BLOOMICE TECHNICAL WHITE PAPER

# Understanding Antenna Efficiency, Gain and Radiation Patterns

*How to interpret the antenna metrics that shape real wireless performance*

Antenna performance is often reduced to a single headline figure: gain. In practice, gain only becomes meaningful when it is considered alongside efficiency, impedance match and the radiation pattern. These parameters answer different questions - how much power is accepted, how much is radiated and where that energy goes.

## Four related measurements - four different meanings

An antenna can be well matched yet inefficient, efficient yet unsuitable for the required coverage direction, or capable of high peak gain while containing deep nulls in important orientations. Reliable selection requires understanding the relationship between the metrics rather than treating any one of them as a complete performance score.

| IMPEDANCE MATCH | RADIATION EFFICIENCY | DIRECTIVITY | GAIN |
|---|---|---|---|
| How much power presented at the antenna port is accepted rather than reflected. Common indicators: return loss and VSWR. | The proportion of accepted power that is radiated. Conductor, dielectric and nearby-material losses reduce it. | How strongly the antenna concentrates radiated energy in a particular direction compared with an isotropic radiator. | Directivity combined with radiation efficiency. Realised gain also includes the effect of impedance mismatch. |

**A low VSWR does not prove that an antenna radiates efficiently.** Power can be accepted at the feed and then lost as heat in conductors, dielectric material, the enclosure or nearby structures. Matching and efficiency must therefore be measured separately.

### The relationships in practical terms

| METRIC | SIMPLIFIED RELATIONSHIP | WHAT IT TELLS YOU |
|---|---|---|
| **Radiation efficiency** | Power radiated / power accepted by the antenna | Shows how effectively accepted RF power becomes radiation. |
| **Total efficiency** | Radiation efficiency x mismatch efficiency | Includes both internal losses and reflected power at the feed. |
| **Gain** | Directivity x radiation efficiency | Combines directional concentration with radiating effectiveness. |
| **Realised gain** | Directivity x total efficiency | Includes mismatch and is often the most useful gain value for an installed passive antenna. |
| **dBi** | Gain relative to an ideal isotropic radiator | Enables a common comparison reference; it does not describe the full pattern. |
| **dBd** | Gain relative to a half-wave dipole | 0 dBd is approximately 2.15 dBi, so units must be checked before comparing figures. |

UNDERSTAND WHERE THE ANTENNA PLACES ITS ENERGY

# Reading radiation patterns correctly

A radiation pattern describes the relative strength of radiation in different directions. The full result is three-dimensional, but datasheets commonly show two-dimensional cuts through the azimuth and elevation planes. These plots reveal the main coverage directions, beamwidth, sidelobes and nulls that a single peak-gain value cannot show.

| PATTERN FEATURE | MEANING | PRACTICAL SIGNIFICANCE |
|---|---|---|
| **Main lobe** | Direction containing the strongest radiation. | Useful for alignment and understanding where peak gain occurs. |
| **Half-power beamwidth** | Angular width between points approximately 3 dB below the lobe peak. | Indicates how broad or concentrated the principal coverage is. |
| **Null** | Direction where radiation falls significantly below surrounding levels. | Can cause orientation-sensitive dead zones despite acceptable peak gain. |
| **Sidelobes** | Secondary lobes outside the desired main beam. | May provide unwanted coverage or receive interference from other directions. |
| **Front-to-back ratio** | Difference between forward and rearward radiation. | Important when energy should favour one direction and reject the opposite. |
| **Polarisation** | Orientation and behaviour of the radiated electric field. | Mismatch between transmitting and receiving polarisations can reduce link margin. |
| **Azimuth pattern** | Horizontal cut around the antenna in its defined installation orientation. | Shows coverage around the site or device. |
| **Elevation pattern** | Vertical cut through the antenna pattern. | Shows how energy is distributed above, below and towards the horizon. |

**Higher gain is not automatically better.** Gain is created by concentrating energy. A higher-gain omnidirectional antenna usually narrows the elevation beam, which can reduce coverage above or below the preferred plane. Directional gain is valuable only when it supports the actual installation geometry.

## Common interpretation mistakes

1. **Comparing peak gain alone.** Two antennas with the same peak value may have very different efficiency, nulls, beamwidth and frequency response.
2. **Assuming omnidirectional means spherical.** A typical monopole or dipole has doughnut-shaped coverage with reduced radiation along its axis.
3. **Ignoring frequency.** Efficiency, match, gain and pattern change across the operating bands; one value cannot represent a wideband antenna.
4. **Ignoring orientation.** Patterns are referenced to a defined antenna position. Rotating the antenna rotates the coverage and polarisation behaviour.
5. **Excluding cable loss.** Feed-line and connector loss reduces system gain, especially with long or thin cable at higher frequencies.
6. **Using free-space results as field guarantees.** Enclosures, PCB ground, mounting surfaces, metal, water and nearby electronics can reshape the installed result.

VALIDATE THE COMPLETE ANTENNA SYSTEM

# From datasheet metrics to reliable field performance

Efficiency, gain and radiation patterns must be considered in the context of the complete device and application. The required result is not the highest number under ideal conditions; it is adequate link margin and repeatable coverage across the necessary bands, orientations, sites and production population.

| STAGE | ACTION | OUTPUT |
|---|---|---|
| **1. Define the coverage requirement** | Confirm bands, countries, operators, installation orientation, serving direction, range, obstructions and network KPIs. | Required pattern and link budget. |
| **2. Assess match across every band** | Measure S11, return loss or VSWR with the final feed, enclosure, PCB ground and mounting conditions. | Accepted-power and tuning evidence. |
| **3. Measure efficiency and realised gain** | Use suitable over-the-air methods to quantify radiated effectiveness and gain, including mismatch and cable effects where relevant. | Frequency-by-frequency OTA results. |
| **4. Review the full radiation pattern** | Examine 3D performance and relevant azimuth/elevation cuts for beamwidth, nulls, sidelobes and polarisation. | Coverage evidence for expected orientations. |
| **5. Validate integration and coexistence** | Test with the actual enclosure, batteries, cables, nearby electronics and simultaneous radios; verify isolation for diversity or MIMO. | Final-assembly RF evidence. |
| **6. Confirm in representative sites** | Compare field network KPIs, packet success and orientation sensitivity against a controlled reference and agreed limits. | Field acceptance and release record. |

## The antenna-performance release gate

Before approving the antenna system, the team should be able to answer yes to each question:

7 Are efficiency and realised gain acceptable across every required operating band?
8 Does the full pattern support the actual mounting orientation and required coverage directions?
9 Have nulls, polarisation, cable loss and ground-plane dependence been considered?
10 Has performance been measured with the final enclosure, PCB, battery, cables and nearby electronics?
11 Have representative field conditions and relevant system KPIs confirmed the laboratory conclusions?

**Good antenna selection is about usable radiation, not a headline gain figure.** Bloomice supports antenna selection, integration, tuning, over-the-air measurement and validation to ensure efficiency, gain and coverage patterns are appropriate for the complete device and its real operating environment.

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