Practical Performance Expectations for Smart Packaging

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Executive Summary

There seems to be a common expectation among radio frequency identification (RFID) newcomers that putting an inexpensive, passive smart label on a box will create an accounting nirvana. Boxes will be read automatically at any and every point where trading partners have installed a reader. But, reality comes crashing in when a pallet of cases comes through a dock door for the first time and only a handful of the labels can be read. Suddenly disappointment, bitterness and buyer's remorse sets in.

This paper will address the expectations that are initially set when dealing with UHF RFID systems in the retail supply chain. First, it will look at realities surrounding read rates and how to address the gaps based on available time and money. It will then address choosing the right tags and then provide practical and effective metrics and test methods to consider. Finally, it will provide recommendations on setting realistic expectations for the RFID system.

Setting expectations

What seems like a straight-forward process – simply adding a tag with a little radio to each box and set the tuner (i.e. reader) to the right station – can result in a variety of problems with reading smart labels.

Several factors can cause these problems, but it generally comes down to the fact that a lot of work is being done with very little power. Remember that the passive smart labels used in retail supply chain applications, like all passive labels, do not have their own power supply and rely on energy absorbed from the reader. A number of sources can interfere with these weak signals: ambient RF interference, the physics of the product being tagged, and even simple damage from handling are some common causes of unreadable smart labels.

There are a several product types that come very close to 100% readability. Generally, those are products with little or no moisture, no metal, and low density. This works well if the items being tracked are clothing or cereal, but the majority of products are not as easy to read.

Products loaded on pallets present greater difficulty as readers try to identify tags located internally on the pallet. While RF is not strictly a line-of-sight technology, the weak signals are easily shielded and while a label can easily be read on the outside of a pallet, it is likely that it will be unreadable inside a loaded pallet.

Reality and what you should expect

It has become obvious to many that have already deployed an RFID system that 100% tag reads at every read point is not a realistic expectation at this level of maturity for the technology. However, it is reasonable to expect labels to be read *somewhere* in the system because there are normally several read points in the supply chain. Some examples on read points are:

- Manufacturer's factory line
- Manufacturer's shipping dock
- Distributor's receiving and shipping dock
- Retailer's DC
- Retail store's receiving dock
- Retail store's stock room exit point
- Retailer's box crusher

A particular "RF-challenged" product may only achieve a 50% read rate at an individual point, but according to probability theory, it will be read at least once in the process 97% (approximately 1 in 33 products will be missed) of the time in a system with only 5 read

points end-to-end. The table below shows the effect of either increasing tag readability or number of read points. Simply increasing the tag readability from 50% to 60% increases the odds of reads for 5 read points to 99% (1 in 100 products). Increasing readability to 90% gives the much sought after five-nines level of performance- 99.999% (1 in 100,000 products) in 5 read points.

Read Points	Systemic read probability					
1	40%	50%	60%	70%	80%	90%
2	64.000%	75.000%	84.000%	91.000%	96.000%	99.000%
3	78.400%	87.500%	93.600%	97.300%	99.200%	99.900%
4	87.040%	93.750%	97.440%	99.190%	99.840%	99.990%
5	92.224%	**96.875%**	**98.976%**	99.757%	99.968%	**99.999%**
6	95.334%	98.438%	99.590%	99.927%	99.994%	100.000%
7	97.201%	99.219%	99.836%	99.978%	99.999%	100.000%
8	98.320%	99.609%	99.934%	99.993%	100.000%	100.000%
9	98.992%	99.805%	99.974%	99.998%	100.000%	100.000%
10	99.395%	99.902%	99.990%	99.999%	100.000%	100.000%

The first issue that needs to be addressed is how to improve overall system performance. There are many choices including finding a more sensitive tag, upgrading the interrogation zones with more sensitive antennae, or adding additional interrogations zones that will get reads at another location. The choices are endless. The decision is finding the one that is right for each organization and the stated objectives.

Keep in mind for goods that are shipped to and from overseas may be read with interegators using different frequencies. For example Europe uses frequencies around 860MHz while North America uses 915MHz and Japan uses 960MHz. When applicable, tag performance should be measured in different frequency ranges. A global tag, such as those based on Texas Instruments' Gen 2 die or strap, applied to a globally optimized reference design, can solve several problems when goods have to cross borders.

The quickest resolution may be to purchase better tags if the goal is trying to save money and time. If time is not an issue and cost of investment is a concern, then looking beyond the current installation to increase optimal performance could be considered. This can be achieved through upgrading antennas to get better read performance or even adding intelligence to the enterprise software. In the end, the decision is based on what meets the end user's objectives.

Baseline of initial performance

If a company is upgrading to Gen 2 or changing to a new type of tag, then it is assumed that an existing system is in place. It is important to understand how well the current system is performing, so the first action is to establish a baseline.

The first step is to choose several attributes of the current process that will be useful. These can be time to perform task, read rates, interrogation zone efficiency, human intervention required, etc. The next step is to measure these factors over a period of time in order to completely understand the process. Once a good measurement of these factors has been established, there is now a baseline to compare the upgraded process and demonstrate the improvements, or recommend changes to address whatever issue may be occurring.

Performance analysis of new tags

Now that the baseline has been established, the next step is to measure the performance of the newly installed system. How does it compare to the benchmark and expectations?

It is a good idea to get measurable trending metrics around the performance of the new system. These new metrics can be compared to the old system to see if there is a significant impact on performance. If this is a completely new installation, now is the time to capture measurements of the improved process as described in the above baseline step.

The best way to measure the success of this change is to understand how the new dynamics that were introduced (i.e. new tags, new antennae, new system) affected the overall performance.

Selecting the right tools (tags) for the job

It is the responsibility of retail suppliers to ensure that their tags are readable. Relying solely on generic tests that compare tag performance in free air and an anechoic chamber will not solve the needs for consistent reads on RF-challenged products. In fact, application-specific testing should be performed. Each supplier's product mix and process will dictate their own unique labeling needs. Here are just some of the variables:

- Product material and density
- Primary packaging materials
- Secondary packaging materials
- Label positions may be limited by automated equipment
- Pallet size and case quantity

Obviously the vast majority of users will not want to test the entire universe of available smart labels for all of their products. This test method would be far too time consuming and expensive to perform. There will be some natural factors to allow testers to narrow down their test set:

- Preferred vendors
- Available label sizes or form factors

Validating performance metrics – Tags

So what level of performance is “good enough”? Until there is more hard data and major retailers complete a detailed business analysis, that question will be difficult to answer. For now, the more pertinent question is, “How do I measure performance and what parameters are most important?” Once those measurements are defined, minimum requirements can be determined with statistics and probability theory.

Most performance data and comparison tests focus on reading tags. Unless tags are pre-programmed when they are purchased, tags will also need to be written. For automated, high-speed production lines, write speed will also be important. If tags are not able to be written quickly enough with the standard Gen 2 writing method of 1 block (or 16 bits) at a time, you may need a tag that supports the optional block write and erase features to write multiple blocks in one operation. This method is more efficient than the standard method.

It is important to test a statistically significant number of labels and products. Testing a limited quantity may not provide enough information to determine the production level performance. While the exact number of “statistically significant” is the matter of some debate, a good rule-of-thumb starting point would be 20-30 tags. If time and resources permit, hundreds of tags would provide more accurate measurements of consistency and performance tolerances. It is also helpful to test labels from different production runs to get a measurement of consistency. A sophisticated test would also include design of experiments methodology that is outside this paper’s scope.

Another practical consideration for testing is to perform the test in a realistic environment. While third party comparison tests performed in an anechoic chamber are good for first pass estimation of performance, smart labels will not be used to collect data in a sterile lab. They will be used in warehouses and retail environments with multiple sources of RF interference, metallic structures, and unique building configurations. If testing in the actual production or shipping sites is impractical, then try to find a “dirty” lab that is located in a realistic warehouse environment.

Static testing

Static testing is the simplest, most easily reproduced, and most comparable test method. Simply stated, the label is tested with a reader and a single antenna while stationary in free air, on an RF neutral material, or on actual products. Generally, the

goal is to determine either the optimal label location on a product or the read range/sensitivity of a particular label/product combination.

Some manufacturer claims and independent lab reviews suggest that tag model X can be read from 30 feet away. While this sounds wonderful, it needs to be examined more carefully. Common portal read zones are anywhere from 10 ft across (five ft from read point) at four MPH, down to three ft across (1.5 ft from read point) at 600 FPM. If these read zones are right next to each other, a very strong tag like this could confuse the system by causing unintended reads. This creates a need to be cautious and select a tag appropriate for the read zones that are being used.

Static test methods:

Test Type	**Basic Description**	**Metric**	**Pros**	**Cons**
Read Range	Label is placed in free air in a large room or outdoors and it is moved towards the reader antenna to determine the furthest distance it is readable.	Max. Read/Write range Distance (ft or m)	Metrics are easily understood and interpreted by laymen Requires no special test setup or equipment	Highly dependent on environment and equipment Test results from different setups not directly comparable
Label Sensitivity	Typically performed in an anechoic chamber to block outside RF interference. The power is gradually reduced from the reader to determine the lowest power level at which the label is readable/writeable.	Minimum Power (dBm or W)	Very controlled and different tests are comparable Can be correlated to read range	Requires specialized equipment and technical expertise
Sweet Spot Testing	Product is stationary and the label is moved around on the product to determine the optimal placement location on the product.	Several methods	Provides valuable information on RF-challenged products Can be done manually or be automated	Time consuming to perform on many products and smart labels

Dynamic testing

Dynamic testing adds a new level difficulty by putting the labeled products in motion. This is an effective way of testing because it provides users with a strong set of metrics for the real world performance of labels on the intended products. It is also the most accurate way for users to determine the best labels for their particular application.

Dynamic test methods:

Test Type	Basic Description	Metric	Pros	Cons
Conveyor Test	Labeled products are placed on a conveyor (typically a conveyor ring) at speeds up to 650 ft/min (3.3 m/s) and passed through a reader portal with 3-4 antennae	Reads per pass Success percentage*	Results are directly applicable to real world application Multiple products can be tested simultaneously	Test results from different setups not directly comparable
Pallet Portal Test	A pallet full of labeled product is passed through a portal with 2-8 antennae	Reads per pass Success percentage *	Results are directly applicable to real world application	Test results from different setups not directly comparable Requires a lot of product and labels
Shrink Wrap Tower or Turntable Test	A pallet full of goods is placed on a turntable and spun around as it is being shrink wrapped for shipping .This is a common step in the shipping process and a logical point to count product.	Success percentage *	Results are directly applicable to real world application	Test results from different setups not directly comparable Requires a lot of product and labels

* Read success percentage- the number of passes through a portal with at least 1 registered read.

Dynamic testing requires more expensive test equipment that is typically housed in a large area. Independent test houses are often used to provide the equipment and expertise.

Tag Hazards

Mishandling of the tag population can cause many problems in the system. Tags, like any electronic component, should be handled with care. Employees that throw boxes of label supplies may be costing 10% or more of useable label stock. Employees handle the tags when they are at their most fragile, prior to adhesion on the product. The best

way to protect the integrity of the tags is to ensure that everyone who handles these devices is educated and handles the tags with care.

It is also a good idea to check the material handling devices for proper maintenance. Many box clamps or appliance clamps have rubber bumpers. These inevitably become worn and can present a hazard to your tags due to breaks in the surfaces causing "pinch points" on product. Ensuring that there is enough pressure to hold the product in these devices is critical, but this needs to be balanced with good sense. The more pressure that is applied to the product, the higher chance there is of damaging it and the attached tag.

It is critical to ensure that freight carriers adhere to the shipping guidelines laid out for them. A carrier who is improperly handling the product can damage tags by crushing them, scrubbing them, or getting them wet.

For products that are subject to rough handling during shipping, tag ruggedness should be a consideration during design selection. There are labs that perform this kind of testing, or if the time and equipment are available to the organization, limited tests can be performed internally.

Conclusion

Even though some may start out with unrealistic expectations, with proper testing and verification, each business can choose the right RFID tags and labels that work best in their environment.

The keys to separating hype and reality are:

- Empirical testing in realistic environments
- Test methods as close to actual practice as practical
- Measurements that are relevant for the given applications

Above and beyond the performance of individual smart labels is the performance of the system to pick up tags at as many read points as possible to help fill in the information. A properly designed information system, coupled with well-tagged assets or goods, will ensure excellent visibility and the realization of the true value RFID can drive. The key to success may be finding a qualified solution provider with the experience and expertise to assist in testing and evaluation. Working closely with an integrator during the project can make this process faster and more efficient.

In the end, each business is unique and should choose a complete system that will meet its objectives and provide the most value.

About the Authors

Chris Cook is an application specialist with Texas Instruments™ RFid Systems, a business unit of Texas Instruments Inc located in Plano, Texas. In this role, he works with UHF customers to provide real world application advice and testing as well as technical assistance. With more than ten years of experience, Chris has extensive expertise in designing and managing electronics packaging solutions.

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About Texas Instruments RFid™ Systems

Texas Instruments is the world's largest integrated manufacturer of radio frequency identification (RFID) transponders and reader systems. Capitalizing on its competencies in high-volume semiconductor manufacturing and microelectronics packaging, TI is a visionary leader and at the forefront of establishing new markets and international standards for RFID applications.

About RFID4U

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