typically 10-30 dBm / 10mW-1W), a high SWR is unlikely to damage hardware immediately, but it does reduce effective radiated power and range. **Exception:** never transmit with the antenna disconnected (an open or shorted port is effectively infinite SWR). Even at LoRa power, repeatedly keying into no load can damage the power amplifier - always have an antenna or dummy load attached before transmitting.

## Return Loss

Return loss is another way to express the same measurement, preferred by RF engineers. It is conventionally reported as a **positive** dB value, and **larger is better** (more dB = less reflected power):

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Return Loss (dB) = -20 * log10(|Γ|) = 20 * log10((SWR+1)/(SWR-1))
  where reflection coefficient |Γ| = (SWR-1)/(SWR+1)

SWR 1.5:1 ≈ 14 dB return loss
SWR 2.0:1 ≈ 9.5 dB return loss
SWR 3.0:1 ≈ 6 dB return loss
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Higher return loss (a larger positive dB number) is better, because it means less power is being reflected back from the antenna. A return loss of 14 dB or better is considered a good antenna match. (Some instruments display the reflection coefficient S11 as a negative number, e.g. -14 dB; return loss is just the magnitude of that value, quoted as positive.)

# Why Antennas Have Poor SWR

- **Wrong resonant frequency** - Antenna cut for wrong frequency. 433 MHz antennas will not match at 915 MHz.
- **Damaged antenna** - Broken internal element or damaged connector.
- **Loose or oxidized connector** - Resistance at connection point adds to mismatch.
- **Incorrect antenna for your radio's impedance** - Most LoRa radios are 50-ohm; some antennas are 75-ohm (designed for cable TV).
- **Near-field interference** - Conductive material too close to the antenna element.

# Measuring SWR Without a VNA

If you don't have a NanoVNA, you can still estimate antenna performance:

- **Two-node range test** - The most practical field test. Compare RSSI/SNR at a known distance with the suspect antenna vs. a known-good stock antenna.
- **RF power meter + dummy load** - Measure forward and reflected power at the transmitter to derive SWR. Be careful with frequency coverage: inexpensive SWR/power meters often top out below ~500 MHz, so a sub-$50 meter may not actually cover 902-928 MHz. Meters or directional couplers that accurately cover 915 MHz generally cost more - verify the meter's rated frequency range includes 915 MHz before relying on it.
- **RSSI comparison** - Place a second node 100m away. Compare received RSSI with the suspect antenna vs. the stock rubber duck. A 3 dB higher RSSI means the receiver got about 2× the power - i.e. one antenna outperforms the other by 3 dB in that direction. This is a rough field comparison, not an SWR measurement, and it is sensitive to placement, orientation, and multipath.

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