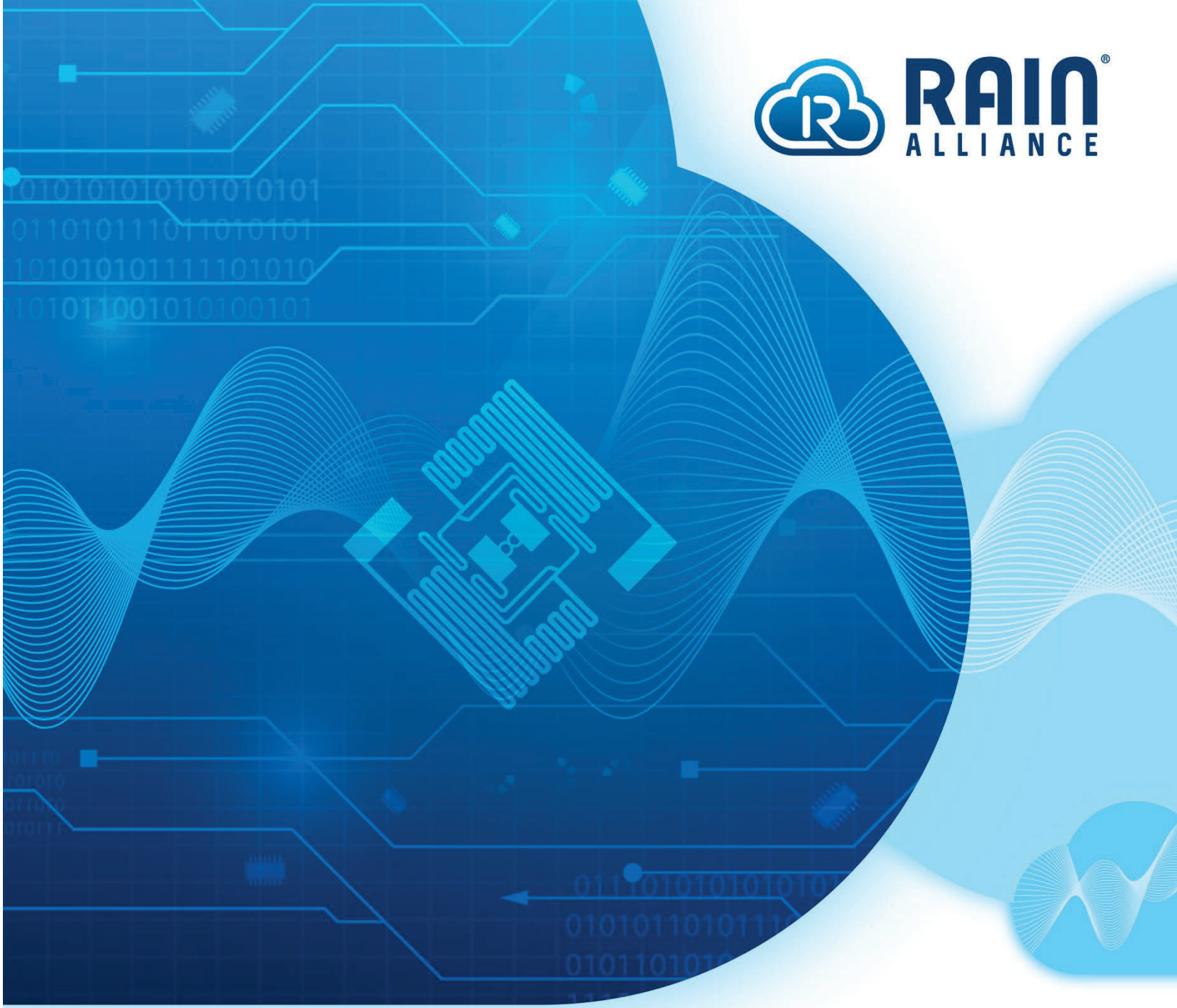

# RAIN Manufacturing Quality Guideline

**V 1.0 – May 2025**

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# 1. Foreword

A key goal of the RAIN Alliance is to accelerate global market adoption of RAIN RFID technology (hereafter "RAIN technology").

RAIN—an acronym derived from RAdio IdentificatioN—is is a standards-based technology that utilizes the ISO/IEC 18000-63 air-interface protocol (also known as GS1 UHF Gen2) that allows readers to capture unique identifiers and optional other data from the data carrier, RAIN tags.

Each RAIN tag must be encoded utilizing controlled numbering practices. This ensures each tag is unique and identifiable within a specific ecosystem, meaning that even in busy read zones, a RAIN reader can pick out the correct, intended tag each time, avoiding error.

The RAIN market has now grown to the extent that over 52 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. A recent RAIN Alliance survey confirms that 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.

The goal of this document is to provide a quality assurance and certification framework which can be relied on by end users around the world to ensure they have access to an ever-increasing volume of tags to meet their growing demand.

The quality assurance and certification framework outlined in this document can be established based on recognized quality audit standards, such as ISO 9001. While ISO 9001 provides a general foundation for quality management systems, this guideline defines specific requirements and

recommendations tailored to RAIN technology. These RAIN-specific quality measures are intended to supplement general audit practices and should be incorporated into the scope of quality audits to ensure consistent performance, reliability, and interoperability of RAIN products.

# 2. Scope of Document

The scope of this document, developed by RAIN Alliance Quality Manufacturing Workgroup, is to address the pressing need for open and transparent guidelines related to manufacturing quality in the RAIN technology industry.

It is important to remember throughout that this document is focused on manufacturing quality, not on tag performance characteristics where there are a number of existing methodologies defined by other organisations. Table 1 clarifies this.

*Table 1*

| | Manufacturing Quality | Performance Characteristics |
|---|---|---|
| **Focus** | How well the tag is made. Can it be made repeatedly (month after month etc) | How well the tag functions |
| **Measured by** | QA metrics, process control, defect rates | Read range, sensitivity, response time |
| **Influences** | Durability, consistency, reliability | Data accuracy, tracking efficiency |
| **Critical for** | Scaling production, minimizing failure | Supply chain visibility, operational RoI |

This framework aims to resolve gaps in current standards, enhance customer trust, and establish a scalable foundation for potential future ISO or ANSI certification.

The framework will cater to the whole RAIN ecosystem, including raw material suppliers, tag manufacturers, and end-users, ensuring impartiality, scalability, and broad applicability.

The framework is a comprehensive document outlining:

- Specific metrics used to assess and ensure the RAIN tag quality;
- Methodologies and procedures to consistently evaluate and benchmark quality metrics across the industry;

- Guidelines for self-assessment and third-party audits, applicable to entities of all sizes and covering the entire manufacturing process, from raw material selection to final product testing.

What is in scope of this document:

- Reliability of a tag in operation
- Tag performance uniformity and performance predictability
- How to communicate tag specification and quality
- Best practices on how to ensure professional manufacturing and high quality

What is out of scope of the current document:

- Label graphics and printing quality
- Label adhesive quality
- Tag encoding practices and numbering systems
- IC security, authentication and cryptographic features

Note: This document establishes guidelines for the RAIN tag ecosystem, described above, to support the enhancement and maintenance of RAIN tag quality. It is intended as a reference and even though it imposes requirements to the party that wishes to adhere to it, it does not impose any regulatory authority. It should be noted that the content of this document can be updated and/or revised based on the industry evolution and requirement.

# 3. 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, system designers, and end-users. The guideline ensures impartiality, scalability, and broad applicability to support consistent and reliable quality assurance across the entire RAIN tag supply chain.

# 4. Definition of Terms

This chapter defines the terminology and abbreviations used in this document that may be unfamiliar or unclear to non-technical readers.

| | |
|---|---|
| **ACP** | Short for Anisotropic Conductive paste. One of the most common terms used for the electrically conductive adhesive type that is typically used to attach RAIN chips to the tag antenna in rapid succession using heat and pressure. |
| **End user** | Parties or individuals making use of tags in their application. Sometimes also referred to as Brand Owners. |
| **Pre-series** | A limited early production run of a new product. Often produced with production recipes or a level of testing different or more extensive than used in the final production series. |
| **Quality** | Refers to measurable and quantitative criteria to ensure uniform standards for RAIN tags |
| **Tag Assembly** | Process of assembling a tag from its individual components, typically the microchip to the antenna using the ACP. |
| **Thermode** | A heating element in a bonding machine providing both pressure and heat to cure the chip bonding adhesive |

# 5. How to Claim Conformance

The cornerstones of production quality are the demonstrable quality of the products and the production process, and efficient implementation of production quality, exception handling and product change management processes.

Some end-users prefer the concept of 3rd party certification, while others welcome a self-certification approach or even a hybrid approach.

This document enables either approach to be taken, so that end-users have a choice. Ultimately in order to enable the market to scale and for end-users to have access to larger volumes of tags which meet their quality requirements the underlying requirements are the same and the outcome should be the same regardless of the certification approach or the 3rd party certifier used.

## 5.1. Requirements

To claim conformance, a company shall document their own product specification, production process, production testing practices, acceptance criteria, and practices for managing process and

product changes and production issues. In addition, it is imperative to list the persons responsible for these processes.

Quality driven corporate culture takes in continuous performance assessment, and improvement of production processes. To claim conformance, a company shall commit to continuous improvement, collect and store performance data, and document the events and changes in the production process. The documentation and proofs shall be prepared and stored for each product, assessed as part of auditing, and used as the basis for the auditor's quality statement.

The quality definition outlined in this guideline applies specifically to RAIN inlay production. It focuses on **measurable and quantitative** criteria to ensure uniform standards. The following are the key quality metrics:

1. **RF Performance**
   RF (Radio Frequency) performance measures how effectively the RAIN inlay transmits and receives radio signals. Common measurements include minimum tag turn on power over frequency (sensitivity curve) and tag backscatter power over frequency (RSSI - Received Signal Strength Indicator).

2. **Consistency**
   Consistency evaluates the uniformity of performance and quality across all RAIN inlays within a production batch and between different production batches. Common measurements include multi-frequency test points and batch RF performance.

3. **Yield Rate**
   The yield rate represents the percentage of RAIN inlays produced that meet quality standards and are free from defects. Common measurements include yield rate per roll and yield rate per batch.

4. **Reliability**
   Reliability assesses the ability of RAIN inlays to consistently perform their intended function over time and under conditions specified for their intended application. Common measurements include functional, mechanical and performance tests under varying environmental conditions in test environments accelerating the tag ageing.

5. **Appearance**
   Appearance examines the physical quality and visual presentation of the RAIN inlay. Common measurements include surface cleanliness, epoxy size, and slitting position.

## 5.2. **Self-Certification**

Manufacturers may self-certify their tag production quality as long as they adhere to the guidelines outlined in this document. The manufacturer shall prepare a short version of their quality statement stating which of the processes described in this guideline are in place, how have they been adapted, what are the numerical targets and limits, and how have they been adapted. This kind of document could be as compact as 2-3 pages if well prepared and should outline a chain of quality procedures from design to continuous deliveries.

Whenever the manufacturer presents conclusions drawn from statistical data, they should openly present where they are basing their claims. In addition, the manufacturer shall provide documented evidence of continuous testing and record keeping to verify compliance with these requirements if required by their consumer.

In the case of self-certification, an auditor shall be appointed from within the company to review and challenge the data and processes, and when ready, to prepare and sign an auditing statement.

## 5.3. **Independent 3rd Party Certification**

Manufacturers may choose to expose their quality processes, result data and operating staff to a third-party auditor. In this approach the industry expert auditor shall have access to and dig in all the aspects of quality touched by this guideline and prepare his statement, observations and future improvement points. This process can also involve sending product batches to an authorized third-party lab for tag quality evaluation. The third-party lab must adhere to the guidelines outlined in this document and provide documented evidence of compliance as required by the manufacturer, auditor, or consumer.

One of the main goals in this approach is that the end user doesn’t need to be an expert in tag production processes and challenges. Instead, the end-user can rely on the statement of the auditor. The independent 3rd party product qualification may be conducted at two distinct levels. The reproduction of the design during the operational lifetime of the product is controlled by the Manufacturer Quality System. The Manufacturer is responsible to identify the need for retesting when changes in the manufacturing processes are applied.

The manufacturing process requirements as laid out in the Manufacturing Quality standards is in this qualification scheme and integral part of the certification.

## 5.4. **Periodic Re-Evaluation**

Manufacturers shall conduct a periodic evaluation of their quality processes and product quality limits and statistics, either through self-assessment or by an authorized third party as outlined in Sections 5.3 and 5.4. This evaluation is typically performed every 12 months.

In the case of self-certification, the evaluation shall include at a minimum bringing their quality statement up to date, controlling if previous development points have been addressed and recognizing future development points.

In the case of a 3rd party audit, the auditor shall make a light re-audit addressing among others matters adherence and/or changes to processes, past development points, future development points, numerical quality targets, proof of actual product quality. Again, relying on an external test lab if deemed needed by the auditor. A new revised auditor statement should be the outcome. This is also the document that should be public to customers and partners to show continuing conformance.

# 6. Processes to Ensure Quality

This chapter describes industry best practices in RAIN tag production quality and includes guidelines on product management through managing changes in the process or product.

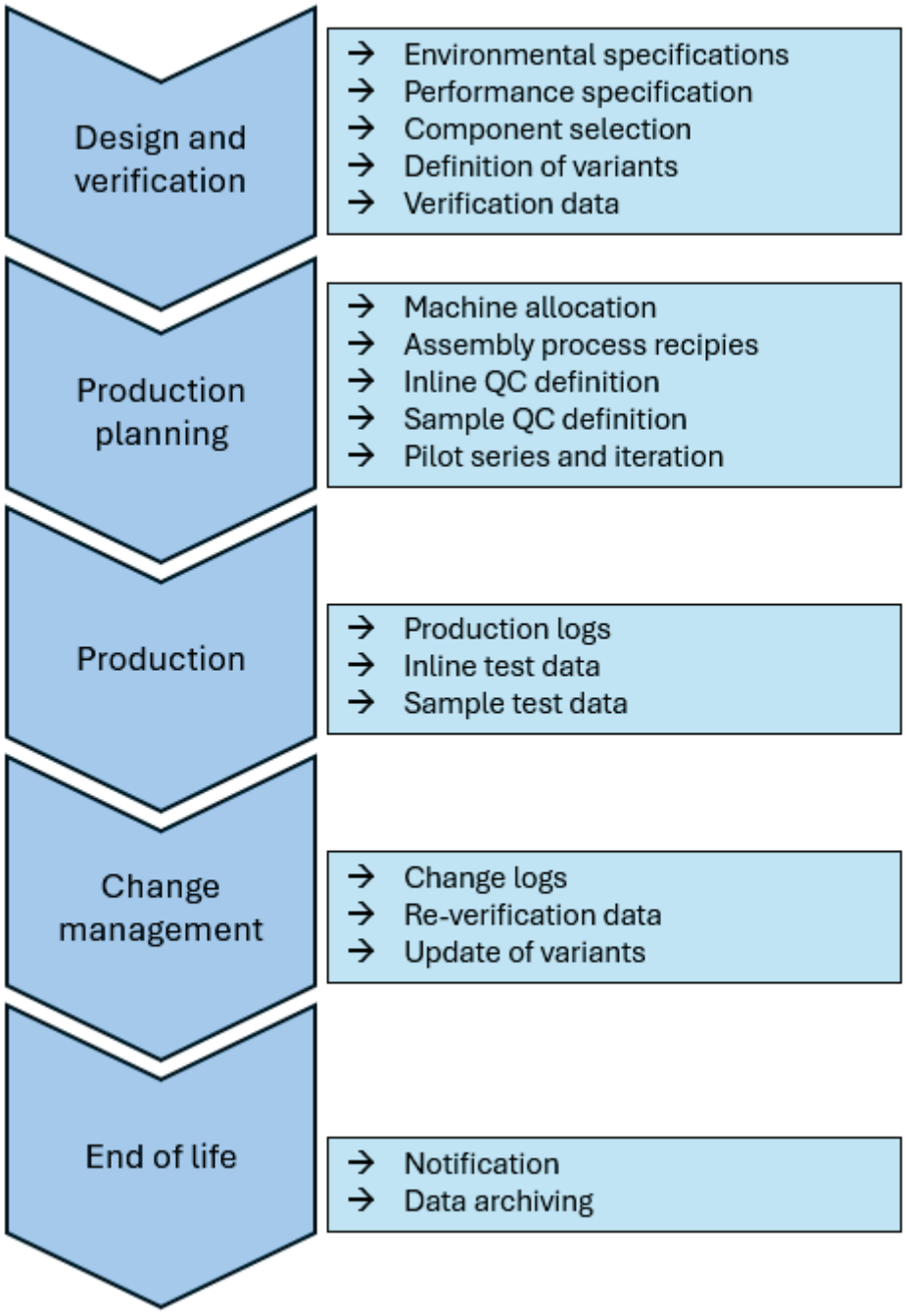



*Figure 1. Typical lifecycle of a tag product showcasing different stages as far as production, quality, testing and specifications are considered.*

Specific to RAIN tags, production quality is about meeting the specifications (RF performance and environmental durability) for every manufactured and quality controlled tag product with a known high probability, and backing this up to the customer by controlled processes, inline and offline measurements and in a transparent fashion.

## 6.1. Manufacturing Process Quality Control Plan

The primary goal is to ensure that products are manufactured consistently and meet the required quality standards by outlining procedures, standards, and responsibilities. Figure 2 represents an overview of the Quality Control (QC) plan.

| Prepare | Process | Process | Check Items | Specification | Standard | Methods |
|---|---|---|---|---|---|---|
| 1 | | Antenna IQC | 1. Dimension<br>2. Adhesion, Bending HF antenna<br>3. RF/electrical resistance | 1. Correct dimension<br>2. Good etching<br>3. Pass cross-cut test<br>4. Bonding test<br>5. Correct RF and electrical resistance | | 1. Visual Inspection<br>2. Cross-cut tester<br>3. Bending tester<br>4. HF tester |
| 2 | | Chip IQC | 1. Quality Certification, Appearance | 1. No contamination<br>2. Chip on tape | | Visual Inspection |
| 3 | | ACP IQC | 1. Appearance, QTY | 1. Certificate<br>2. Color<br>3. Shelf life<br>4. No bubble<br>5. No contamination | | Visual Inspection |
| 4 | | ACP Check (prior to use) | 1. Thaw Time<br>2. Shelf Life<br>3. Environment Exposure | 1. Thaw Time<br>2. Shelf Life | | Visual Inspection |
| | 1 | Epoxy | 1. Pressure<br>2. Amount (parameters)<br>3. Dispensing position | 1. Correct parameters<br>2. Correct dispensing position | Drawing | In-line Inspection |
| | 2 | Bonding | 1. Chip position | 1. Chip position | Drawing | In-line Inspection |
| | 3 | Curing | 1. Time<br>2. Pressure<br>3. Temperature<br>4. Bump Imprint<br>5. Chip surface | 1. Die shear force<br>2. Setting of Time, Pressure & Temperature | Drawing | In-line Inspection |
| | 4 | Test | 1. Protocol<br>2. Read distance, frequency, and Q factor | Bad mark position<br>Bad mark size | Drawing | 1. HF reader and tester<br>2. UHF reader and tester |
| | 5 | Winding | 1. Core height & OD<br>2. Winding force<br>3. Roll External diameter<br>4. Telescoping<br>5. Roll QTY | 1.Core spec.<br>2.Winding tension<br>3.Roll External diameter<br>4.Telescoping<br>5.Roll QTY | Drawing | In-line Inspection |
| | 6 | FQC | 1. Reading Test<br>2. Appearance<br>3. Dimensions | 1. Reading Test<br>2. Appearance<br>3. Dimensions | | Visual Inspection |
| | 7 | Packaging | 1. Correct product<br>2. Correct QTY | 1. QTY<br>2. Packing materials | Custom | Visual Inspection |

*Figure 2. Typical manufacturing Quality Control plan.*

## 6.2. **New Product Introduction**

To ensure product quality, a manufacturer shall establish procedures for "Product Design and Development" with defined test metrics and acceptable thresholds. The procedure typically includes stages of "Product Requirement," "Evaluation," "Design," "Pre-series" and "Monitoring." (Figure 3). The design and engineering team will produce a new product design and product specification for bonding workshops to follow.

Manufacturer shall define and document RF performance specifications, environmental specifications, how they're tested, and the acceptance criteria.

In the pre-production phase, the manufacturer shall produce a series of the product and perform comprehensive quality control testing to verify that the produced products fulfil production specifications.

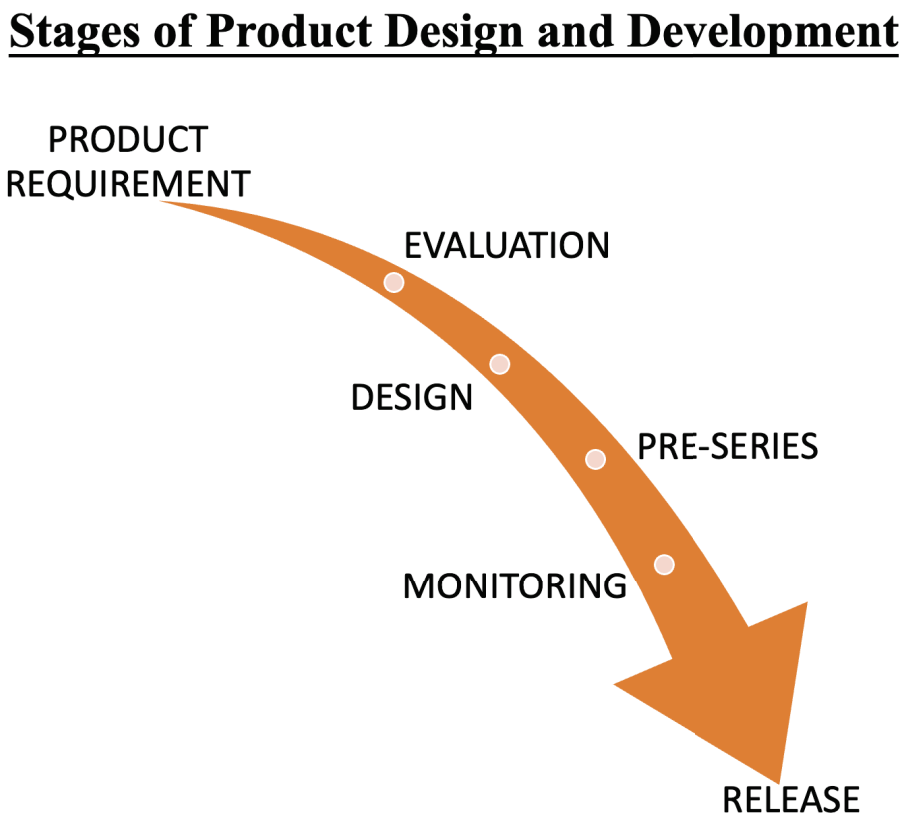



*Figure 3. Typical representations of stages involved in Product Design and Development.*

**1. Requirement Stage**

- Objective: Define customer and market requirements.
- Key Activities:
    - Receive and document requests from customers or the Sales team.
    - Analyze market needs and trends.

**2. Evaluation Stage**

- Objective: Assess feasibility and define initial specifications.
- Key Activities:

- Conduct a feasibility study (technical, cost, and timeline evaluation).
- Draft initial product specifications based on requirements.

**3. Design Stage**

- Objective: Develop prototypes and validate design compliance.
- Key Activities:
  - Create inlay designs and prototype samples.
  - Perform RF Performance Testing to ensure alignment with specifications.

**4. Pre-Series Stage**

- Objective: Validate production readiness and finalize product specs.
- Key Activities:
  - Conduct trial production runs for process verification.
  - Execute required tests:
    1. RF Performance Test
    2. Consistency Test
    3. Yield Rate Evaluation
    4. Reliability Test
    5. Appearance Inspection
  - Finalize product specifications upon successful validation.

**5. Batch Monitoring Stage**

- Objective: Ensure consistent quality before full release.
- Key Activities:
  - Monitor pilot batches for compliance.
  - Confirm all tests and checks are passed.
  - Approve product release upon meeting quality standards.

## 6.3. **Management of Product and Process Changes**

When managing a product, its manufacturing process, quality, and routine production, the following practices typically apply:

- Only previously qualified material suppliers are used.
- Only previously approved manufacturing lines are utilized.
- Only pre-selected key recipes are followed for tag assembly.

To prepare for future planned or unplanned changes in the manufacturing process, the manufacturer shall document potential events that may trigger a re-qualification process, along with the corresponding tests required for each event.

Typical changes in a tag assembly process that may require re-qualification include:

- Assigning a new maximum line speed
- Introducing a new formulation of the chip adhesive
- Using a new antenna and/or substrate material supplier
- Changing curing parameters such as time, temperature, or pressure
- Rearranging the tag layout to accommodate a new pitch, orientation, or number of lanes

Other modifications impacting product performance or process consistency

The manufacturer shall list for each of the triggering changes, which of the product quality tests shall be re-run, and to perform the tests a sample run of a significant statistical size should be produced. The tests will most probably be composed of a selection of RF-performance tests, mechanical tests, optical inspections, and environmental and aging tests.

Whenever a change is accepted, the manufacturer shall decide whether a new external variant of the product is born. If not, it is then expected that the current product specifications are still met and it is an internal variant or a new version of such.

## 6.4. Traceability and Record Keeping Process

Traceability is the ability to track a product's origin, history, and movement across the supply chain, from raw materials to final delivery. Record Keeping is the systematic documentation of all quality-related processes, inspections, and decisions to provide evidence of compliance and continuous improvement.

Both traceability and record keeping are fundamental principles in quality management, ensuring that every product, material, and process step can be tracked throughout the production lifecycle. This enables organizations to identify, analyze, and resolve quality issues efficiently.

Manufacturers shall have their own standard operating procedures in place for each stage of the production, customer interaction, equipment calibration and maintenance, and process modifications. Manufacturer shall have a procedure clearly defining how to keep the track of the

records. Manufacturer shall demonstrate their traceability log and documentation to the auditor if necessary.

## 6.5. Handling Defects and Feedback Process

To ensure product quality, a manufacturer shall establish procedures to systematically identify, address, and prevent production issues while maintaining compliance and continuous improvement. Manufacturers can follow the guidelines provided in ISO 9001 standards such as Corrective and Preventive Actions, Risk Identification & Mitigation, Process Control, and Nonconforming Product Handling.

Management of defects and feedback processes are crucial to ensure quality of the RAIN Manufacturing process. Manufacturers shall have regular customer feedback discovery and evaluate their product. Manufacturers shall have reviewed the customer feedback within the management review and take appropriate actions to address any complaint. To do so, manufacturers shall have an effective communication process and data analysis procedures.

## 6.6. Recognizing Product Variants

A RAIN tag model—defined by a specific antenna design and often marketed under a common name—is typically offered with a selection of multiple RAIN IC options. These ICs, particularly when sourced from different manufacturers or product generations, often differ in impedance.

As a result, minor adjustments to the antenna design are frequently required to maintain performance. In addition, the ICs vary in features such as die size, bonding requirements, supported protocol commands, and more. Given these differences, tag variants incorporating different ICs should, by default, be treated as distinct products—unless there are strong, well-justified reasons to consider them equivalent.

When examining a product in greater detail, beyond just the antenna design and selected IC model, there exists a long list of parameters that may vary. These changes can lead to the creation of internal product variants—hidden from the customer—as well as external variants that must be communicated to the customer. External variants should be clearly distinguished through unique order codes, specific markings, or product documentation, among other means.

A non-exhaustive list of some common differences which may be a trigger for the decision to create a variant of either type are:

- Different tag material supplier
- Different level of readiness, i.e. dry inlay, wet inlay

- Different IC adhesive provider
- Different manufacturing site
- Different accept/reject criteria
- Different process recipes of the IC attach process
- Different wafer processes, e.g. “plasma etched dies from a 12” wafer vs. laser diced from a 8” wafer”
- Different brand/technology IC attach machine
- Different subversion IC

It is the responsibility of the tag manufacturer to maintain a comprehensive list or diagram of all existing product variants, along with clear documentation on which variants are publicly disclosed. Public variants must be visible in product documentation, order information, and delivery records.

The manufacturer shall establish and maintain documented quality processes that define the actions required when a new internal or external variant is created. These processes must also specify the criteria that must be met before any new variant can be released to the market.

When product specifications are declared, they may vary between variants and shall apply strictly to the specified external variant. Any statements about performance uniformity or statistical spread are assumed to refer only to the specified external variant unless explicitly stated to apply across multiple or all variants. Furthermore, all specifications for a particular external variant must be valid for all internal subvariants within that external variant. If this condition cannot be met, a new external variant must be created to ensure specification accuracy and consistency.

# 7. Test Methods

Test methods are divided into two main branches. Firstly, inline testing of each tag and secondly, sample-based offline testing.

Inline testing time is limited by the production throughput and aims at collecting as much information as possible in the often-small time window available. Under the high time pressure, inline testing is typically a compromise and only includes testing for the most critical parameters of each tag produced. Inline testing, by definition, applies to tests done to products that will or even possibly will end up to a customer. This automatically excludes any destructive or damaging tests such as chip shear tests, bending tests, or environmental survivability. In most cases it is automatically assumed that inline tests are performed at production speed and for each product equally. This contrasts with sample based testing.

Offline testing includes a more thorough testing inspection of a sample batch taken from the production lot, potentially also containing destructive tests. Whereas inline testing forms a quality gate that each and every tag needs to pass, offline testing provides a means for more thorough characterization of the lot quality. To ensure the quality, there should be a correlation between inline and offline testing results.

## 7.1. Inline Testing

| Parameter | Explanation | Actions |
|---|---|---|
| RF | RF performance verification | Go/no go testing at least one or more different carrier states. Optionally the tests may include Sensitivity, Frequency tuning, Backscatter (RSSI) |
| Traceability | Collect tracking data | Recommended when possible:<br>Read/Record TID<br>Read/Record EPC |
| Optical | Optional documentation of die attach process | Presence of glue or not glue<br>Chip position (X/Y)<br>Chip rotation<br>Glue dosing |

**Requirements for inline testing**

### 7.1.1. RF Sensitivity Testing

RF performance testing refers to a process of evaluating and defining functional attributes and capabilities of a tag. This includes assessing its ability to perform under various conditions, such as durability, readability, signal strength, range, environmental resistance (e.g., temperature, moisture), and any other factors that might affect its performance.

Tag sensitivity commonly refers to how much power is required to activate the tag. Tag sensitivity defines how far the interrogator can energize the tag, and variation can affect end-user experience through ambiguity of the resulting read range. Sensitivity variation may be a result of different factors including failed chip bonding, for example. Low quality bonding causes the contact impedance to change from optimal, higher RF loss at the contact, and changes in tag tuning.

**Requirements for inline test system**

To ensure the accuracy and repeatability of RF test, the following aspects shall be considered:

- Test equipment shall be calibrated regularly based on the industry standards to ensure consistency and comparability of results
- An appropriate antenna or coupling element should be used which allows singulation of tag tested and preferably provides a coupling mechanism which resembles operation in the far field

Repeatability, and reproducibility of results is of key importance. As quality should be traceable throughout the chain from the manufacturer to the end user (brand owner), it is important that quality including performance can be verified, and it is independent of the used test equipment.

**Test recipe definition**

While for tag/inlay/label performance testing in the far field, international standards like ISO/IEC 18046, ISO/IEC 18047 define metrics procedures to obtain absolute values of performance, in near field this is not possible. Different equipment (especially various coupling elements) used for inline testing in the near field will result in different results and different inline test recipes.

Minimum tag activation power in the near field is typically different from the minimum tag activation power in the far field. Tags may also be detuned due to the antenna and possible other objects and materials in the near-field. Relative sensitivity variations observed in the near-field typically correlate well with changes in the far-field. Thus, the test recipe and the approval criteria can typically be defined according to a typical tag test result (real or statistical reference result) and the variation allowed.

The manufacturer shall perform sample-based tests in the far-field to document the correlation with the near-field inline tests and adjust the test recipe accordingly.

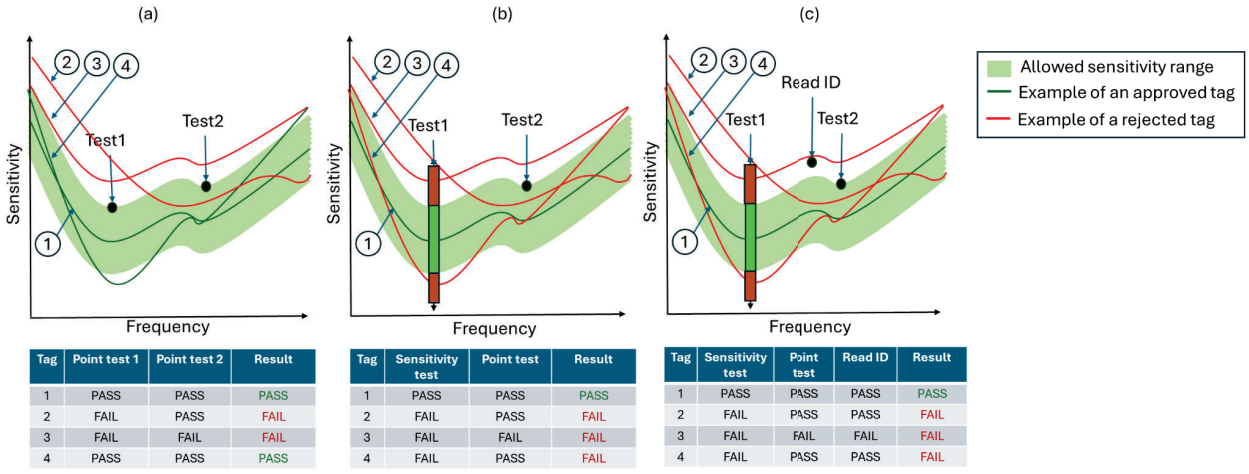
**Inline testing for every tag**

The purpose of inline testing is to put every tag through a quality gate and to allow rejection of deviant units. The manufacturer shall implement inline tag sensitivity gating as part of the production process to validate sensitivity of each tag and monitor quality variation. The testing shall be performed at least after chip bonding.

The simplest way to validate tag sensitivity and tuning is to test tag readability at one or more points at different frequencies. Test frequencies and power levels are defined to match with production variance allowed, and tags failing to meet the criteria rejected. Test points may be positioned, for example, at resonance frequencies to allow detection of defect tags with tuning shifts (for practical example, see Figure 4 (a)).

To increase diagnostic capability of the inline tests, testing may include measurement of tag sensitivity. Should the time budget allow, it's recommended to include sensitivity testing at least on a single frequency to allow detection and processing of low performing tags and to enable monitoring of quality variations in the process. In the example of Figure 4 (b) below, the other point test is replaced with a sensitivity test. This allows monitoring sensitivity variation and rejecting tags which are too sensitive.

The third aspect of inline performance testing is about collecting tag identification information to be able to trace test data back to the individual tag produced. In the example in Figure 4 (c) below, an ID read task has been added with the point and sensitivity test. Test frequency and power has been chosen so that it also allows bad quality tags to be identified. In some cases, it might be beneficial to set the criteria tighter and replace a point test with ID read to save testing time.




| Tag | Point test 1 | Point test 2 | Result |
|---|---|---|---|
| 1 | PASS | PASS | PASS |
| 2 | FAIL | PASS | FAIL |
| 3 | FAIL | FAIL | FAIL |
| 4 | PASS | PASS | PASS |

| Tag | Sensitivity test | Point test | Result |
|---|---|---|---|
| 1 | PASS | PASS | PASS |
| 2 | FAIL | PASS | FAIL |
| 3 | FAIL | FAIL | FAIL |
| 4 | FAIL | PASS | FAIL |

| Tag | Sensitivity test | Point test | Read ID | Result |
|---|---|---|---|---|
| 1 | PASS | PASS | PASS | PASS |
| 2 | FAIL | PASS | PASS | FAIL |
| 3 | FAIL | FAIL | FAIL | FAIL |
| 4 | FAIL | PASS | PASS | FAIL |

*Figure 4. Inline test case examples - (a) a simple test with 2 points at resonance frequencies, (b) the other point replaced by sensitivity test, and (c) test added with ID reading at an assumable safe carrier power and frequency point.*

### Sample testing

While the inline sensitivity testing makes up the quality gate used to accept/reject tags produced, the manufacturer shall also perform more detailed characterization for samples acquired among tags produced to provide more detailed information of the quality. The manufacturer shall specify the frequency of the sampling. Each first article inspection, each production run and each lot are typical example sampling frequencies.

The manufacturer shall record the sampling test results and link the sample test data recorded with the inline test results.

### 7.1.2. Optical Tests

Optical testing can be performed inline and used to detect and process malicious units during production. The tests are camera-based, and image recognition is used to detect issues at different phases of the process.

**Antenna integrity**

Since RAIN tag antennas are typically 1-layer constructions, imperfections in the structure can be detected by comparing the image on a functional reference. Typical imperfections to detect are cracks, shorts, faulty forms, and surface imperfections which may all affect antenna performance.

**Chip placement**

RAIN chips typically have 2 contact pads, which need to be in contact with the antenna. Typical placement issues are XY-positioning and placement angle, which may be detected by image recognition.

**Glue dosing and curing**

Good quality chip bonding is critical for the tag performance and glue dosing and curing play a critical role in the success of the process. Image recognition can be used to monitor the shape and other characteristics of the glue dot after applying and curing to detect issues.

## 7.2. Offline Testing

**Requirements for offline testing**

| Parameter | Explanation | Required actions |
|---|---|---|
| Mechanical stress | Durability of tags against:<br>sheer<br>pressure<br>bending | Manufacturer is responsible for collecting enough test data to prove by measurements initial performance against product specifications and being able to maintain performance over time by sample-based, offline tests.<br>The manufacturer shall define the frequency of sample-based, offline tests, and the tests relevant to the product. |
| Environments | Tolerance of temperature cycling<br>Tolerance of extreme | Manufacturer is responsible for collecting enough test data to prove by measurements initial performance against product specifications and being able to maintain performance over time by sample-based, offline tests.<br>The manufacturer shall define the frequency of sample-based, |

| | | |
|---|---|---|
| | temperatures | offline tests, and the tests relevant to the product. |
| RF | RF performance verification of sensitivity, tuning, backscatter | Manufacturer is responsible for collecting enough test data to prove by measurements initial performance against product specifications and being able to maintain performance over time by sample-based, offline tests.<br>The manufacturer shall define the frequency of sample-based, offline tests, and the tests relevant to the product. |
| Reliability | Reliability documents if tags will work throughout their life-cycle. | Manufacturer is responsible to perform tests to ensure the reliability of tags. Sampling Frequency is determined by the manufacturer, depending on the product volume. |

### 7.2.1. Mechanical Tests

Mechanical testing aims at verification of the mechanical durability of the tags. Stress and shear may damage the structure of the tags, and mechanical tests are performed to validate the durability of the tags. Typically, the weakest links in the tag structure are chip bonding and the chip, which may crack due to pressure applied, or because of bending, stretching or scraping.

Mechanical tests are destructive, and materials may be tested until the limit of braking. Typically, the test arrangement includes providing a controlled force repetitively, increasingly, or both, and monitoring when and if the tag breaks. Monitoring can be made by, e.g., measuring tag sensitivity or checking the health of the tag after applying mechanical stress, or indirectly by detecting changes through the stress applicator.

A difference should be made between mechanical stress tests simulating stress during converting (bend tests) and mechanical stress tests simulating stress during label life cycle after application by the brand owner (shear tests or other tests that are used to test label surface quality e.g. Sutherland Rub Tester or similar).

**Bend Test**

Bend testing is mechanical testing of RAIN tags where they are inflicted with different stress modes such as clockwise and counterclockwise bending over rollers, pull tension, and nip (compressive) pressure. One of the purposes is to see how durable the tags are when they are subjected to other machines down the value chain, such as converting, encoding and printing. Another purpose is to see how likely the tags are to survive actual use, wear and tear.

Bend testing is a process step often associated with the validation of process changes and new material verification, such as new ACPs, ACP curing recipes, new inlay substrate and new ICs. The target values to pass are something that each manufacturer needs to set for themselves suitable for the tag type, materials used, expected process, and intended use.

The manufacturer shall apply adequate processes to make sure the tags produced and delivered are healthy and perform according to specs when delivered to a customer. Bend testing is not required but is recommended particularly for products with specifications for mechanical stress.

Figure 6 presents principles of bend testing. In bending test (Figure 5A), the material is fed around a roller which causes vertical bending for the chip and the bondings. Bending angle is controlled by the diameter of the bending roller.  In pressure test (Figure 5B), the material is passed between two rollers which cause a controlled pressure force on the tag. In pulling test (Figure 5C), the track tension is controlled to cause a controlled stretching force for the tag. This can be achieved e.g., using a dancing arm tightening the material with a controlled force.

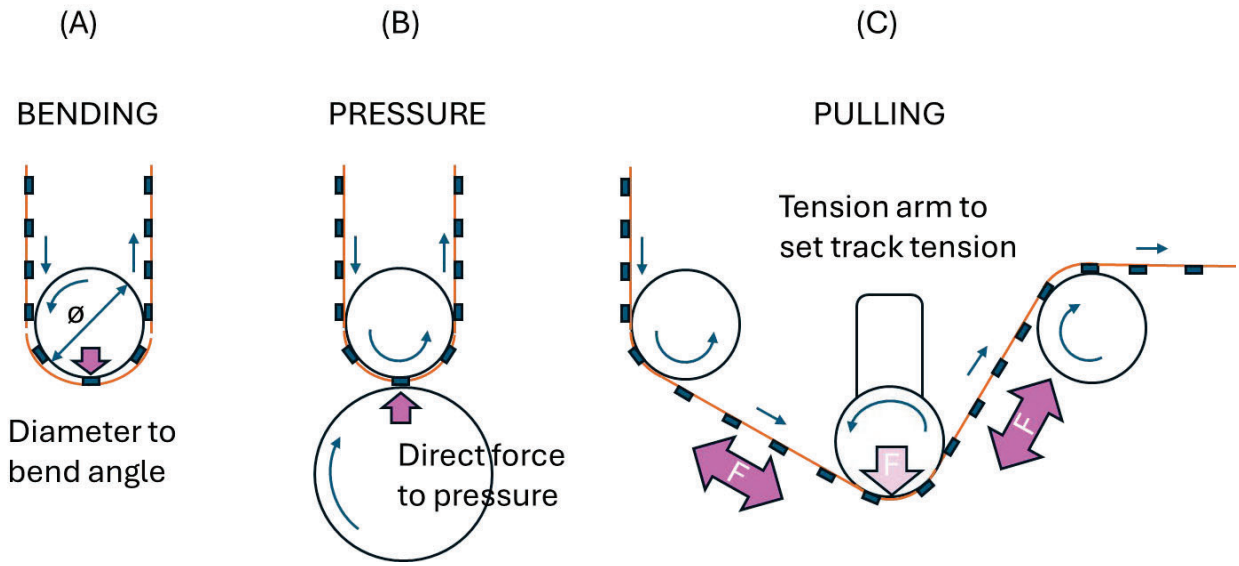



*Figure 5. Principles of bend testing (A) by bending using a roller with a certain diameter, (B) by applying pressure using a nip roller, and (C) by tension which can be adjusted e.g., by a dancing arm with force feedback.*

There is commonly used equipment for bend testing in the market where tags can be tested for RF performance after or while they have been subjected to stress for a preselected number of revolutions through the system.

**Die Shear Test**

Die shear testing is a common way to verify how strongly the IC has been bonded onto the antenna. In the test, the tag is fixed down while a chisel tool is moved across the ICs position thus ultimately

detaching the IC. As a function of the movement the force it pushes the IC with is monitored. The peak force value is the recorded shear force.

Standards such as MIL 883E can be used as a basis to find a suitable limit value. Also Bonding machine manufacturers, IC manufacturers and the ACP producers can be consulted for a good baseline. It should be noticed that shear test values are rarely 100% transferable between different shear testers. In addition, many practicalities will affect the outcome, such as how the label is fixed down, or for how long has the ACP post-cured, among others.

A common good practice is to test at least 30 samples or the number of thermodes in the machine, whichever is largest. In the end, the label manufacturer should set his own limit and follow for consistency in sample tests and re-check at predetermined events such as first article inspection, or process changes.

Shear force values should always be specified based on how the measurement is done, stating important parameters and factors, as they can have significant influence on the results. For example, a sample fixation method that does not prevent tilting of the die during the shear test may introduce a stress pattern that differs from a completely rigid fixation.

Important parameters for die shear testing:

- Shear force measurement tool manufacturer and type
- Time between inlay production and measurement
- Fixation method, for example:
    - Mechanical clamp
    - Vacuum plate
    - Glue on rigid carrier
    - Double-sided sticky tape on flexible carrier
    - Combination of different methods
- Shear speed
- Shear height above antenna or antenna substrate level

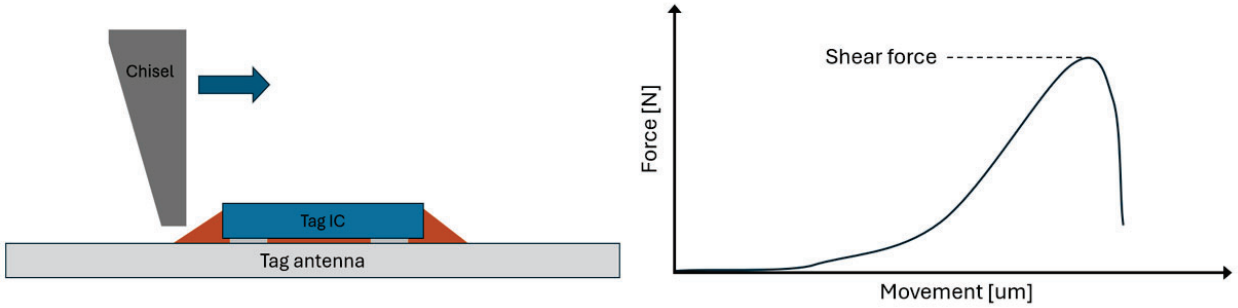



*Figure 6. Principles of die shear testing.*

**Calculation:**

Die shear stress [MPa = N/mm²] $\sigma = \frac{F}{A}$ Die shear force [N]

Chip base area [mm²]

### 7.2.2. RF Variation

**RF performance variation verification (production line / Site)**

Tag sensitivity varies between samples of the same tag type due to inconsistencies in the manufacturing process. This variation can be determined by placing the tags on an RF-neutral material and measuring their response threshold 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.

Following the Central Limit Theorem (CLT), a minimum sample size of 30 randomly selected tags from a population of 300 tags (per production line/site) is recommended to ensure that the sample mean of the measured values approximates a normal distribution. This provides a statistically sound basis for comparing tag performance. The metrics reported include both the minimum activation power threshold and the backscattered tag signal response measured in accordance with ISO/IEC 18046-3 and the Tag Performance Parameters and Test Methods (Version 1.1.3).

The theoretical read range should be calculated using the Effective Radiated Power (ERP) of 33 dBm ERP as defined in the ETSI lower band (which results in the lowest theoretical read ranges). Theoretical read ranges at higher EIRP/ERP powers can then be estimated by multiplying the calculated read ranges by the higher factor as specified in FCC (36 dBm EIRP) or ETSI upper band (36 dBm ERP).

The estimation of the theoretical backscatter range must take into account the sensitivity of the reader, the gain of the receiver antenna and any cable losses in the system to ensure an accurate representation of the expected field performance.

When a specific RAIN tag model is manufactured on different production lines or at different manufacturing sites, performance verification must be performed independently for each line or site. This ensures that variations introduced by different configuration or process conditions are properly identified. Ideally, the variation in performance measured over the verified frequency spectrum should be small, providing stable performance within a product. In addition, the tag manufacturer should document known variations and be able to provide values for these variations when requested by a customer or third-party auditor.

**RF performance variation (reference materials)**

RAIN tags are typically applied directly to products, and their nominal performance is significantly influenced by the dielectric properties of the materials to which they are mounted. Variations in material composition, density, and moisture content can all affect the electromagnetic behaviour of the tag, leading to shifts in resonance frequency, changes in read range, and reduced signal strength. Therefore, it is essential to evaluate tag performance not only in free space or on RF-neutral materials but also in representative on-product conditions to ensure reliable operation in real-world applications.

To guarantee comparable results among different testing entities, a standardized set of reference materials with defined dielectric properties should be established. While it is not feasible to represent the full range of materials to which UHF transponders may be applied, the selected reference materials should reflect the electromagnetic characteristics of commonly tagged surfaces such as cotton, cardboard, plastic, and rubber. These reference substrates should be readily available on the open market, yet exhibit stable and well-documented dielectric behaviour to ensure consistent and repeatable measurement conditions across different laboratories and testing setups

The test follows a similar methodology as described in the previous section, but instead of using an RF-neutral mounting surface, the RAIN transponder is affixed to the selected reference material to evaluate its performance under more representative dielectric conditions.

As an example, the graph below (Figure 7) shows the read range (y-axis) changes using different reference materials in the range of 800 MHz to 1000 MHz (x-axis). This is a tag model with the same IC, but other factors clearly affect the response over frequency.

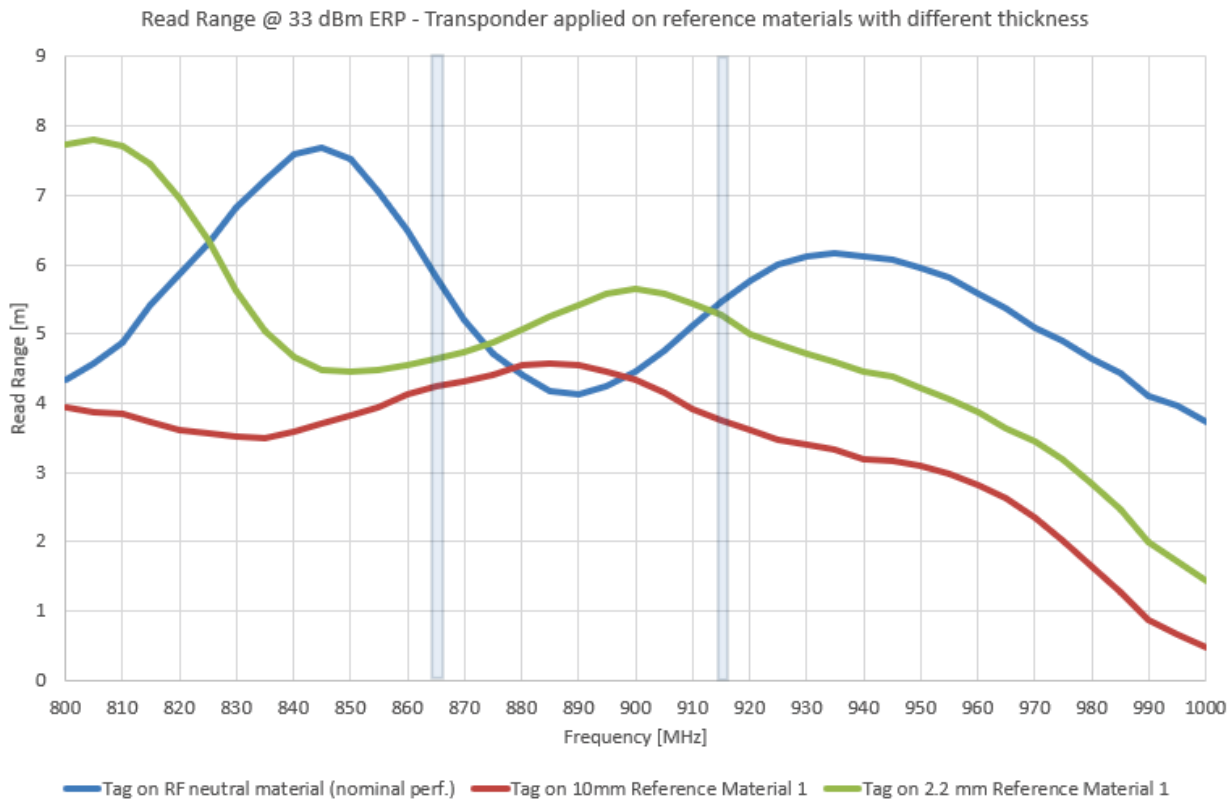



*Figure 7. An example to demonstrate how a transponder applied on different reference materials with different thickness could change the read range.*

### 7.2.3. **Reliability**

Reliability for RAIN tags refers to the consistent and accurate ability of the tag to be read and identified by a reader within a specific environment and under defined conditions. It is crucial for ensuring that the tags perform as expected throughout their lifecycle.

Key aspects of reliability are durability and performance consistency. Durability is a way to ensure the RAIN inlay survives during its lifetime without failure. While reliability is not about tag-to-tag performance consistency, it focuses on the overall durability and functionality of the product.

To ensure reliability, various tests are conducted. These tests are commonly asked by the customer. If customers request additional tests like vibration, UV exposure, gamma radiation exposure, or static discharge, manufacturers must define a validation plan and may use third-party labs for testing.

The commonly used tests to ensure reliability of RAIN tags are Environmental tests.

### Sampling and Frequency

Sampling Frequency is determined by the manufacturer, depending on the product volume. Sampling is typically based on various factors, with a common size being 144 samples. Examples include periodic checks (1 or 2 per year). Manufacturers need a plan and justification for the frequency.

### Environmental tests

Environmental tests are offline evaluations conducted on RAIN tag samples under various conditions to determine how well they perform after exposure to those environments. There are two commonly recognized tests to be performed:

### Temperature cycling test (JESD22-A104-F)

This test is conducted to determine the resistance of a part to extremes of high and low temperatures, and to the effect of alternating exposures to these extremes. The test conditions are -40°C...+85°C (-40°F.... +185°F) and total 100 cycles.

### Temperature and humidity test (IEC 60068-2-67)

This test is conducted to determine, in an accelerated manner, the resistance of component parts and constituent materials to the deteriorating effects of the high humidity and heat conditions typical for tropical environments. Test conditions are +85°C (+185°F), humidity 85% RH and test duration 168 hours.

To conduct Environmental tests, take samples from the production lot (ie, ANSI Z1.4 table or set number of samples.) Perform frequency sweep for all samples. After exposing samples, perform an RF test and record sensitivity differences per tag to verify the effect of these climatic tests on the tags. Test is a pass if sensitivity changes are less than <X> dBm across all frequencies tested.

Note: While the described tests (e.g., JESD22-A104-F and IEC 60068-2-67) are established standards for evaluating the durability of electronic components, it is important to note that simulating climate conditions using extreme exposures such as +85 °C and 85 % RH over 168 hours would disproportionately penalize paper-based, sustainable label materials. Especially in the context of expanding Digital Product Passport (DPP) applications— there is a clear need to develop more use-case-specific and differentiated test scenarios that better reflect realistic environmental exposures across the product lifecycle.

# 8.Accepting/Rejecting Tags

This chapter discusses production quality testing and the acceptance process. It describes how to implement a credible testing process while allowing high production throughput and provides recommendations for data to be recorded and how to manage defects.

Manufacturers shall define their sample-based testing criteria. This might include the frequency of sampling and the type of the tests.

The manufacturer shall have an inline testing process in place where every tag is tested for functionality and performance. The primary purpose of the inline performance testing is to catch tags with abnormal sensitivity and/or tuning by RF tests. Other inline tests, such as optical verification are also possible, such as verifying chip placement or bonding quality by images and additional metrics based on the images. Any further tests such as mechanical tolerance or environmental tolerance are extremely hard to realize in an inline fashion as they often stress or otherwise compromise the tags so that they cannot be used in customer deliveries anymore.

Whenever tags are rejected in production, a yield of less than 100% occurs. 100% meaning that all tags are accepted and 0% meaning that all tags were failed. Primarily the yield is therefore a measure of efficiency, and it shows how little waste is created.

Yield can also happen in several stages. First, the wafer will have a yield. The IC manufacturer has marked in a wafer map the ICs that can be used and the ones that should not be used as they didn't meet the IC manufacturer's specifications. If the tag manufacturer so chooses, he can be even more picky about what to use from the wafer and what not. In any case, the wafer will produce an IC yield. Next, when ICs are bonded and tested on a substrate, inlay material typically, and again a portion of the products will fail, and we have another yield. This can either be an internal measure, if only the passed ones are kept and shipped to the customer as 100% QC passed tags. This will most probably be communicated to the customer as a 100% yield. In many cases, also the failed tags are shipped as it can be costly to remove and replace them in some processes. In such a situation the failed tags shall be identified in a manner communicated and known to the customer. Either they are marked, the ICs physically crushed or punched out, a list of IDs/TIDs that should not be used is provided with the roll or some other method used to help the customer to avoid the failed tags and to see the yield of the batch.

So, as a measure of quality, yield is quite ambiguous without any further explanation. A high yield can be either a proof of high and repeatable quality, or just the result of very loose criteria where anything is accepted. The true process yield can also often be hidden from the customer and already cleaned up and the created waste hidden. When communicating yield, and explanation of criteria and associated process shall always be briefly mentioned.

Internally, any significant change in yield, especially towards worse, should always be reacted to and possibly examined if an alert level is reached.

# Background and Contributors

Since its founding in 2014 the goal of the RAIN Alliance has been to accelerate global market adoption of RAIN 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.

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# About the RAIN ALLIANCE

The RAIN Alliance enables organizations to improve traceability, effectiveness, and sustainability by simplifying, standardizing and accelerating the adoption of RAIN technology through global collaboration and innovation. Its global membership consists of companies and organizations which develop and deploy RAIN technology solutions across many vertical markets.

RAIN is a standards-based wireless technology that enables businesses and consumers to identify, locate and authenticate billions of items connected to the Internet of Things. RAIN technology uses the ISO/IEC 18000-63 protocol (also known as GS1 UHF Gen2).

**For more information, please visit therainalliance.org**