Testing the Complete Product: Not Just the Radio!

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How to Verify That Wi-Fi and Bluetooth Links Are Robust in Factories, Mines and Hospitals

This Bluetest White Paper is written for R&D and test managers who develop Wi-Fi and Bluetooth products for industrial and medical use. It explains why a certified radio module is not enough, what to measure on the finished product, and how a reverberation chamber makes those measurements repeatable.

Certification tells you whether a product may be sold or not. But it does not tell you how much link margin is left in a metal cabinet, on a patient's wrist or in a crowded 2.4 GHz band.

A Bluetest reverberation test system provides you with the answers to those questions already during development, while changes are cheap and still possible to introduce.

A radio that works on the bench can still fail as a product. Test before you ship!

This paper in brief

- **Why is a certified radio module not enough?** Housing, placement and surroundings change what reaches the air. Conducted and antenna-only tests cannot see this.
- **What should be measured?** Isotropic radiated power, isotropic radiated sensitivity, MIMO performance, and throughput under stress and interference. Radiated emission and immunity (EMC) can be pre-tested in the same chamber.
- **How is it done repeatably?** In a reverberation chamber: the complete product in a controlled isotropic multipath field, repeatable for every run.
- **Where does it fit?** In development and pre-compliance, before formal coexistence tests, field trials and certification.



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November 2026.
Document No. BTW-26-005
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Why Wireless Reliability Matters

Wi-Fi and Bluetooth are built into a growing range of industrial and medical products: mobile robots, automated guided vehicles (AGVs), handheld terminals, sensors, patient monitors and wearables. In all of them the antennas sit inside a housing, close to metal, batteries and electronics, which may degrade the radio reception.

For many of these products the link is mission-critical: when it drops, operation stops and/or data arrives delayed.

- **Factory automation.** Safety protocols such as *PROFIsafe* treat the radio link as a "black channel": if messages are late or missing, the machine goes to a safe state, as if the emergency stop had been pressed [1]. Safety is protected by design, but every connection drop results in an unplanned stop.
- **Mining.** Tunnels with rugged blasted rock walls [2], metal structures and moving machines make radio conditions harsh. Wireless emergency-stop systems share the spectrum with Wi-Fi. In coexistence tests by NIOSH and NIST researchers, Wi-Fi interference caused false trips of a wireless emergency stop, which stopped the conveyor, while genuine stop commands still got through [3].
- **Healthcare.** FDA guidance asks manufacturers to show that wireless functions work in the expected RF environment, including coexistence with other wireless devices [4]. A dropped link in a patient monitor or wearable must be caught by the device's risk controls.

Wireless reliability decides uptime and data continuity. Verifying it on the complete radiating product is key: chipset, antenna, placement in the housing and surroundings.

Why a Certified Radio Module Is Not Enough

Most products are built around a pre-certified radio module and an antenna chosen from a datasheet. Both perform well on their own. What the user experiences is decided after integration:

- **Housing:** Metal, batteries, displays and cables near the antenna absorb power and detune it.
- **Other electronics:** Processors and power converters create noise that desensitizes the receiver (desense).
- **Placement:** On a wrist, on a forklift or in a metal cabinet, the same device radiates very differently.
- **Surroundings:** Reflections, obstructions and other radios change the link from moment to moment.

Figure 1 shows which of these effects each test method covers. Only an over-the-air (OTA) test in a reverberation chamber covers the complete product and can provide repeatable results.



Figure 1. What each test method covers.

Antenna checks can hide losses

Matching at the antenna connector (S-parameters) and radiation patterns are useful design tools, but neither shows how much power the finished product radiates. Losses in the housing and nearby materials do not show up at the connector.

MIMO is a clear example. Wi-Fi uses two or more antennas, and the gain depends on how independent their signals are. A study presented at EuCAP 2024 found that estimating this from connector measurements alone can be misleading for antennas with realistic losses: it predicts better MIMO performance than the antennas deliver [5]. Including measured efficiency improves the estimate, but the efficiency must still be measured over the air.

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A good antenna match does not guarantee a good wireless link. Measuring the complete product over the air does!

What to Measure on the Complete Product

Four measurements to assess how well a product communicates are described below. All four can be made on the finished product in the same reverberation chamber [6], [7].

Measurement	Question it answers	Why it matters
Radiated power (TRP) and efficiency	How much of the transmitted power leaves the product?	Low efficiency reduces link margin, so the link fails earlier when the signal fades.
Receiver sensitivity (TIS)	How weak a signal can be received?	Reveals desense from the product's own electronics, in addition to antenna efficiency.
MIMO performance	Do the antennas give independent signal paths?	Wi-Fi 6 and Wi-Fi 7 rely on several antennas. If they see the same signal, the extra antennas add little improvement.
Throughput and packet delivery	How much data gets through on a complete system level, and when does the link fail? Also under external desense conditions.	This is the true user experience.

Low margin rarely shows up as a clean failure. It shows up as retries, lower data rates and reconnections: A robot that pauses, or a gap in a patient's data.

High efficiency gives link margin. Independent antennas give MIMO gain. Both must be measured, not assumed.

Bluetooth and Wi-Fi applications usually use electrically small antennas that are designed to radiate uniformly into the surroundings with no specific direction. It is thus important that the radiated output power and receiver sensitivity are measured in an isotropic fashion. Using the reverberation chamber ensures that no angles are missed.

The reverberation chamber provides true isotropic metrics. No angles will be missed!

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How a Reverberation Chamber Tests the Complete Product

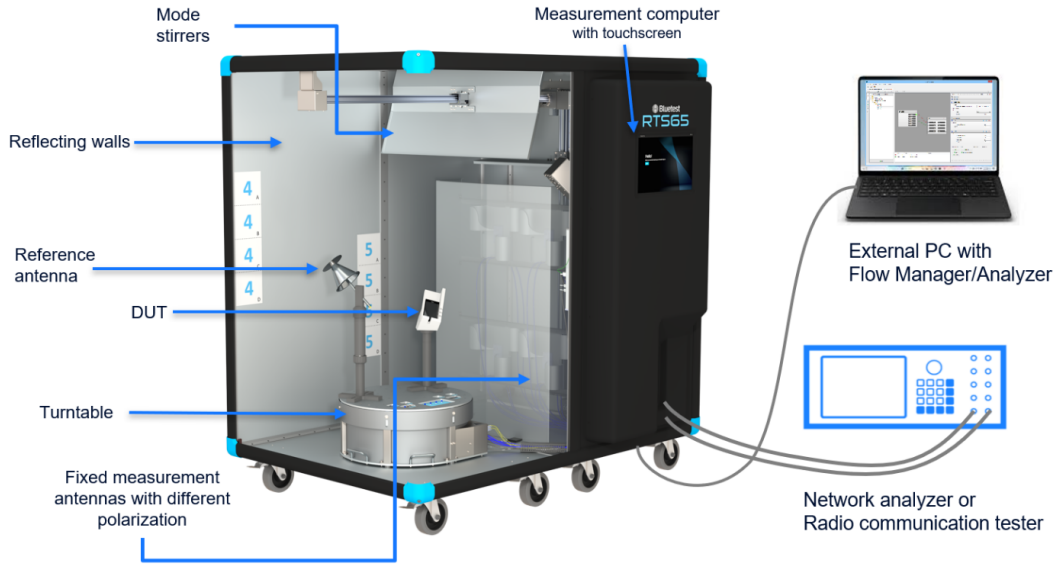


Figure 2. Bluetest RTS: mode stirrers, turntable and fixed measurement antennas create a repeatable multipath field around the device under test (DUT).

A Bluetest Reverberation Test System (RTS) is a shielded chamber with reflective walls, measurement antennas, mode stirrers and a turntable (Figure 2). As the stirrers and turntable move, the device is measured over many different field patterns, with signals arriving from all directions. The environment provides multipath and fading representative of a factory hall or hospital ward, but it is controlled and repeatable [6], [8].

What you get	Why it matters
Complete product test	The device is tested in its final housing, with its own battery and firmware, and with no test cable to the antenna.
Representative multipath and true isotropic metrics	The chamber inherently emulates multipath fading representative of indoor conditions [8]. All directions are measured at once.
Repeatable results	Turntable and mode stirrers recreate the same statistical environment on every run, which makes A/B comparison of design revisions reliable.
Wi-Fi 7 and Bluetooth	RTS65 covers 650 MHz to 12 GHz, including Bluetooth and the Wi-Fi 6E and Wi-Fi 7 bands up to 7.125 GHz, with up to 4×4 MIMO [7]. Wi-Fi 7 signaling with the Rohde & Schwarz CMX500 is integrated in Bluetest Flow [8].
Small and large devices	RTS25: compact chamber for Wi-Fi, Bluetooth and IoT devices up to 0.4 × 0.3 × 0.3 m and 12 kg [9]. RTS65: test volume of about 0.5 × 0.5 × 0.5 m [7]. RTS95B: devices up to 1.5 × 1.5 × 2 m and 500 kg [10].
Automation	Test sequences in Bluetest Flow run unattended and store every result in one database.

EMC in the same chamber

Reverberation chambers are a well-established method for EMC testing. IEC 61000-4-21 describes reverberation chamber methods for both radiated emission and radiated immunity [11]. The stirred field exposes the device from all directions and polarizations without repositioning it. The same RTS and fixture can therefore be used for radio performance and for EMC pre-compliance, including radiated spurious emissions within the chamber's frequency range.

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Stress Testing: Link Margin, Interference and Coexistence

Knowing that a link works is not enough; you need to know its margin. A Bluetest RTS allows engineers to lower the signal step by step until the link breaks, add competing Wi-Fi or Bluetooth traffic, and log packet errors, throughput and recovery. The same test is rerun after every design change in a repeatable fashion.

Examples from industry and healthcare

Application	What can go wrong	Example of what to test in the RTS
AGVs, mobile robots and forklifts	Late commands trigger safe stops and halt production.	Robustness and recovery as the signal weakens; antenna position on the vehicle; coexistence with nearby Wi-Fi.
Mining and heavy industry	Metal structures and tunnels cause deep fading.	The installed antenna system and enclosure; link margin and MIMO gain in rich multipath.
Patient monitors and infusion pumps	Data or alarms are delayed in a crowded 2.4 GHz band.	Throughput and data continuity with other Wi-Fi and Bluetooth interferers active.
Wearables and body-worn sensors	The body and wear position detune the antenna.	Efficiency and link margin per wear position and firmware version.

Repeatable over-the-air tests expose design margins before wireless weaknesses become operational interruptions.

A Practical Verification Workflow

Figure 3 illustrates the workflow we recommend for device makers. Steps 1 to 7 run in the same Bluetest RTS and every result is stored in Bluetest Flow, so results stay comparable from the first prototype to production. Step 6 turns every hardware, firmware or installation change into a regression test, and step 7 covers EMC and coexistence pre-tests before the formal tests in an accredited lab.

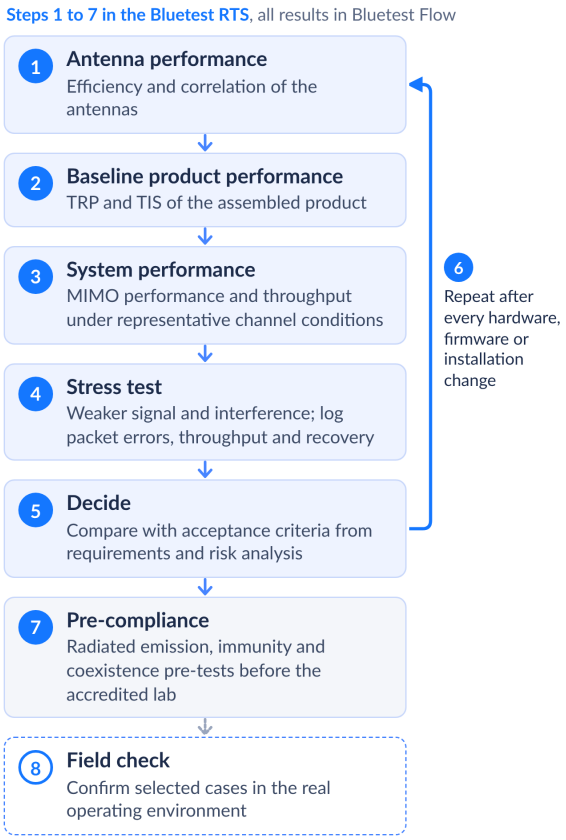


Figure 3. Recommended verification workflow.

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Where Chamber Testing Fits

The chamber does what is hardest to do elsewhere: repeatable radiated tests of the complete product, early and often. Its results feed the evaluations that regulators and standards ask for.

The regulatory frame

Framework	What it asks for	How the RTS supports it
FDA guidance on RF wireless technology [4]	Wireless functions that work in the expected RF environment, including coexistence.	Repeatable performance and coexistence data for design verification.
ANSI C63.27-2021 [12]	Risk-based coexistence evaluation with conducted, radiated anechoic, radiated open environment or multiple chamber methods.	Weaknesses are fixed in development, so there are fewer surprises in the formal test.
AAMI TIR69 [13]	Risk management of RF wireless coexistence for medical devices.	Measured margins as input to the risk analysis.
Safety protocols per IEC 61784-3 [1]	Late or lost messages force a safe state.	Shows how often, and under which conditions, the link drops, which is the cost of downtime.
CTIA test plan for Wi-Fi converged devices [14]	Wi-Fi TRP and TIS, and desense between Wi-Fi and cellular in the same device.	TRP, TIS and desense are checked in development, before the formal test in an authorized lab.

Scope

- **Pre-compliance, not certification.** Formal coexistence and EMC tests stay with an accredited lab.
- **Statistical multipath, not one site.** Site-specific cases are confirmed in the field (step 8).
- **Wireless performance, not system safety.** Machine and clinical safety have their own processes; RTS results feed into them.

Why Bluetest

- **Origin in the method.** Bluetest was founded in 2000 by Professor Per-Simon Kildal of Chalmers University of Technology [15], whose research established reverberation chambers for OTA testing of antennas and MIMO devices [6].
- **Proven platform.** Several hundred systems are installed worldwide [15]. RTS95B is CTIA approved for large form factor devices [10].
- **Ready for Wi-Fi 7 and Bluetooth.** RTS65 and RTS25 support both [7], [9], with Wi-Fi 7 signaling integrated in Bluetest Flow [8].
- **Antenna to application in one chamber.** Efficiency, radiated power, sensitivity, MIMO performance, throughput and EMC pre-compliance in one chamber and one Flow database.

Summary

A certified radio module and a good antenna datasheet do not guarantee a robust wireless link. What decides uptime and data continuity is the complete product: chipset, antenna, housing, placement and surroundings. A Bluetest reverberation test system measures that complete product over the air, isotropically and repeatably, from the first antenna prototype to EMC pre-compliance.

Bluetest welcomes a technical discussion about your test needs, and a demonstration of the method on your own device. Contact sales@bluetest.se, +46 31 778 61 61, www.bluetest.se.

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