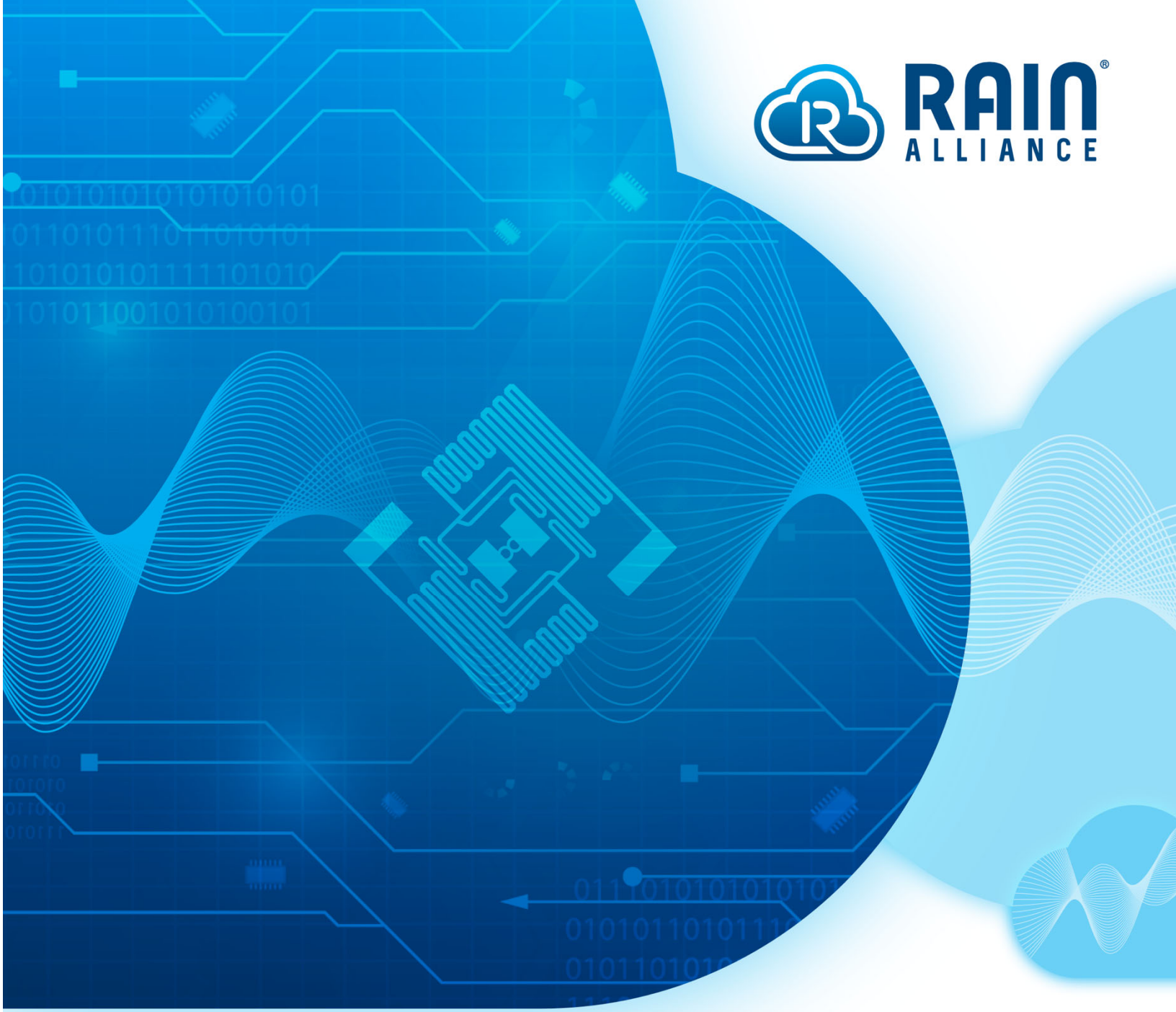

RAIN Manufacturing Quality Guideline

Use Case Scenarios

v2

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Scope of Document

The adoption of RAIN RFID technology spans multiple industries, each with unique operational environments, regulatory requirements, and performance expectations. While RAIN Manufacturing Quality Guideline (V1.0 – May 2025) establishes a universal baseline for manufacturing quality, the current document provides insights into how to define detailed tag quality requirements to ensure that tags perform reliably under real-world conditions specific to each application.

This extended guideline builds upon the original RAIN Manufacturing Quality Guideline (V1.0 – May 2025) by introducing measurable, quantitative performance criteria for definition of tag quality and providing examples of use case specific quality requirements to address evolving market needs and regulatory expectations.

The purpose of the document is to

1. Establish clear, measurable benchmarks for RAIN RFID tag quality.
2. Enable manufacturers and end-users to align on performance expectations.
3. Support traceability and compliance with industry standards.

This document introduces a list of tag performance criteria to be used for specifying tag performance and quality requirements which is described in Section 3. Section 4 of this document provides examples on how to apply this framework in practice and determines requirements for different RAIN use cases.

Target Audience

This guideline is designed for individuals or organizations interested in learning about and following industry best practices to ensure quality in RAIN tag production. It is intended for a wide range of stakeholders, including raw material suppliers, tag manufacturers, quality managers, process auditors, and end-users. The guideline ensures fair, scalable, and broad applicability to support consistent and reliable quality assurance across the entire RAIN tag supply chain.

Quality Requirements and Performance Criteria

The quality definition outlined in this guideline applies specifically to RAIN RFID inlay production, and recognizes the following list of **measurable and quantitative** criteria for requirements:

- RF Performance: RF (Radio Frequency) performance measures how effectively the RAIN inlay receives and transmits radio signals. Common practical requirements include maximum read range and applicable reading directions. Qualification measurements include minimum tag turn-on power over frequency (sensitivity curve) and tag backscatter power over frequency (RSSI – Received Signal Strength Indicator).
- Data Retention: Defines minimum retention period for data stored into tag memory and capabilities for error detection.
- Quality of Documentation: Outlines expectations for transparency and chain of custody in test procedures and results.
- RF Performance Variation: Determines the acceptable tag sensitivity variation (+/- dB) across tags and provides recommendations for the variability before and after inline and sample-based testing.
- Mechanical Durability (Bend & Shear): Establishes stress test parameters for bending and shear force to ensure structural integrity.
- Environmental Resistance: Demonstrates how well tags maintain their performances under different temperature/humidity cycling.
- Other Special Conditions: Covers additional stress factors for custom applications such as, but not limited to, gamma radiation, vibration, and washing and drying.

Details for each requirement are presented in Table 1. Each requirement is associated with a symbol, performance criteria, and notes that provide context for implementation and testing. There are three pre-defined criteria (e.g., P1, P2, P3) for most requirements which represent certain performance classes to form a common basis for target setting. There's also an option to define a custom criterion (PX) to allow flexibility for e.g., untypical application context.

Table 1. Quality Requirements and Performance Criteria

Quality Requirement	**Symbol**	**Performance Criteria**	**Notes**
RF-Performance		Common practical requirements include maximum read range and applicable reading directions. Qualification measurements include minimum tag turn-on power over frequency (sensitivity curve) and tag backscatter power over frequency (RSSI – Received Signal Strength Indicator).	There are grading systems available for tag and tagged-item performance. These requirements are associated with the end-user or regulatory requirement. ISO/IEC 18046-3 and GS1 TIPP guidelines define these performance definitions.
Data Retention	R	R1 = 15y OR bit error detection R2 = 10y OR bit error detection R3 = 5y RX = Custom	
Quality of Documentation	D	D1 = Supplier must provide all the details of test procedures, results, and the variation of the results D2 = Supplier must provide the results of the tests D3 = Supplier must provide generic tag specifications, and no proofs of quality is required DX = Custom	Manufacturers shall provide generic performance specifications, possible application-specific instructions, and indicate quality e.g., variations as part of the documentation for their product to allow informed tag selection. End-users may require proofs for manufacturing quality, i.e., test data (statistics and/or individualised). Provision of tag specific test data requires recording TID (+EPC) at the production process and association of test data with the tag identifier. The end-user may (in some cases) also require description of test procedures.
RF Performance Variation	P	P1 = +/-2dB (high requirements for RF performance consistency)	Inline testing: Every tag shall be tested inline for performance on at least single (or preferably more)

Quality Requirement	Symbol	Performance Criteria	Notes
		P2 = +/-3dB (typical application production variation of a reasonable range) P3 = +/-4dB (stable performance variation) PX = Custom	frequency & power condition to detect defects not meeting this criterion. When feasible without limiting process throughput, it's recommended to collect Tag ID from each tag processed to enable association of the test data with the individual tag. Sample testing: A number of tags are picked from production and tested offline to collect more thorough performance data that's representative for e.g., a certain production batch. Sample based testing may be performed e.g., by measuring response threshold of each individual in far-field, on air as a minimum across the ISO/IEC 18046-3 frequency spectrum defined between 860 MHz and 930 MHz, with measurement frequency steps of 5 MHz. It's recommended to store sample test data with Tag ID information to allow traceability of the test data to an individual tag.
Bend Durability	M	M1 = 4200 bends, 600 compressions at 200N, 98% must pass M2 = 4200 bends, 600 compressions at 150N, 95% must pass M3 = 4200 bends, No compression, 95% must pass MX = Custom	Test procedure: Sensitivity of tag samples is measured before and after bending and yield assessed by comparing variation across samples to the average performance before test, as compared to the target RF performance variation (P1, P2, etc.). 1st sensitivity test: samples are tested before bending and an average sensitivity is calculated to provide a

Quality Requirement	Symbol	Performance Criteria	Notes
			reference for the yield assessment in the next step. Deficient units may be excluded. 2nd sensitivity test: samples are tested after bending, and deviation of the sensitivity from the reference are calculated individually. Pass/fail criterion: passing tags should not deviate from the reference by more than what's defined as allowed production variance, or by no more than +/-3dB if production variance is undefined. Yield assessment: yield is calculated as a ratio of how many valid samples pass the test criterion after bending. Test arrangements for bend testing: - Bending: 90° or more, Bend diameter: 40mm or less - Compression force defined for a setup where tag is compressed between a metal surface and a rubber surface (ShoreA: 60-70) with chip facing the rubber - The line tension is 40 N for material width of 60 mm or wider. - For material widths narrower than 60mm, the tension shall be reduced in inverse relation after the 60mm. E.g. for ¾*60mm=45mm material width, ¾ of the tension can be used. - Chip facing rollers may be covered with rubber.

Quality Requirement	Symbol	Performance Criteria	Notes
			Definition of sample count: - Preferably enough to gain statistically significant results - Might be different for original analysis and monitoring - e.g., 3x number of thermoids on the production machine
Shear Force	S	S1 = 6 x MIL-spec S2 = 4 x MIL-spec S3 = 2 x MIL-spec SX = custom	MIL 883E Standard might be quite low for small chips. Industry might demand higher shear force for RFID chips.
Temperature Cycling	TC	TC1 = -40 °C…85 °C, 100 cycles TC2 = -40 °C…85 °C, 50 cycles TC3 = -40 °C…85 °C, 10 cycles TCX = Custom	JESD22-A104-F The soaking time (time kept at certain temperature) varies based on the equipment capability. Regarding paper-based labels, using the classic JEDEC/IEC high-humidity cycling standards becomes overly strict and unrepresentative. Pass/fail criterion: 100% passing tags should not deviate from a reference by more than what's defined as allowed production variance, or by no more than +/-3dB if production variance is undefined.
Temperature and Humidity	TH	TH1 = 85 °C, 85% humidity, 168 hours TH2 = 85 °C, 85% humidity, 72 hours TH3 = 85 °C, 85% humidity, 24 hours THX = Custom	IEC 60068-2-67 Regarding paper-based labels, using the classic JEDEC/IEC high-humidity cycling standards becomes overly strict and unrepresentative. Pass/fail criterion: passing tags should not deviate from a reference by more

Quality Requirement	Symbol	Performance Criteria	Notes
			than what's defined as allowed production variance, or by no more than +/-3dB if production variance is undefined.
Other Special Process Requirements, i.e., Gamma Radiation, Vibration, Special Processing, etc	O	OG = Gamma Radiation OW =Textile Washing OM = Microwave Safe OS =Medical Sterilization (Autoclave) OV = Vibration OSW = Stone Washing	ISO 6330 (Domestic washing and drying procedures for textile testing). NF EN ISO 15797 (Industrial washing and finishing procedures for testing of workwear). AATCC 61 (Test Method for Colourfastness to Laundering with accelerated washing conditions). OW1=200 cycles (industrial use) OW2 =50 cycles (domestic use) OW3 =10 cycles (quick fashion) OWX = custom

Industry-Specific Requirements

This chapter demonstrates how to apply the suggested guideline into practice by providing examples of requirements setting for different RAIN applications. Two use case examples are provided separately for each Sector including Retail & Apparel, Healthcare & Pharmaceutical, Logistic & Transportation, Aviation & Aerospace, Food & Perishables, and Automotive.

Retail & Apparel

Retail and apparel applications require RAIN RFID tags to maintain performance throughout the product lifecycle—from manufacturing and distribution to in-store environments and consumer use. Tags must withstand handling, environmental exposure, and integration with packaging and labelling processes.

EXAMPLE 1: Apparel Tagging for Store Inventory Management

Quality Requirement	**Performance Criteria**	**Notes**
RF Performance		Will be defined in future work packages of this group
Data Retention	R3	
Quality of Documentation	D2	
RF Performance Variation	P1	
Bend Durability	M3	
Sheer Force	S3	
Temperature Cycling	TC3	
Temperature and Humidity	TH3	
Other Special Process Requirement	-	

Manufacturing Quality Grade: R3-D2-P1-M3-S3-TC3-TH3

EXAMPLE 2: Apparel Tagging for Digital Product Passport, DPP (Washable)

Quality Requirement	**Performance Criteria**	**Notes**
RF Performance		Will be defined in future work packages of this group.

Data Retention	R1	
Quality of Documentation	D2	
RF Performance Variation	P2	
Bend Durability	M3	
Sheer Force	S3	
Temperature Cycling	TC1	
Temperature and Humidity	TH1	
Other Special Process Requirement	OW	Textile Washing

Manufacturing Quality Grade: R1-D2-P2-M3-S3-TC1-TH1-OW

Healthcare & Pharmaceutical

Healthcare and pharmaceutical applications require RAIN RFID tags to meet stringent regulatory and operational standards. Tags must maintain functionality after sterilization, withstand exposure to chemicals, and comply with healthcare-specific quality norms.

EXAMPLE 1: Pharmaceutical Tagging for Traceability

Quality Requirement	**Performance Criteria**	**Notes**
RF Performance		Will be defined in future work packages of this group.
Data Retention	R1	
Quality of Documentation	D1	
RF Performance Variation	P1	
Bend Durability	M2	
Sheer Force	S2	
Temperature Cycling	TC1	
Temperature and Humidity	TH1	
Other Special Process Requirement	-	

Manufacturing Quality Grade: R1-D1-P1-M2-S2-TC1-TH1

EXAMPLE 2: Surgical Trays Tagging for Traceability (Soft Tag/Label)

Quality Requirement	**Performance Criteria**	**Notes**
RF Performance		Will be defined in future work packages of this group.
Data Retention	R1	
Quality of Documentation	D1	
RF Performance Variation	P1	
Bend Durability	M1	
Sheer Force	S1	
Temperature Cycling	TC1	
Temperature and Humidity	TH1	
Other Special Process Requirement	OS	Medical Sterilization

Manufacturing Quality Grade: R1-D1-P1-M1-S1-TC1-TH1-OS

Logistic & Transportation

In logistics, RAIN RFID tags must survive handling, palletization, and transportation while maintaining consistent read ranges in mixed-load environments. Tags should perform reliably under compression, stacking, and exposure to varying humidity and temperature.

EXAMPLE 1: Plastic RTI (Reusable Transport Items)

Quality Requirement	**Performance Criteria**	**Notes**
RF Performance		Will be defined in future work packages of this group.
Data Retention	R1	
Quality of Documentation	D2	
RF Performance Variation	P1	
Bend Durability	M3	
Sheer Force	S2	

Temperature Cycling	TC1	
Temperature and Humidity	TH1	
Other Special Process Requirement	OW1	Industrial cleaning: +200 Washing Cycles during lifetime

Manufacturing Quality Grade: R1-D2-P1-M3-S2-TC1-TH1-OW1

EXAMPLE 2: Pallet Tagging (SSCC Transportation Labels)

Quality Requirement	**Performance Criteria**	**Notes**
RF Performance		Will be defined in future work packages of this group.
Data Retention	R3	
Quality of Documentation	D2	
RF Performance Variation	P1	
Bend Durability	M3	
Sheer Force	S2	
Temperature Cycling	TC3	
Temperature and Humidity	TH3	
Other Special Process Requirement	-	

Manufacturing Quality Grade: R3-D2-P1-M3-S2-TC3-TH3

Aviation & Aerospace

In the aerospace sector a clear division is made with parts and processes that are referred to as “airborne”, meaning that they are part of the flying fleet, airplane parts, their security, or maintenance processes. These are governed by documentation, such as ATA spec 2000 and the underlying standards, AS5678 (US) and EN4905(Europe).

The process typically is that the RAIN tag shall withstand all equivalent environmental conditions that the part it is attached to. In aerospace this typically means extreme temperatures, fluids, pressure variation, washing cycles among others. Cost is not a strong driver, but quality and reliability are very important. RAIN RFID is not the primary method of detection, so failure is not critical as long as the failure is detected and doesn’t misguide. In other words a

dead tag is not a big issue, but a detached tag or one with wrong data is not acceptable. Non airborne use cases, such as luggage tracking are governed by IATA and have looser criteria.

EXAMPLE 1: Airborne Parts

Quality Requirement	**Performance Criteria**	**Notes**
RF Performance		AS5678/EN4905 grades
Data Retention	R2	Data corruption should be detected
Quality of Documentation	D1	Traceability is important
RF Performance Variation	P1	
Bend Durability	M2	Parts typically rigid
Sheer Force	S2	
Temperature Cycling	TC1	Refer: AS5678/EN4905
Temperature and Humidity	TH1	
Other Special Process Requirement	OV	Vibration. A5678/EN4905 describes several additional environmental tests

Manufacturing Quality Grade: R2-D1-P1-M2-S2-TC1-TH1-OV

EXAMPLE 2: Luggage Tagging for Tracking

Quality Requirement	**Performance Criteria**	**Notes**
RF Performance		IATA requirements
Data Retention	R2	Short lifetime
Quality of Documentation	D2	
RF Performance Variation	P2	
Bend Durability	M2	Tags remain loosely attached
Sheer Force	S2	
Temperature Cycling	TC2	

Temperature and Humidity	TH2	
Other Special Process Requirement	-	

Manufacturing Quality Grade: R2-D2-P2-M2-S2-TC2-TH2

Food & Perishables

Food and perishable goods require RAIN RFID tags that can withstand harsh conditions such as cold-chain environments, including refrigeration and freezing, or microwave and heat, without compromising performance. Tags must maintain readability despite condensation, temperature fluctuations, and packaging variations.

EXAMPLE 1: Product Tagging for Cold Chain Applications

Quality Requirement	**Performance Criteria**	**Notes**
RF Performance		Will be defined in future work packages of this group.
Data Retention	R2	
Quality of Documentation	D2	
RF Performance Variation	P2	
Bend Durability	M2	
Sheer Force	S2	
Temperature Cycling	TC1	
Temperature and Humidity	TH1	
Other Special Process Requirement	-	

Manufacturing Quality Grade: R2-D2-P2-M2-S2-TC1-TH1

EXAMPLE 2: Microwave Safe Tags for Instant Foods

Quality Requirement	**Performance Criteria**	**Notes**
RF Performance		Will be defined in future work packages of this group.
Data Retention	R2	
Quality of Documentation	D2	

RF Performance Variation	P2	
Bend Durability	M2	
Sheer Force	S2	
Temperature Cycling	TC2	
Temperature and Humidity	TH2	
Other Special Process Requirement	OM	Microwave Safe

Manufacturing Quality Grade: R2-D2-P2-M2-S2-TC2-TH2-OM

Automotive

Some use cases in the automotive sector expose RAIN RFID tags to harsh conditions, including vibration, extreme temperatures, and mechanical stress. In these cases, tags must demonstrate long-term reliability, withstand environmental cycles, and maintain performance during assembly and operational use. Having stated that, many tagging cases in the automotive sector are purely for the tracking of parts and assembly of the car, and the tags often have no purpose once the car is built.

EXAMPLE 1: Tire Tagging (in tire use case)

Quality Requirement	**Performance Criteria**	**Notes**
RF Performance		ISO 20909 (criteria) ISO 20912 (method)
Data Retention	R2	Long product lifetime.
Quality of Documentation	D3	
RF Performance Variation	P2	
Bend Durability	MX	Must tolerate tire deformation Requirements depend on the embedding.
Sheer Force	SX	(whenever applicable) Must tolerate scraping in the production process.

Temperature Cycling	TC3	Must last through typical tire lifetime, cannot be replaced easily.
Temperature and Humidity	TH3	
Other Special Process Requirement	-	

Manufacturing Quality Grade: R2-D3-P2-MX-SX-TC3-TH3

EXAMPLE 2: Windshield Tagging

Quality Requirement	**Performance Criteria**	**Notes**
RF Performance		Long read ranges in road tolling cases. The windshield material and attachment location are critical.
Data Retention	R2	
Quality of Documentation	D2	
RF Performance Variation	P1	
Bend Durability	M3	
Sheer Force	S2	
Temperature Cycling	TC2	Assume attached inside
Temperature and Humidity	TH2	
Other Special Process Requirement	-	Sunshine, UV, rapid aging.

Manufacturing Quality Grade: R2-D2-P1-M3-S2- TC2-TH2

Background and Contributors

Since its founding in 2014 the goal of the RAIN Alliance has been to accelerate global market adoption of RAIN RFID technology. From humble beginnings, the market has now grown to the extent that over 50 billion RAIN tag chips were shipped in 2024 and it's projected that over 100 billion RAIN tag chips will be shipped in 2028. RAIN technology is relied upon to provide massive business benefits in a wide variety of industry sectors including Retail, Luxury goods, Healthcare, Pharmaceuticals, Logistics, Automotive, Aviation and Manufacturing.

It's crucial for end user confidence in the technology that quality standards remain reliably high. The industry needs quality standards which are open, common and consistent around the world coupled with certification capabilities with adequate capacity and throughput speed to meet global demand as the industry continues to scale.

To facilitate this, the RAIN Alliance established a Manufacturing Quality Workgroup in August 2024 to develop the necessary global, openly available, transparent specifications and processes against which certification can be performed. We expect this document to underpin ongoing end-user confidence in technology and ensure technological companies all around the globe can prove their manufacturing quality in a consistent and transparent manner. This document is developed within the RAIN Manufacturing Quality Workgroup.

This document is developed within the RAIN Manufacturing Quality Workgroup. All Workgroup members listed in the table contributed to the shaping, editing, and review of this document.

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About the RAIN Alliance

The RAIN Alliance unites 200+ global organizations to drive universal adoption of RAIN technology. Serving as the collective voice of the industry, the Alliance influences policy and drives regulatory progress to realize a world where every item connects to the Internet of Things using RAIN technology.

RAIN (also known as UHF RFID) is a standards-based wireless technology built on the ISO/IEC 18000-63 protocol that enables businesses and consumers to identify, locate and authenticate billions of items connected to the Internet of Things, helping organizations improve traceability, effectiveness, and sustainability.

For more information, please visit therainalliance.org