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A Quantum Future Requires Quantum Qualification

New specialized qualification standards are needed in the RF and microwave industry to support the rapid growth of quantum technologies. Learn how establishing quantum qualified standards will ensure the reliability and performance of quantum systems in real-world applications.

The quantum revolution is nigh. With advances in quantum computing, quantum communication, and quantum sensing moving from theoretical to tangible, we're now on the brink of breakthroughs that will reshape entire industries.

As such, the RF and microwave systems enabling quantum technology will need to perform in ways that extend far beyond the established military standards like MIL-STD and MIL-PRF, pushing the boundaries of what's possible in performance and reliability. This article explores why it's time for the RF and microwave industry to begin defining new qualification standards that are specific to quantum applications.

The Case for Quantum Qualified

Existing RF and microwave qualification standards are insufficient for quantum applications, which operate under entirely different constraints. Military standards, such as MIL-STD-202 (for general electronic component testing) and MIL-PRF-38534 (for hybrid integrated circuits), focus on ensuring the long-term reliability of components under harsh conditions through rigorous tests for thermal cycling, vibration, humidity, and other factors. While these standards provide a solid foundation for qualifying traditional RF components, they don't fully address the specialized needs of quantum applications.

Quantum systems rely on a delicate balance of quantum states. This makes them highly sensitive to external factors such as temperature fluctuations, electromagnetic interference, and mechanical vibrations.

Unlike traditional RF components that can withstand these conditions, quantum applications require elevated standards of performance. For example, quantum coherence—the ability of qubits to maintain their state—can be disrupted by even the smallest environmental shifts, leading to errors or system failures. Also, many quantum technologies operate at cryogenic temperatures near absolute zero, where even minimal thermal drift can degrade performance.

Hybrid systems that combine quantum technology with traditional RF and microwave components introduce additional challenges. RF signals used in quantum communications must be tested not only for conventional performance characteristics like signal strength and noise, but also for their impact on quantum-state stability. Similarly, quantum sensors paired with RF and microwave systems require testing for interoperability and long-term reliability in dynamic environments.

What Quantum Qualification Standards Could Look Like

Defining new qualification standards will require a fundamental shift in RF and microwave design, new approaches to testing, and cross-industry collaboration. RF engineers, physicists, and manufacturers must work together to define qualification standards, share technical insights, and drive the advancement of quantum-enabled RF and microwave capability.

Establishing specific quantum qualified benchmarks will be essential to ensuring these systems transition from theoretical to real-world applications:

Noise Immunity and Signal Integrity

Qualification levels to ensure that RF components maintain signal integrity and resist disruptions from external electromagnetic fields, thermal fluctuations, and background radiation.

- **Electromagnetic-interference (EMI) resistance:** Components must function in environments with ≤ -100 dBm of background noise at relevant operational frequencies. Shielding effectiveness should meet or exceed 80-dB attenuation.
- **Thermal fluctuation stability:** Frequency drift should be ≤ 1 ppb/K (parts per billion per Kelvin) for high-stability applications.
- **Radiation hardness:** For aerospace and defense applications, components should withstand ≥ 100 krad (Si) total ionizing dose (TID) without degradation in performance.

Environmental Sensitivity

Many quantum devices operate in extreme conditions, such as ultra-low temperatures for superconducting qubits or high-radiation environments for space-based quantum sensors.

- **Cryogenic performance:** Components must operate reliably at ≤ 10 mK for superconducting applications, with minimal phase-noise drift.
- **Vibration tolerance:** Must meet MIL-STD-810G for mechanical shock and vibration in military and aerospace environments.
- **High-radiation environments:** Quantum sensors for space applications must sustain performance under $\geq 10^6$ rad (Si) TID and single-event effects (SEE) testing per NASA EEE-INST-002.

Coherence and Error Correction

Qualification levels should evaluate error-correction performance and a system's ability to maintain quantum coherence under operational stress.

- **Quantum coherence time (T_2):** For superconducting qubits, T_2 should be ≥ 100 μs; for trapped ions, ≥ 1 second is ideal.
- **Gate fidelity:** Quantum operations should achieve $\geq 99.9\%$ fidelity for error correction to be viable.
- **Decoherence rate:** System-wide decoherence should remain below 1% per millisecond under operational conditions.

Long-Term Reliability

Qualification levels should incorporate reliability testing that simulates long-term decoherence, cryogenic cycling, and quantum state preservation.

- **Accelerated life testing:** Components should demonstrate operational integrity after 10^5 cryogenic cycles (for superconducting applications) and > 10 years equivalent accelerated aging for general reliability.
- **Quantum state preservation:** Quantum memories must maintain coherence with <1% fidelity loss per day over extended storage periods.
- **Material degradation metrics:** Outgassing and contamination levels should be within NASA ASTM E595 standards for space applications.

Cross-Qualification Compatibility

Qualification standards should include hybrid testing procedures that assess both traditional and quantum performance levels to ensure interoperability and minimize signal degradation.

- **Hybrid system interoperability:** RF and quantum components must maintain phase coherence across >99.99% synchronization during integration.
- **Signal compatibility:** RF signals used in quantum operations must have <-140 dBc/Hz phase noise at 10-kHz offset.
- **Integration standards:** Must comply with IEEE P7130 (Quantum Computing Definitions) and industry-recognized RF/microwave testing protocols.

Current Efforts and Challenges

The need for quantum qualification is clear, but the development of comprehensive standards is still in its early stages.

The National Institute of Standards and Technology (NIST) has been developing measurement standards for quantum sensors and quantum key distribution (QKD), which are important for secure communications.

However, their work at the moment is focused mainly on QKD and doesn't address the full range of RF and microwave component requirements in quantum technology, such as noise immunity or control. This narrow focus leaves a large gap in the qualification standards needed to ensure robust integration of quantum technologies with RF and microwave systems.

Similarly, the Institute of Electrical and Electronics Engineers (IEEE) is making strides with initiatives like IEEE P2861, aimed at quantum computing and communication, but these efforts remain fragmented. The RF aspects of quantum integration—such as cryogenic performance and system stability in harsh environments—aren't fully addressed yet.

While organizations like the International Standards Organization (ISO) and the International Electrotechnical Commission (IEC) are exploring standards for quantum computing, they too are in the early stages and haven't yet tackled RF and microwave-specific qualifications. This lack of cohesion in quantum standards highlights the need for a unified approach to ensure quantum and RF function together reliably.

The Future of RF Is Quantum—Let's Make Sure We're Ready

The need for quantum qualification standards is urgent as quantum technologies rapidly advance and are adopted in industries like telecommunications, defense, and more. Without unified standards, we in the RF and microwave industry risk hindering progress and falling short of quantum's potential.

Just as space qualification standards accelerated space industry capabilities, quantum qualified standards will ensure that quantum systems meet performance requirements. A quantum future requires quantum qualification, and the demand for new standards will only continue to ramp up. Let's make sure we're ready.

William Walsh is a seasoned marketing communications professional with expertise in the electronics industry, particularly mission-critical applications in aerospace, defense, and emerging technologies. Walsh has a strong track record of developing strategies that bridge technical innovation with customer requirements, especially in fields requiring high-performance solutions.