RF · WIRELESS MODULE · ANTENNA · CERT · REFERENCE DOCUMENT · PUBLIC

Wireless and antenna integration

Reference for selecting wireless modules (BLE, Wi-Fi, LTE, LoRa, Cellular), choosing antenna topology, tuning the RF chain, and navigating the regulatory paths (RED, FCC Part 15C, KDB).

REVISION	ISSUED	OWNER	COMPANION
1.0	May 2026	Ideambox engineering	PDF reference

ABSTRACT

Wireless integration is the most regulatory-heavy aspect of consumer hardware design. A misstep at the module-selection stage cascades into 4–12 weeks of compliance delay and 5–15 thousand dollars of unexpected lab cost.

Section 1 covers wireless protocols and their use cases. Section 2 covers module selection (pre-certified vs. custom). Section 3 covers antenna topology selection. Section 4 covers RF design rules. Section 5 covers the regulatory paths (RED, FCC, IC, etc.). Section 6 covers testing and certification timeline.

THE FOUR ELEMENTS OF COMPLIANCE

01
Standards
Mechanical, electrical, EMC, radio, flammability, choke hazards.
EN 55032 · ASTM F963 · IEC 62368 · EN 71

02
Documents
DoC, technical file, risk assessment, test reports, supplier evidence.
DoC · Tech file · Substance declarations

COMP

03
Testing
Mandatory lab for some categories; pre-compliance + self-declared for others.
CPSC lab · EU notified body · Self-declared

04
Labelling
Marks, position, dimensions, languages, batch ID, importer details.
CE · FCC ID · Origin · WEEE · Battery

WIRELESS PRODUCTS HIT TWO COMPLIANCE REGIMES: THE RADIO STANDARDS (RED / FCC PART 15C) AND THE GENERAL EMC STANDARDS (EN 55032 / FCC PART 15B).

CONTENTS

1. Wireless protocol selection

Picking the wrong protocol leads to range, battery life, or interoperability problems that surface at first user trial.

1.1 Protocol comparison

PROTOCOL	RANGE	DATA RATE	POWER	TYPICAL USE
BLE 5.x	10–50 m	1–2 Mbps	µA sleep, 5–15 mA active	Wearables, sensors, IoT
Wi-Fi 4 (802.11n, 2.4 GHz)	30–50 m	150 Mbps	mA sleep, 50–250 mA active	Home electronics, IoT
Wi-Fi 5 (802.11ac, 5 GHz)	30–50 m	433+ Mbps	100–500 mA active	Streaming, file transfer
Wi-Fi 6 (802.11ax)	30–50 m	Gbps	High	Premium devices, density
Wi-Fi HaLow (802.11ah)	1+ km	100 kbps – 10 Mbps	Low	IoT, smart agriculture
LoRa / LoRaWAN	1–10 km (urban)	0.3–50 kbps	µA sleep, 50 mA active	Sensor networks, agriculture
Sigfox	10+ km	<1 kbps	µA average	Asset tracking, sensors
Cellular LTE-M	Cell coverage	300 kbps	mA-tier when active	IoT with cell backhaul
Cellular NB-IoT	Cell coverage	200 kbps	Very low	Static sensors, meters
Cellular 4G/5G	Cell coverage	Mbps – Gbps	High	Mobile devices, vehicles
NFC	<10 cm	424 kbps	mA when active	Payment, access, tap-pair
UWB	10–200 m	6.8+ Mbps	mA	Precision positioning
Thread / Matter	30–100 m (mesh)	250 kbps	µA sleep	Smart-home mesh
Zigbee	30–100 m	250 kbps	µA sleep	Industrial, mesh networks

1.2 Selection criteria

PRIORITY	RECOMMENDED
Lowest power, short-range	BLE 5.x
Indoor home networking	Wi-Fi 4/5/6
Long range, low data	LoRa, Sigfox
Cellular backhaul	NB-IoT (low rate), LTE-M, 4G
Mesh networking (home/industrial)	Zigbee, Thread, Matter
Precise positioning	UWB
Payment / access	NFC
Premium mobile data	5G + Wi-Fi 6

2. Module selection: pre-cert vs. custom

The biggest decision in wireless design. Pre-certified modules are faster and cheaper for low volume; custom designs are better for premium products at scale.

2.1 Pre-certified module

- **Pre-tested and certified by the module manufacturer (RED, FCC Part 15C, IC).**
- **Modular certification transfer**
  Your product inherits the certification when used per the module manufacturer's design guide.
- **Limited customisation**
  Fixed antenna interface, sometimes fixed antenna.
- **Higher per-unit cost**
  Module typically $3–15 in volume.
- **Faster time-to-market**
  4–8 weeks lead time + standard EMC testing only.

2.2 Custom RF design

- **Full control of antenna, layout, performance.**
- **Lower per-unit cost at scale**
  Often 30–50 % cheaper than a pre-cert module.
- **Full certification required**
  RED + FCC Part 15C lab testing from scratch.
- **Longer time-to-market**
  12–20 weeks + $10–30k in test fees.
- **Higher engineering investment**
  Requires RF engineer or external consultant.

2.3 Module ecosystem (popular pre-cert modules)

MANUFACTURER	COMMON MODULES	USE
Espressif	ESP32-S, ESP32-C, ESP32-H, ESP8266	Wi-Fi + BLE, IoT
Nordic	nRF52832, nRF52840	BLE, Thread, Zigbee
Quectel	EC25, BG95, BC660K	Cellular IoT, NB-IoT, 4G
u-blox	LARA, SARA, ZED-F9	Cellular + GNSS
Murata	LBEE / Type LBC	Wi-Fi + BLE combo
Sierra Wireless	EM7430, HL7800	Industrial cellular
Microchip	ATSAMW25, ATWILC1000	Wi-Fi for embedded
Silicon Labs	EFR32 Mighty Gecko	Multi-protocol IoT
Semtech	SX1262, SX1276	LoRa transceiver IC
Decawave / Qorvo	DWM3000, DWM1000	UWB precision

2.4 Selection criteria for modules

- **Certifications already obtained**
  Look for RED, FCC Part 15C, IC certified.

- **Module integration design guide**
  Modular cert transfer requires following the design guide.
- **Antenna interface**
  Internal antenna (most modules) vs. external coaxial connection.
- **Pin compatibility**
  Same footprint across module variants to enable upgrade path.
- **Supplier stability**
  Module suppliers go through EoL cycles; check NRND status.

3. Antenna topology

The antenna is the most-overlooked piece of RF design. Wrong antenna = poor range, no certification, no compliance.

3.1 Antenna types

TYPE	COST	PERFORMANCE	COMPACTNESS
PCB trace antenna	$0	Decent (2–4 dBi typical)	Compact
Ceramic chip antenna	$0.20–1.50	Decent (-1 to +1 dBi)	Very compact
Helical antenna	$0.50–3	Good for sub-GHz (LoRa)	Compact
Whip antenna (external)	$0.30–3	Excellent (3–5 dBi)	Bulky
Patch antenna	$1–5	Highly directional	Flat, large area
Slot antenna (PCB-etched)	$0 (in PCB)	Decent (0–2 dBi)	Compact
Coax fed monopole	$0.50–5	Best for small device	Flexible position
Dual / triple-band antenna	$1–10	Multiple bands	Compact for modules

3.2 Antenna placement rules

- **Antenna outside the case**
  Use coax-to-PCB connection. Best performance.
- **PCB trace antenna with clearance zone**
  10–20 mm keep-out around the antenna; no copper, no components.
- **Ceramic chip antenna on board edge**
  5 mm keep-out; ground plane shape matters.
- **Avoid placing antenna near**
  Battery, metal screws, conductive plastic, LCD, ICs.

3.3 Antenna tuning

- **Tune at the antenna feed point**
  Series + parallel components to match 50 Ω.
- **Match for return loss**
  S_{11} < -10 dB (≥90 % power transferred) at operating frequency.
- **Verify with Smith chart**
  Look at impedance across band.
- **Re-tune for production variance**
  Build 5–10 units of each material/finish and check.

3.4 Cable / coax considerations

- **U.FL connectors**
  Common for small RF connections; 50 Ω. Limited mating cycles (~30).
- **MHF / IPEX**
  Similar to U.FL but different keying.
- **SMA connectors**
  Higher quality, more mating cycles, used for external antennas.
- **Coax cable type**
  RG-178 (0.3 mm OD), RG-316 (1.5 mm OD), MMCX. Choose by loss vs. flexibility.

4. RF design rules

Schematic + PCB layout discipline that separates good RF design from EMC-failure RF design.

4.1 Schematic rules

- **Matching network footprint reserved**
  2–3 components (series L + shunt C, or pi-network).
- **50 Ω impedance trace to the antenna feed.**
- **Ground reference plane continuous under the antenna feed and matching network.**
- **ESD protection at the antenna feed**
  Bidirectional TVS, typically clamping at 6–8 V.

4.2 PCB layout for RF

- **Antenna trace impedance 50 Ω**
  Calculated for the layer stack-up.
- **Antenna feed length minimal**
  From module to antenna match, then to antenna. Total typically <20 mm.
- **Ground plane shape**
  Ceramic chip antennas often need a specific ground plane size (typically PCB length × 1/4 wavelength minimum).
- **No copper near the antenna**
  Cuts in ground plane act as antenna parasitic.
- **Capacitor placement**
  Decoupling caps at the RF amplifier should be ground-referenced and very close.

4.3 Common RF mistakes

- **Antenna trace too long**
  Becomes a parasitic emitter; affects radiation pattern.
- **Antenna too close to battery**
  Battery absorbs RF; range halves.
- **Antenna in a metallic enclosure**
  Faraday cage; needs an antenna outside or window.
- **Two antennas too close**
  Coupling; isolation < 20 dB causes interference.
- **No ground plane under antenna feed**
  Asymmetric ground, radiation pattern shifts.

5. Regulatory paths

Each wireless technology has a defined certification path. Choose the path before sample order.

5.1 RED (Radio Equipment Directive, EU)

- **Applies to all radio transmitters above 9 kHz, with intentional emission.**
- **Notified Body assessment**
  Optional for most consumer products (self-declaration if harmonized standards are used).
- **Required tests (per harmonized standards):**

- EN 300 328 (2.4 GHz general) - EN 301 893 (5 GHz Wi-Fi) - EN 301 489 (EMC for radio) - EN 62311 (RF exposure) - EN 62479 (RF exposure for low-power devices) - EN 50360 / EN 62209 (SAR for body-worn)

5.2 FCC Part 15 (US)

- **Part 15B**
  Unintentional radiators (DCs, MCUs, digital logic).
- **Part 15C**
  Intentional radiators (Wi-Fi, BLE, transmitters > 9 kHz).
- **15.247**
  License-exempt low-power transmitters in ISM bands (2.4 GHz, 5 GHz).
- **FCC ID required**
  Unique identifier per device model.
- **Modular cert transfer**
  When using pre-cert modules per manufacturer's design guide.

5.3 IC (Industry Canada / ISED)

- **Mirror of FCC for Canadian market.**
- **IC ID**
  Required, similar to FCC ID.
- **Many modules pre-cert for both FCC and IC.**

5.4 Test scope per certification type

CERTIFICATION	LAB TEST COST	LEAD TIME
Modular cert transfer (using pre-cert module)	$0–500 (engineering)	1–2 weeks
FCC Part 15B (unintentional, EMC)	$1 500–4 000	2–3 weeks
FCC Part 15C custom + ID	$8 000–25 000	4–8 weeks
RED (EU radio) custom	$6 000–18 000	4–6 weeks
RED + RF safety (SAR)	$5 000–15 000 added	2–4 weeks added
RED + EMC (full pathway)	$15 000–35 000 total	6–10 weeks
IC custom	$5 000–15 000	4–6 weeks

5.5 Wireless module pre-cert advantage

A pre-certified module saves typically **8–12 weeks** of compliance time and **$10–20k** in lab fees vs. custom RF design. The trade-off is the per-unit cost premium ($3–10 vs. $1–3 in custom).

For volumes under 100k units/year, pre-cert modules are almost always cheaper net. Above that volume, custom designs amortise.

6. Wireless certification timeline

For a typical new device with one wireless protocol (BLE or Wi-Fi).

6.1 Pre-certified module path

WEEK	ACTIVITY
T-0	Spec lock, module + antenna selected
T+2	PCB design + antenna placement
T+4	Pre-production samples
T+5	EMC pre-scan (in-house)
T+6	Book formal EMC lab
T+8	EMC lab testing
T+10	Cert documentation + filing
T+12	Production-ready

6.2 Custom RF design path

WEEK	ACTIVITY
T-0	Spec lock, antenna design begun
T+3	Antenna prototype + matching
T+5	RF section PCB design
T+8	Pre-production samples
T+9	Pre-compliance scans
T+11	Book formal RF + EMC lab
T+15	Lab testing (radio + EMC)
T+17	Cert documentation + filing
T+20	FCC ID + RED documentation complete
T+22	Production-ready

CRITICAL — NEVER SKIP PRE-COMPLIANCE

Lab tests for wireless certification cost $5–25k per booking. A failed test means re-design + re-test, often $10–40k and 4–8 weeks delay.

Pre-compliance scans at $300–1 500 each catch 70–80 % of issues that would otherwise fail formal lab testing. The math is simple: 2–3 pre-compliance scans before booking the lab costs $1 000–4 500; one failed lab session costs $10 000+. Pay for the pre-compliance.

FINAL NOTE. wireless integration is the place where consumer hardware projects most frequently slip 4–8 weeks past their planned launch. The discipline is to commit to pre-certified modules in low-volume designs, invest in pre-compliance early, and never assume "we'll fix the antenna in the next rev." Get the antenna and the regulatory path right at design freeze.