The Global Language of Business

TIPP Solutions Providers Support Tool

Provides an understanding of the Technical Details of Tagged Item Performance Protocol

Release 1.0, Approved, Dec 2016

Document Summary

Document Item	Current Value
Document Name	TIPP Solutions Providers Support Tool
Document Date	Dec 2016
Document Version	1.0
Document Issue	
Document Status	Approved
Document Description	Provides an understanding of the Technical Details of Tagged Item Performance Protocol

Contributors

Name	Organisation
Pfeifferling, Goetz	Impinj, Inc.
Stanton, Matt	Impinj, Inc.
Arredondo, Ricardo	Checkpoint Systems, Inc.
Cooduvalli, Umesh	Checkpoint Systems, Inc.
De Taeye, Robin	r-pac International Corp.
Arguin, Paul	r-pac International Corp.
Reese, Chris	Smartrac Technology Group
Hoentsch, Marc	Smartrac Technology Group
Stromberg, Petteri	Smartrac Technology Group
Ramzan, Mo	SML
Liu, Jeremy	SML
Nyswonger, Margaret	Stealth Network Communications
Partanen, Juho	Voyantic Ltd.
Ainasoja, Teemu	Voyantic Ltd.
Tulimaa, Harri	Voyantic Ltd.
Buehler, Stephan	TexTrace AG
Compaijen, Jasper	Nedap
Haak, Danny	Nedap
Heiv, Plamen	Embisphere
Jerome, Lemay	Embisphere
Costalonga, Fabiola	Flextronics Instituto de Tecnolgia
Ivansson, Gunnar	Learningwell AB
Preishuber-Pflugl, Josef	CISC Semiconductor GmbH
Quide, Uwe	Tailorit GmbH
Ras, Hennie	Operations Visibility Solutions (pty) Ltd
Schneider, Andreas	GCS Consulting GmbH
Wilkerson, Brett	MSM Solutions

Name	Organisation
Williamson, McLeod	RR Donnelley
Miguita, Camilo	CRYSTAL
Hubert, Hans Peter	Moods of Norway
Le Lay, Gwenn	Korben Smart Retail – RFID
Leitz, Roland	Adler Modemarkte AG
Pletcher, Ian	John Lewis
Polworth, Sarah	Saks Fifth Avenue
Wilkens, Joachim	C&A SCS
Haibin, Li	Qingdao Redcollar Group Co, Ltd
Purcell, Bebe	VF Corporation
Von Grone, Christian	CBR Fashion Operations GmbH
Patton, Justin	Auburn University
Ehrenberg, Isaac	Auto-ID Labs at MIT
Peterlik, Alexander	GS1 Austria
Sloan, Sean	GS1 Australia
Vaid, Ankur	GS1 Australia
Costa, Luiz	GS1 Brasil
Matsubayashi, Roberto	GS1 Brasil
Li, Zhimin	GS1 China
Liu, Jia	GS1 China
Lu, Marisa	GS1 China
Luo, Yan	GS1 China
Perng, James	GS1 China
Qiang, Jiang	GS1 China
Yan, Ruoyan	GS1 China
Wen, Carrie	GS1 China
Tabares, Katherine	GS1 Columbia
Luet, Carole	GS1 France
Pang, Edward	GS1 Hong Kong
Ho, Tsz Lung	GS1 Hong Kong
Asano, Koji	GS1 Japan
Kimura, Kazuna	GS1 Japan
Mama, Noriyuki	GS1 Japan
Moritani, Reiko	GS1 Japan
Shimizu, Yuko	GS1 Japan
Amador, Sandra	GS1 Mexico
Grabia, Michal	GS1 Poland
Van der Linde, Fiona	GS1 South Africa

Name	Organisation
Buskenfried, Jonas	GS1 Sweden
Reid, Paul	GS1 UK
Morgan, Gena	GS1 US
Javick, Patrick	GS1 US
El-Leithy, Hussam	GS1 US

Log of Changes

Release	Date of Change	Changed By	Summary of Change
1.0	Dec 2016	P Dietrich	Initial publication

Disclaimer

GS1®, under its IP Policy, seeks to avoid uncertainty regarding intellectual property claims by requiring the participants in the Work Group that developed this **TIPP Solutions Providers Support Tool** to agree to grant to GS1 members a royalty-free licence or a RAND licence to Necessary Claims, as that term is defined in the GS1 IP Policy. Furthermore, attention is drawn to the possibility that an implementation of one or more features of this Specification may be the subject of a patent or other intellectual property right that does not involve a Necessary Claim. Any such patent or other intellectual property right is not subject to the licencing obligations of GS1. Moreover, the agreement to grant licences provided under the GS1 IP Policy does not include IP rights and any claims of third parties who were not participants in the Work Group.

Accordingly, GS1 recommends that any organization developing an implementation designed to be in conformance with this Specification should determine whether there are any patents that may encompass a specific implementation that the organisation is developing in compliance with the Specification and whether a licence under a patent or other intellectual property right is needed. Such a determination of a need for licencing should be made in view of the details of the specific system designed by the organisation in consultation with their own patent counsel.

THIS DOCUMENT IS PROVIDED “AS IS” WITH NO WARRANTIES WHATSOEVER, INCLUDING ANY WARRANTY OF MERCHANTABILITY, NONINFRINGMENT, FITNESS FOR PARTICULAR PURPOSE, OR ANY WARRANTY OTHER WISE ARISING OUT OF THIS SPECIFICATION. GS1 disclaims all liability for any damages arising from use or misuse of this Standard, whether special, indirect, consequential, or compensatory damages, and including liability for infringement of any intellectual property rights, relating to use of information in or reliance upon this document.

GS1 retains the right to make changes to this document at any time, without notice. GS1 makes no warranty for the use of this document and assumes no responsibility for any errors which may appear in the document, nor does it make a commitment to update the information contained herein.

Table of Contents

1 Introduction

While UHF RFID has exploded in popularity over the past 5 years -- especially so for retail apparel inventory use cases -- adoption rates are anticipated to accelerate exponentially in the coming years. Moreover, the vast majority of UHF RFID is used in retail inventory tracking applications, particularly so for apparel over the past few years. Owing to its relatively low impact on detuning RF tags and relatively high margins, clothing has proven a natural starting point for large-scale item-level RFID deployments. Much effort has been spent in this space using RFID to establish more accurate and timely inventories of items on sales floors and back rooms, as compared to those traditionally performed by combining hand counts and tabulated register receipts. Though apparel tracking is likely the most common large-scale use case at present, it represents just a tiny proportion of the possible applications. Passive UHF RFID technologies permit a universe of disparate applications, including: locating tagged items with increasing levels of resolution, passively configuring electronic devices, wirelessly transmitting sensor data, enabling enhanced security applications and more. In fact, in the realm of the “Internet of Things”, UHF RFID is a bedrock technology whose ability to enable digital communications with every day “things” is virtually limitless.

The TIPP is intended to provide a standardized method for classifying the *RF-quality* (i.e. readability) of a single and/or small grouping of tagged-item(s). TIPP has established a correlation between tagged item performances in a controlled lab environment and expected performances of those same items in the natural world. Establishing these general linkages is crucial for solutions providers so they can provide thoughtful guidance on optimizing the tag selection component of the total RF system design.

The TIPP must not be understood to be a definitive “cookbook” mapping grades to use cases. While it is true that WiFi, GPS, cellular and many other RF-based industries have generated and iteratively refined predictive models of performance based on years of careful data collection and subsequent sophisticated mathematical analysis, UHF RFID has not reached that level of maturity. In the RFID space a similarly extensive corpus of models has yet to appear, though the industry is actively working to address this. In passive UHF the number of factors affecting performance compound because the tag derives its operating power from the wireless communications link itself. Moreover, the interaction of tags in close proximity to each other and to the items to which they are attached adds exponential complexity. While the mathematical equations exist to describe completely all of these interactions, it is economically and physically impractical to model at these deep levels. Consequently, passive UHF systems can perform unpredictably when solutions providers fail to carefully engineer all components in the system.

2 Document Intent

This purpose of this technical document is to identify both *why* and *how* the TIPP should be used. The authors hope readers will gain from this document:

- A basic understanding of how an RFID solution is a *system* of critical, mutually-interacting parts
- An appreciation for how the TIPP can be used to optimize one of the most important aspects a of carefully engineered, high performance RFID system: the tagged-items.
- The encouragement to rapidly incorporate TIPP into their supply chains to foster a logical, sound approach to classifying the performances of tagged-items based on a common classification system and collectively-understood vocabulary

3 Document Assumptions

1. The authors anticipate readers of this document having experience in RFID and or related fields.
2. In this document the authors have intentionally neglected to address the full mathematical rigor required for a deep physical understanding of UHF RFID. Equations may be simplified and therefore imprecise. The authors will simplify to enable faster comprehension and in the interest of brevity.

3. The authors sometimes resort to analogies and similes, but fully admit such language analogues can be imperfect and can overly-simplify complex phenomenon. Readers seeking a more thorough understanding of RFID physics should consider consulting the vast amount of technical reference materials covering electromagnetics, antenna theory and practice, and communications systems.
4. Throughout this document the common industry terms "inlay" and "tag" appear interchangeably. Both refer to an RFID IC, its paired inlay (meaning substrate and antenna), and any optional conversion processes performed to generate a label.

4 Why the TIPP matters

Across the globe there are tens of thousands of retailers, thousands of brands, countless manufacturers, and an ever expanding list of product categories. As RFID adoption continues its rapid advance, it's not practical for every retailer in the industry to build inlay lists, the traditional method of providing a list of approved inlays specific trading partners have chosen to limit themselves to. This method is neither sustainable nor scalable. As underlying RFID technology continues to improve, and the list of inlays for sell on the market expand, it's critical to remove unnecessary trading burdens by standardizing on a set of commonly understood performance grades. It can even be anticipated that there comes a time when tagging may no longer be based on inlay technology.

Looking at the issue more closely, we find a strong motivation for establishing common grades because it's imperative that retailers be able to predict generally how tags may perform in their intended use cases. Choosing a grade under-matched to the intended use case(s) likely leads to a poorly performing system and/or a system requiring unreasonable amounts of corrective human intervention. Likewise, choosing an over-performing grade may lead to unnecessary expenses or sub-optimum system performance due to highly sensitive tags being read outside a particular zone of interest.

Additionally, applications relying on less (meaning worse) sensitive radios must account for tag backscatter, the other parameter specified in the TIPP. RFID readers with limited receiver sensitivities such as those found in older generation handhelds, some older fixed reader models, or even newer budget-priced fixed readers with sensitivities < -70dBm, could mean users have to avoid selecting higher tag grades until their RFID reader infrastructure is updated. This is due to their radios being ill equipped to accurately recover the reflected signals from contemporary (and likely, all future) tags operating at their lowest power levels – in industry jargon, tags operating "at their sensitivity" level.

5 Limits of the TIPP

Organizations deploying UHF RFID should understand both the limits of the TIPP and how those limits should be considered when designing a system. In understanding the limits, the technologist must recognize what a TIPP grade is: a single, quantitatively based classification of *the RFID-quality of a tagged item* (i.e. readability) as determined by its behaviour in a controlled, standardized test environment. The TIPP grade should not be understood as an assessment of the RF-quality or fitness of either the tag or the item by themselves. Indeed, a TIPP grade provides no universal guarantee of *system performance*. Said alternatively**:** the TIPP is not a definitive stand-alone predictor of how either a single or cluster of tagged item(s) performs in the natural world. Rather, TIPP defines the performance levels of one component (tagged items) within an RFID system. In conjunction with performance specifications for other components (e.g. readers, antennas, fixtures), TIPP allows the overall system performance to be broken down into component system performance. RFID users should therefore realize that the application environment itself is one major factor in RFID system level performance.

6 System performance and TIPP grades

Simplified Link Budget Analysis

To appreciate the underlying metrics establishing a TIPP grade, the reader of this document requires a basic understanding of an RF link budget in the context of an RFID system, where the term "system" refers to the RFID readers, tags, and environment, collectively.

The link budget is a simple way to visualize how a signal's power decays as it moves through time and space from the RFID reader to the tag, and then back to the RFID reader in the form of a modulated reflection. With this well known, yet admittedly highly simplified model, one can make rough approximations of the following:

1. The maximum ideal free-space distance at which a tag with a given sensitivity can operate for a defined power density.
2. The power density of the tag's modulated response when the tag is operating at sensitivity. This measurement informs the minimum sensitivity of the reader required to interpret correctly the longest distance response from the tag in free space.

✓ **Note of caution**: this is an extremely simple approximation using a free space path loss model and a single tag. The natural world is ***far*** more complex as a multitude of factors often interact to either increase or decrease the actual read distance relative to what a free space model predicts. Indeed, placing tags close to one another introduces non-trivial effects still being researched by the industry. Experienced RFID practitioners may use a rule of thumb to compensate for the differences between lab and real world performances: they may add between 4-12 dB of margin over chamber-based values. In most use cases present in the natural world, tags typically require more power than measured in an anechoic chamber. This is especially true when items are grouped together. Fading effects measured in the real world can drop signal powers by 20-40dB or more than the value predicted by a purely free space model! Interestingly, those same complex interactions degrading overall performance can, in some cases, actually boost performance for a small but seemingly random number of tags in the grouping. That we can neither easily predict those specific *boosted* tags nor the extent of the *boost* means practitioners should never depend exclusively on the presence of this phenomenon as a reliable offset to the general degradation arising from clustering of tagged items. One additional factor enhancing performance not represented in static chamber testing is this: RF works better in almost all cases when there is movement. Either the RF is moving via electrical or mechanical steering, or the tagged objects themselves move through an electromagnetic field. Inducing diversity via movement is a common mechanism employed to enhance read rates. Therefore, in some respects, static tests in the chamber can provide a falsely pessimistic view of performance in the natural world. On-going research in the industry ultimately will yield better predictive models tantamount to those present in other radio-based industries, e.g. WiFi and cellular.

In summary, a deep analysis of all factors accounting for loss is beyond the scope of this document. We encourage readers inclined to enhance their understanding of the topic to read Griffin & Durgin's paper, which forms the bulk of this document's discussion of loss. In general, loss factors include: path blockages/shadowing, reflections, so-called detuning from the environment and the object to which a tag is applied, polarization mismatches, tag-to-tag coupling, forms of scattering, small and large-scale fading effects, and others. Propagation analysis is an extraordinarily rich and complex field continually being updated as new understandings emerge.

To guide our discussion of link budgets, we'll refer to Figure 1 below. It is a simplified depiction of power leaving the reader, travelling to the tag, and then being reflected with a modulated overlaid back to the transmitter. On the left we list the parameters affecting the power of the signal as it makes its round trip journey. We assume use of an RFID reader with monostatic antenna(s), meaning transmit and receive operations occur through the same antenna; therefore, the signal path is symmetric.

Modulation loss, which we discuss later, is an inherent power loss we can model simply as an approximately 12dB loss.

6.1 Link budget

We will use the following diagram throughout the remainder of this section to provide a simplified explanation of the factors affecting tag readability.

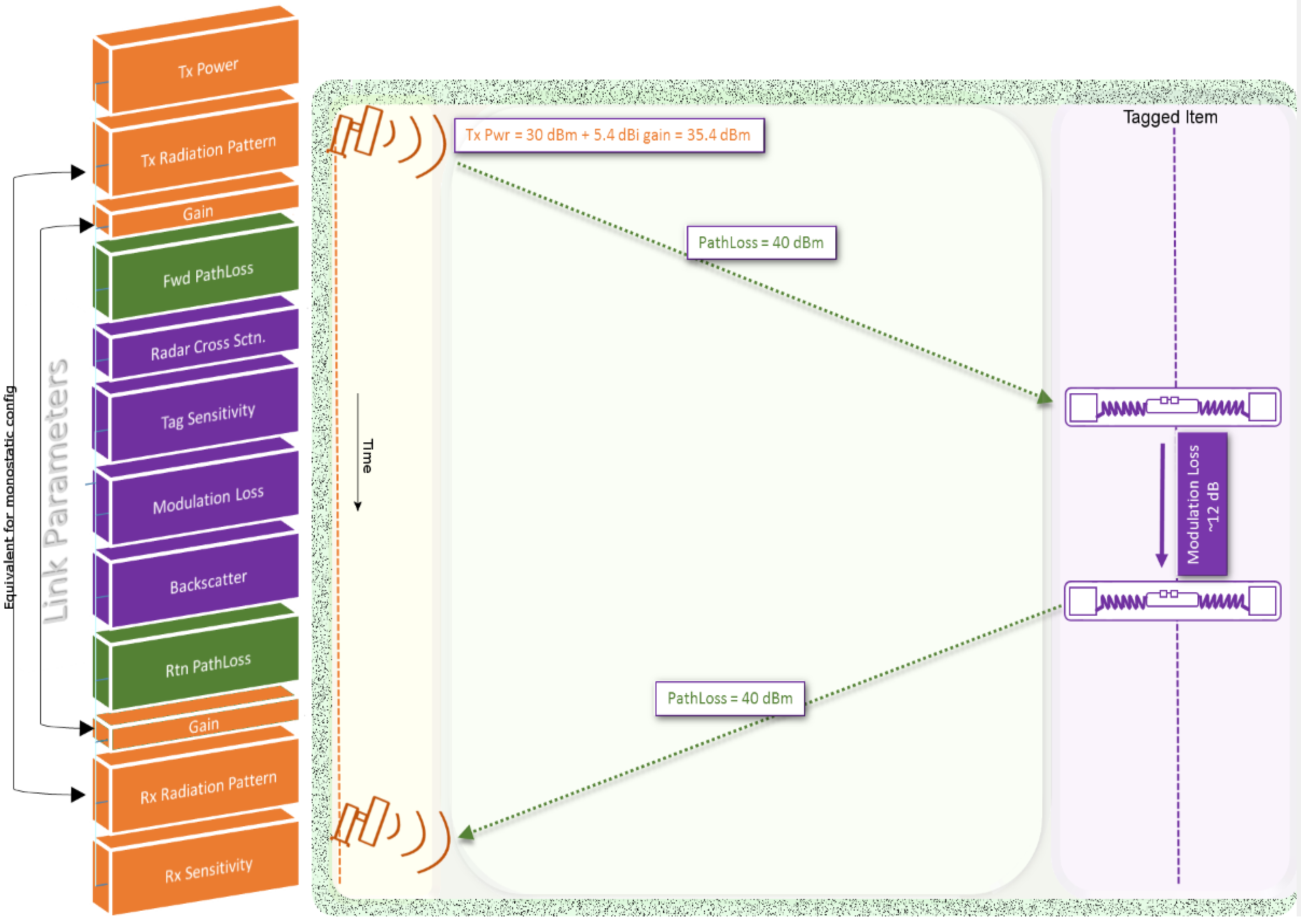


Figure 6-1 Link budget (Orange = reader area, green = free space region, purple = tag region, speckled= environmental region)

6.2 Reader Transmission/Reception (Orange)

To begin our journey through the link budget, we start from the RFID reader (top three orange blocks). Permissible maximum transmit power varies around the world; each country's radio regulatory authority sets the permissible maximum radiated power. For our example, we'll assume a reader operating in a region using United States FCC regulations. The native power generated the reader can be gain-amplified via antenna to a maximum of 36 EIRP (i.e. 4 watts relative to what would be produced by an isotropic radiator). For this exercise we assume a monostatic antenna, meaning transmit and receive gains are symmetric. This permits us to simplify even more some of the equations below.

6.3 Forward and Return Path (Green)

In Figure 1, the dimensionless free space path (green blocks) loss is computed using a simplified form of the canonical Friis equation:

$$PL_{OneWay} = |20\log(\tfrac{4\pi d}{\lambda})| \qquad (1)$$

Where PL_{OneWay} is the one-way path loss, d = distance in meters, and λ is the wavelength (~ 0.33m for FCC). In the example drawn in Figure 1, we arbitrarily pick a path loss of 40dB. A drop of that magnitude means the source signal drops to a level 1/10,000th of the original during transit from the antenna to the point where the signal intersects the tag's antenna. Rearranging (1) we observe that at UHF RFID frequencies, a one way path loss of 40dB translates roughly to about 2 meters in unobstructed space. To compute maximum read distance given solely the chip's sensitivity, we can use:

$$\boldsymbol{d} = \frac{\lambda}{4\pi} 10^{\frac{P_T - tag\_sensitivity}{20}} \qquad (2)$$

where P_T is total transmitted power (including gain). To get an estimate of power arriving at the tag we can use:

$$\boldsymbol{PwrTagFwd} = P_T - PL_{OneWay} \qquad (3)$$

where P_T is the transmitted power, including any antenna gain. Recall that "*sensitivity*" or "PwrTagFwd" is the *minimum* amount of power required for the tag to operate. It may also be called RIP (received isotropic power), or Tag-Sensitivity Read (TSR). Per the current TIPP, all measurements apply only to tags returning the contents of their electronic product code (EPC),, their Protocol Control bits (PC) and Cyclic redundancy Check (CRC). No writing of the tag is occurring. Writing typically requires an additional power relative to read power. Power received at the tag in excess of the minimum required for operation is *margin in the forward link.*

We can also easily derive an estimation of the power in the signal reflected back from the tag, as measured at the tag (i.e. before the return path loss is factored). In certain test devices this is called "Power on Tag Reverse (PTR)" or as it appears in the TIPP, "Backscatter." From this same equation we then can easily obtain a general idea of the RSSI the reader records for a backscattered signal after moving through space:

$$\boldsymbol{PwrTagRev} = PwrTagFwd - |ModulationLoss| \qquad (4)$$

&

$$\boldsymbol{RSSI} = PwrTagRev - PL_{OneWay} \qquad (5)$$

In order for a reader to properly decode the modulated reflection, the reader's sensitivity must be equal to or better than the power in the return signal. The power in the reflected signal exceeding the sensitivity of the radio is *margin in the reverse link.*

6.4 Tag Region (Purple)

Backscatter is not simply a measure of the amount of power reflecting from a tag. If it were, RFID would involve straightforward radar analyses. In fact, passive RFID is best termed "modulated radar", whereby the tag imposes a self-generated signal representing digital data on the incident waves provided by the reader/transmitter. Succinctly, as explained in [1], the "power of the digital information scattered toward the reader is also related to the *difference* in load states." In this case, the two load states refer to the switch in the impedance resulting from a tag signalling a data 0 or data 1.Below, $\Gamma_{A\ and\ B}$ are the reflection coefficients: $\Gamma_A$for state A, and Γ_B for state B. M is the modulation factor and is proportional the amount of power backscattered resulting from the difference between states:

$$M = \frac{1}{4}|\Gamma_A - \Gamma_B|^2 \quad (6)$$

Furthermore,

$$\Gamma_{A,B} = \frac{Z_{RFIC}^{A,B} - Z_{ant}^{*}}{Z_{RFIC}^{A,B} + Z_{ant}^{*}} \qquad (7)$$

where $Z_{RFIC}^{A,B}$ is the input impedances of the chip for states A and B, Z_{ant} is the input impedance of the antenna, and Z_{ant}^{*} is the complex conjugate of the antenna impedance.

Switching states between a short (Γ = +1, or digital "1") and open (Γ = -1, or digital "0") would mean all power is backscattered, and the tag would not have sufficient power to operate. So, DSB-ASK modulation is often used, and is in fact the mode specified for tag testing in the TIPP testing methodology.

Assuming the existence of a tag consistently reflecting perfectly, the modulation loss would total ~6dB. This assumes 3dB in loss since the tag is reflecting ½ of the time. The other 3dB of loss arises due to ½ the power being in the modulated reflection and the ½ other half in information-less CW. In actuality, loss is typically in the range of 10db to 12dB as a result of the aggregate 6dB innate loss discussed above AND the loss arising from imperfect matching.

Thus,

$$ML = 6dB\ (ideal)\ to\ \mathbf{12dB}\ (\boldsymbol{usual})$$

Thus, approximation of total link loss is:

$$Loss_{Total} = 2 * PL_{OneWay} + Modulation\ Loss \qquad (8)$$

where *Modulation Loss* should be assumed to be a constant of ~12dB.

6.5 Backscatter

Tag sensitivity is but only half of the link budget to be considered. The RFID reader *must* be capable of deciphering the encoded reflection. Fundamentally this means the reader radio must have adequate electronics and signal processing to properly decode low-power tag signals.

Backscatter is a measure of the amount of power being reflected by the tag. But backscattered power is not strictly equal to the forward loss as it comprises not only reverse link losses, but also the roughly 12db of modulation loss discussed above. In the more than a decade since standardization of UHF RFID via the Gen2 protocol, the industry has continuously provided radios with better sensitivities at economical prices. Concurrently, the industry has engineered -- and will do so for the foreseeable future -- tag innovations yielding dramatic improvements in tag sensitivity. Current generation ultra-low power tags are now common in the marketplace. Some manufacturers' claim their chips have sensitivities of -20 dBm or more. As a general observation, the industry has improved sensitivity every year by roughly 1.25dB per year since about 2006. Now the industry is at a point where the forward link less frequently dominates system read range, a reversal of the key limiting factor in the early years of Gen2 RFID. In summary, to read modern and future low-power tags, radio sensitivities must be adequate to decode these anticipated "weaker" tag responses.

A simple measure of backscatter power, from the reference point of power leaving the tags and not accounting for modulation losses, is calculated as:

$$P_{backscattered} = \frac{P_t G_t^2 \lambda^2 \sigma}{4\pi^3 r^3} \qquad (9)$$

where $P_{backscattered}$ = power backscattered, P_t = reader power transmitted, G_t = gain of transmitting antenna, λ = wavelength, σ = radar cross-section, and r = one-way radial distance from reader to tag.

6.6 Tag family classifications

Tag grades symbolize compact representations of objective RF-performance information about a tag *and* item combination. TIPP tag grades are intended to form a set of standards-based expectations between commercial trading partners. Isolating the grades like this (a) ensures grades exist independent of parties representing conformance to a grade level(s), and (b) ensures independence from the certification/verification labs. One can think of TIPP grades as serving a similar function as the Society of Automotive Engineers (SAE) motor oil grades (e.g. 5w-20, 10w-30, and so on). Additionally, a grade does not depend on any attributes of the items to which tags may be attached. So, an M35D grade is always an M35D, whether the item to which the graded tag is being attached is a consumer electronics device, an apparel item, a large bag of dry dog food, or a common sporting good.

A grade family is determined by looking at the similarity across 4 data dimensions: rotation angle, elevation, tag-sensitivity and backscatter. Per the TIPP standard, grades can be separated whenever either condition apply:

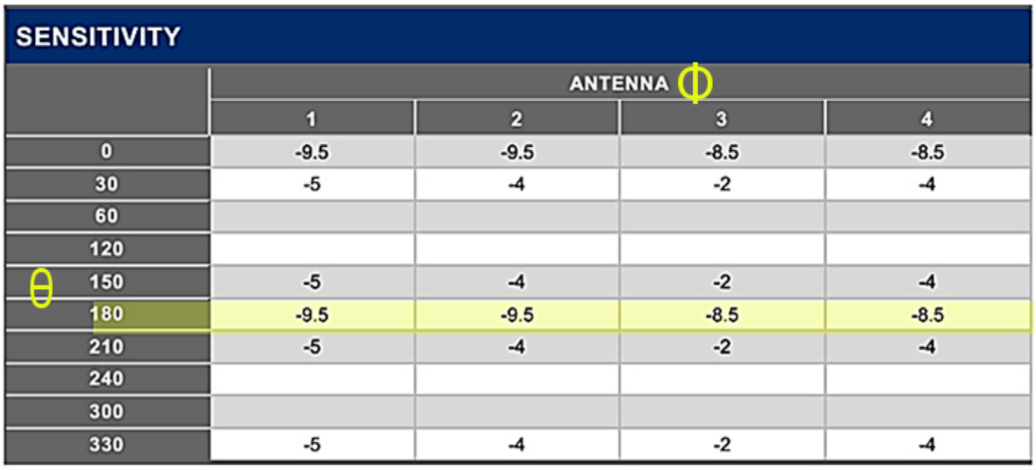
- Peak sensitivity or peak backscatter differ by >= 2 dB
- rotation angle or elevation 3dB beam-width of 60 degrees or more
- Minimum Success Rate difference larger than 10%

Some parts of a TIPP grade do not require consulting a matrix of sensitivity and backscatter values. FCC, EU, or worldwide operation designations appear directly in the grade name.

6.7 Deriving read range from TIPP Sensitivity and Backscatter tables

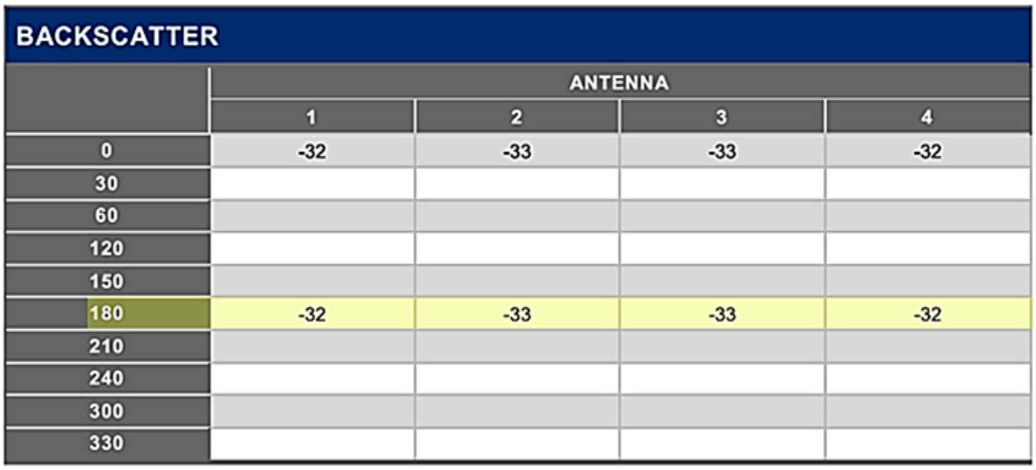
Sensitivity

The significance of the foregoing background theory can be understood in the context of the TIPP Grade Definitions. The tag sensitivity and backscatter power tables accompanying each TIPP Grade allow end users to calculate free-space read distances (FSRD). While recognizing that the natural world seldom provides a signal path as simple as that calculated by the FSRD, the FSRD sometimes correlates with (though does not directly map to) general real-world performance. Specifically, we'll examine the criteria for a rotation angle (θ) of 180° at for four angles of elevation (Φ=0°, 30°, 60°, 90°). We reprint the S20B tables here for convenience, highlighting the row for the rotation angle of interest:



SENSITIVITY

	ANTENNA			
	1	2	3	4
0	-9.5	-9.5	-8.5	-8.5
30	-5	-4	-2	-4
60				
120				
150	-5	-4	-2	-4
180	-9.5	-9.5	-8.5	-8.5
210	-5	-4	-2	-4
240				
300				
330	-5	-4	-2	-4



BACKSCATTER

	ANTENNA			
	1	2	3	4
0	-32	-33	-33	-32
30				
60				
120				
150				
180	-32	-33	-33	-32
210				
240				
300				
330				

We use this simplified equation to relate sensitivity to read distance, grossly, using (2). Using that equation we can easily compute the maximum free-space distance at which the tag receives power at levels conforming to the sensitivity requirements of the TIPP grade. The following table summarizes these read distances. Please note that in these calculations we assume: (1) a frequency of 915MHz-FCC; (2) a maximum transmit power of 36 dBi (max 4W EIRP per FCC); (3) a monostatic antenna configuration; and (4) adherence to all other mandatory requirements specified in the TIPP testing methodology.

Antenna 1 (Φ=0)	Antenna 2 (Φ=30°)	Antenna 3 (Φ=60°)	Antenna 4 *Φ=90°)
~4.99 meters	~4.99 meters	~4.45 meters	~4.45 meters

It bears repeating that this is the expected read distance of a single tag in a perfectly unobstructed environment, which is unlikely to exist in the natural world. Environmental conditions can cause large deviations from this predicted value.

6.7.1 Workflow/Walkthrough

We will step through a series of hypothetical use cases to understand how one might exercise the TIPP to satisfy system performance requirements. The use cases below have a basis in real-world engagements.

Use Case 1

A particular use case has been analysed and the engineers have determined the customer should choose tags that have the following performance characteristics:

1. The best-read performance possible for inventorying with a handheld reader. Typically the tagged items will be read with the handheld pointing directly over each stack, with a sweeping motion, left to right, descending down row by row. The maximum distance of the handheld from the tags is roughly 2 meters.
2. The handhelds the customer uses have a published sensitivity of -65 dBm, an output power of 29dBm, and a stated gain of 5 dBiL.
3. The retailer’s stores are in North America.
4. The tagged items reside in shelves in the back of the customer’s retail site. There are 5 unique stacks (from the front of the shelf edge to back of shelf) and each item stack has up to 8 articles in it. The items are apparel in nature. Testing of tags on items shows tags have about 8 dB of loss arising from the material ($\text{Loss}_{\text{Material}}$) to which the tag is applied.

Question: how do we use this information to inform our search for the correct TIPP grade(s)?

First, rearrange (2) so that instead of solving for ***d (distance)*** we are instead solving for minimum sensitivity:

$$Sens_{\min @\, d\ meters} = (P_T - Loss_{Material}) - 20log\left(\frac{4\pi d}{\lambda}\right) \tag{10}$$

Thus, $Sens_{\min @\, 2\ meters} = (34 - 8) - 20log\left(\frac{4*2meters*\pi}{0.33\ m}\right) = -11.6\ dBm$ for a tagged item in the FCC band operation. For ETSI, the wavelength is slightly longer - about 0.35 meters, and P_T is almost 1dB less.

In our use case, this means that at a distance of 2m, with 10dB of loss arising from the item to which the tag is attached, a tag on an item must be capable of operating with -11.6 dBm of power.

Simple backscatter calculations reveal that at sensitivity, the tag’s signal arriving at the reader should be roughly:

$$-11.6\ (\text{sens}) + -12\ (\text{inherent modulation loss}) + -38\ (\text{FSPL return at 2m}) = -62\ \text{dBm}$$

Therefore, the handheld reader’s sensitivity in this example is sufficient to accurately decode the tag’s response. However, if the sensitivity of the handheld were -60dBm, the reader could not recover the tag’s response in this example.

Use Case 2

A medium-sized clothing retailer in the European Union has an overhead reading system. Relevant characteristics of the system are:

5. The maximum distance of the reader’s beam-formed antenna to the farthest tags is roughly 5 meters. The overhead system publishes a sensitivity of -81 dBm, an output power of 30dBm, and a stated gain of 5.2 dBiL.
6. The retailer’s radios all operate according to ETSI rules.
7. Chamber tests reveal approximately 6dB of loss arising from the materials to which the tags are applied, including stacking effects.

$$Sens_{\min @\, d\ meters} = (P_T - Loss_{Material}) - 20log\left(\frac{4\pi d}{\lambda}\right)$$

Thus, $Sens_{\min @\, 2\ meters} = (35.2 - 6) - 20log\left(\frac{4*5meters*\pi}{0.35\ m}\right) = -15.8\ dBm$ for a tagged item in the ETSI region.
Backscatter is calculated as above, revealing:

$$-15.8\ (\text{sens}) + -12\ (\text{inherent modulation loss}) + -45\ (\text{FSPL return at 5m}) = -73\ \text{dBm}$$

Thus, the overhead system would be able to decode the tag response, with ~8 dB of margin.

7 Dynamic system range

As referenced previously, robust RFID deployments emerge only when taking a system-wide approach and deliberately engineering each component of the system. TIPP addresses one aspect of this component evaluation: ensuring that the selected tags, when applied to items, meet a minimum performance level assigned to a particular TIPP grade. Topics not addressed directly by the TIPP are:

- Identifying the "right" tag(s) for a particular use case or set of use cases
- Ensuring the RFID readers can perform at the levels demanded of both the use case and the TIPP grade selected

8 Frequently Asked Questions (FAQ)

8.1 Why wouldn't end users just always pick the most sensitive tag?

All things being equal, a more sensitive tag is usually better than a less sensitive one in virtually all presently known use cases. Of course, that statement begs the question: "why shouldn't I always chose the most sensitive tag to ensure success." The answer to that question requires a high level discussion of basic tag physics and economics.

The amount of transformable electrical energy impinging upon a tags' antenna is represented partially by the notion of radar cross section (RCS, symbolically denoted by σ). In a simple summation: the larger the antenna, the larger the RCS, and so the greater power collection for the ICs use. This is why a larger tag almost always outperforms a smaller tag given the same RFID IC and optimized antenna tuning for each.

Of course, the nature of what's being tagged frequently prevents applying a "large" tag. In retail settings, tags typically must reside on packaged items in a space no larger than 1X – 3X that of the existing barcode. Furthermore, it's necessarily true that a larger tag antenna requires additional antenna metal (typically aluminium, occasionally copper) than a smaller one. In fact, it's been empirically shown up to 7.5dB+ of sensitivity loss accumulates by moving from a standard 70mm tag to an equivalent but smaller variant, a 40mm garment tag. A larger antenna necessarily involves additional cost from a raw materials perspective. This inherent tension between read distance/readability and size/price is unavoidable and the practitioner must balance these competing goals thoughtfully. Finally, a tag's geometry, size, and possible encapsulation/isolation may be highly customized to ensure maximum performance when applied to a particular item. When a custom design is most appropriate, tag costs may be higher than those of a common, mass-produced off-the-shelf tag. Moreover, custom tag design may involve significant one-time engineering fees.

Finally, as tags undoubtedly become more sensitive (meaning less power is required to operate the tag) then one should expect new tag chips to backscatter at levels older generation readers cannot decode. This is especially true when comparing sensitivities in handheld readers versus higher performance fixed readers. Note: it is possible to deliberately "tweak" a modern high performance tag design to deliver a higher backscatter, but this comes with an extreme performance penalty. Deliberately detuning to increase backscatter means "borrowing" from the sensitivity side of the equation.

8.2 How to confirm compliance using tagged-items from the field?

Since the TIPP makes no predictive claims about real world performance, the only way to ensure conformance of a/group of tagged item(s) is to take the item(s) from the field and test them exactly as done in the Tagged Item Performance Test Protocol (TODO reference). Testing tag performance in the field (as opposed to in the chamber with the exact same parameters/configurations as in the original testing) is not a recommended way to validate grade conformance. *Note and warning: seemingly inconsequential changes in packaging and/or item composition may produce markedly* *different RF results. This holds especially true with shiny graphics that are likely to have electric conductivity.*

8.3 What if I can't find a tag in the market satisfying my size/cost/feature requirements for the performance grade I need?

Custom designs are always a possibility, but likely provided at additional expense over readily available tags. Moreover, the engineering time and cost involved in developing a custom design may be prohibitive for those having limited time and/or sensitive budget. Additionally, it's important for solutions providers to understand the limits of the technology. Sometimes, it may be that the requirements cannot be satisfied. As an example of a likely unsatisfiable set of requirements consider: a customer asking for a, 20mm x 20mm label that can be applied to an item – irrespective of item composition, whether it be metal, paper, cotton, thick plastic – and readable from 15 meters away from a single reader. It's most likely such a set of requirements cannot be entirely satisfied with today's technology and current regulatory limits on emitted power.

A Normative references

- J. Griffin and G. Durgin, *Complete Link Budgets for Backscatter-Radio and RFID Systems*," IEEE Antennas and Propagation Magazine, **51**, 2, 2009.
- D.M. Dobkin, The RF in RFID: passive UHF RFID in Practice. Burlington, MA, Newnes, 208.
- P. Nikitin and K.V.S. Rao, "Theory and Measurement of Backscattering from RFID Tags," *IEEE Antennas and Propagation Magazine*, **48**, 6, 2006.

B SIMPLIFIED Terminology/Concepts

Modulation loss: The total power loss in the reflected signal due to encoding and internal chip losses

Backscatter: The modulated energy reflected back from a tag

Free Space Path Loss: The signal strength loss an electromagnetic wave resulting from a direct, line-of-sight, path through unobstructed space. IEEE Std. 145-1983, defines it as "The loss between two isotropic radiators in free space, expressed as a power ratio."

Tag Sensitivity: The minimum amount of power required by a tag enabling it to successfully complete a read operation

Tag Sensitivity-Write (TSW): The minimum amount of power required by a tag enabling it to successfully complete a write operation

Power on Tag Forward (PTF) or RIP: The calculated amount of power appearing at the tag; it is received isotropic power (RIP)

Power on Tag Reverse (PTR): The amount of power in the modulated signal being reflected at the tag’s surface. This is total power (both modulated and not-modulated) and does not account for the reverse link path loss.

Return Signal Strength Indicator (RSSI): The amount of power in the reflected signal from the tag as measured at the point of demodulation in the RFID reader.

Forward Link: The path of power from a transmitting reading to an RFID tag

Reverse Link: The path of modulated power from a tag to the receiving reader antenna

Reader Sensitivity: The lowest signal at which a reader can successfully decode a tag’s response

Shadowing/Fading: Differences in the attenuation affecting a propagating signal

Link Budget: An arithmetic analysis showing how the power of a transmitted signal decays as it interacts with a tag and then backscatters to the transmitter.

Forward Link Margin: The difference between the power actually received by the tag and the power required for the tag to power-up. If a tag’s sensitivity is higher than the power delivered, then there is insufficient power for tag operations.

Reverse Link Margin: The difference between the power present in the backscatter from the tag and the lowest level supported by the reader to achieve a given maximum bit error rate. If the reflected tag signal is lower than the lowest power the reader can decode, then the reader has insufficient receive sensitivity for that tag’s response.