Suggested ISO Battery Supported UHF RFID Standard Improvements and Roadmap

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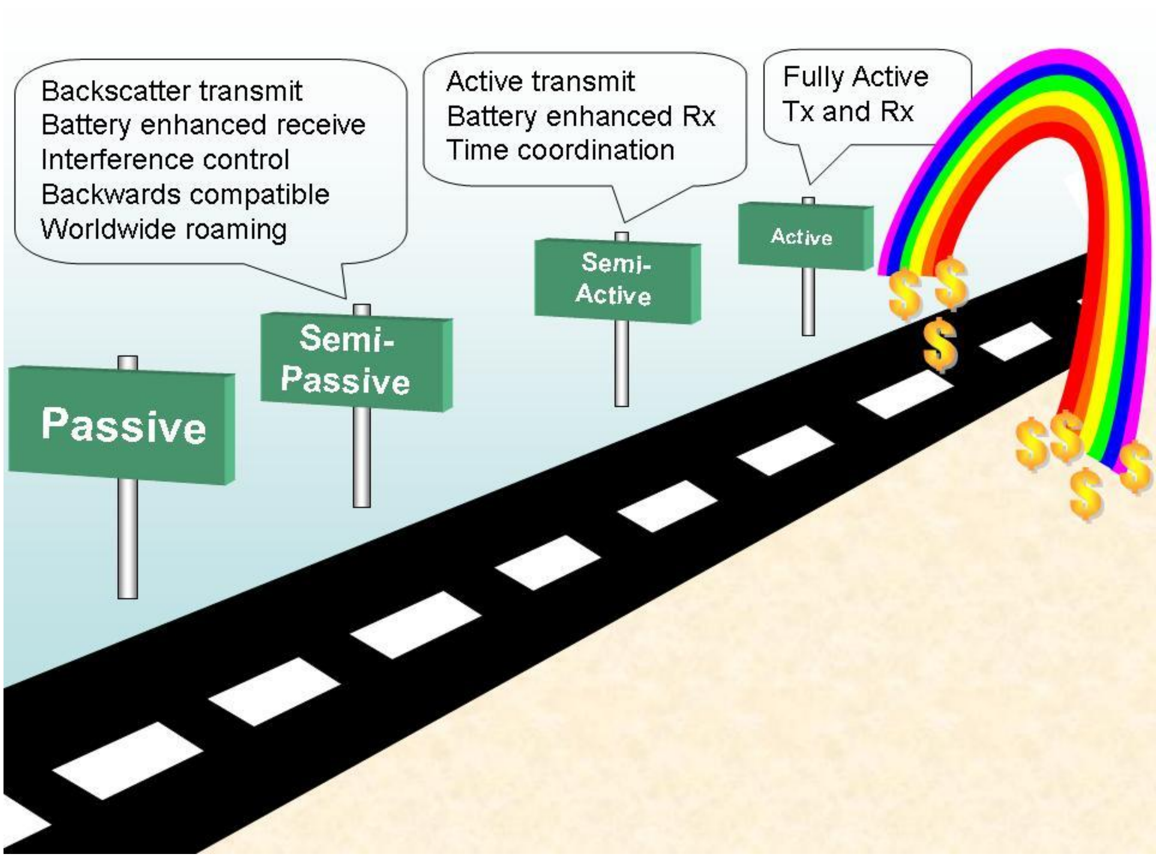


The time to plan for the battery supported RFID future is NOW...

The WAY to plan that future is to get the basics right...

Document Schedule and Status

This document is a work in progress. Early versions are incomplete and expected to have mistakes and oversights. We expect to have it sufficiently completed by mid October, 2007 that it may be submitted to the full SC-31 committeee. In concert with reviews and inputs from committee members, we hope to have it in a well refined state with considerable consensus before the mid November ISO meeting. It is hoped that by the conclusion of that meeting committee members will have come to a decision about the basic philosophy of the battery supported mode, meaning whether to stay with modest performance and growth potential, or to go for the higher performance and growth potential proposed here. If changes are agreed to, then either at the meeting or shortly afterward we will need consensus on what additions and changes should go in the next draft.

The first six drafts of this white paper, with version 0.6 released Oct 3, 2007, are fairly complete on the battery supported backscatter (Semi-Passive, or Class 3) command set and feature modifications and additions. This includes features and commands supporting the described power leveling algorithm, regulatory region roaming, and some provision for possible later advancement to Semi-Active and Active tags. It is fairly complete on recommended preambles for asymptotic settling of tag AC coupling for high sensitivity tag receivers with that power leveling algorithm. It thus represents a workable system design for battery supported backscatter with high sensitivity tags and readers and partial interference control. Most of the changes we recommend for this round of the standard are thus captured.

However, draft 0.6 is still incomplete with regards to:

- "Overshoot" based faster settling preambles that can speed up tag reads per second with power leveling in use. These would be useful, but are tricky with use of multiple dynamic range state receivers.
- Documenting interference analysis (such as reader on reader and reader on tag interferences and how much they are helped by reader power level control)
- Specific recommendations for optional split bandplans. This material could be included in the standard draft as an annex.

Revision History

Date	Version / File	Editor(s)	Comments
09/10/07	Version 0.1 Maxim_ISO_BatSupport_ Recommendations_v0p1	Farron Dacus Alfonso Rodriguez Herre-ra Jan van Niekerk	Introduction of first draft, still needing consider-able work.
09/12/07	Version 0.2 Maxim_ISO_BatSupport_ Recommendations_v0p2	Farron Dacus Alfonso Rodriguez Herre-ra Jan van Niekerk	Bug fixes on power leveling description with proposed command set. Added description of power leveling using exist-ing command set. Added Active material to Chap 6.
09/19/07	Version 0.3 Maxim_ISO_BatSupport_ Recommendations_v0p3	Alfonso Rodriguez Herre-ra	Primarily add material supporting duty cycling statistical analysis. Material supporting tag sensitivity, which is covered in related presenta-tion, still needs to be added.
09/23/07	Version 0.4 Maxim_ISO_BatSupport_ Recommendations_v0p4	Alfonso Rodriguez Herre-ra Jan van Niekerk	Added Sleep_DC_PIE command. Added Next_PIE command. Modified RX_Control_DC command.
09/26/07	Version 0.5 Maxim_ISO_BatSupport_ Recommendations_v0p5	Farron Dacus	Adding tag sensitivity limits analyses, still in-complete as of 9/26/07. Specifically added pager interference analysis, SIR requirements for square law receivers, and some of the elec-tronic sensitivity analysis.
10/3/07	Version 0.6 Maxim_ISO_BatSupport_ Recommendations_v0p6	Alfonso Rodriguez Herre-ra Farron Dacus	Complete addition of tag sensitivity basic analy-sis. Add practical range basic analysis with fade taken into account. Add initial IP discussion.

Table of Contents

We've strained to apply good fundamentals, but no doubt there are mistakes and omissions in our work. Please report your comments to farron.dacus@dalsemi.com.

The Maxim goal is a professional grade royalty free Semi-Passive (Class 3) standard that allows a successful industry now and a deliberate plan for growth.

1 Executive Summary: The Recommended Road

With regards to battery supported RFID system designs, the only option that has ever been available to the committee is the one now captured in the Committee Draft of ISO 18000-6C. In our opinion, it has never been fully explained to the committee what it is “buying” when it votes in this plan, and what it is giving up. Based on fundamental analysis of possible performance, this system design is one supporting limited backward compatibility in PIE mode (since it may require a hardware reader upgrade to implement the optional Activate command needed to provide acceptable battery life), and only modest performance in its more sensitive Manchester forward mode. It is possible to take this forward mode to the point (about -35 dBm tag sensitivity) where the reverse link becomes the limit (about -100 dBm reader sensitivity), but this state is only achieved when the reader is transmitting full power. It is a negative to require the reader to transmit at full power in the forward link, because it leads to reader induced interference, less reliability and throughput in the interference limited situation, poorer band citizenship, and in the United States a requirement to always use frequency hopping. Some applications, such as pharmaceutical, have additional reasons not to favor full power. There is also little deliberate planning for the likely advance to higher classes of RFID with active circuitry in the tags that operate under one 900 MHz infrastructure. In our opinion the technical and business reasons for active behavior at 900 MHz are very compelling, and the 900 MHz RFID industry and users would greatly benefit from having these higher performance options be available under the same infrastructure.

We therefore wish to put another option before the committee, a deliberately more backward compatible and yet higher performance option, and one that much more conveniently allows for future advance to active behavior in the tags. If that inspires other companies to contribute their own detailed reasoning, which leads to detailed debate, then at least the committee will have been provided the information necessary to allow making informed decisions as to the goals and future roadmap of the standard. Perhaps that decision will be to stay with the more limited performance and roadmap we now have, or perhaps it will be to take the opportunity now to lay a foundation allowing higher performance and a more ambitious roadmap for the 900 MHz RFID industry.

The decision criteria to stay more simple and limited, or be more ambitious, logically comes down to a time and benefit trade-off. On the time side, we believe these improvements can be implemented with little schedule impact, actually going into the very next draft in December or January. Since our company believes in the future of battery suppported RFID, we can commit to providing the necessary hours for quick addition of these improvements into the standard. On the benefit side, we believe these changes will allow the standard to be more commercially successful, enjoy a much longer life with smoother transition to inclusion of Semi-Active and Active tags, and achieve the greatest odds of EPCglobal co-adoption (if it meets all goals, it seems hard for EPC not to adopt it). This white paper presents our detailed recommendations and justifications for implementing these improvements.

Now, if we make the assumption that the standard should provide for higher levels of Semi-Passive performance and a viable future path to Active, then the specific problems in the battery supported portion of the current Committee Draft are as follows:

- The current standard design, without explicitly saying so or being supplemented by explanatory material, seems to be designed around tags with -30 to -40 dBm sensitivity, apparently implemented in a single dynamic range state (perhaps +10 to -35 dBm) with only limited training required, and providing only limited interference control (also unexplained). However, diode detector architecture "square law" receivers are capable of reaching -60 dBm without LNA and about -75 dBm with LNA. Also, there is little accounting for the major differences between DC and AC coupled modes in tag receivers.
- Based on the above points, lack of planning for interference protection of the high sensitivity of the tags and readers, and adequate AC coupling training with such protection in place and under the likely case of needing several dynamic range states in the receiver (such as -60 to -20 dBm, and -20 to +20 dBm). Better interference control requires several new features and commands, and modification of some other commands. Training to account for multiple dynamic range state tag receivers requires improved preambles.
- Lack of foundation level planning for advancement of 900 MHz RFID technology to active circuitry in the tags, consequent coexistence of all classes of tags, and preparation for readers to meet these requirements with firmware upgrades. An example of such a requirement is recognition that active systems will tend to operate with narrowband channels, such that planning for narrowband channels in commands and next generation reader hardware should be made now. Thus, provision should be made to specify channels with sufficient granularity to meet those future requirements, and the lower limit of data rates used should allow fitting within those channels.

Then, staying with the assumption that keeping open the options of higher performance and future advancement are our guiding philosophy, what appears to be the optimum battery supported backscatter (Semi-Passive, or Class 3) standard plan is to have:

1. A requirement for battery supported tags to implement a <u>fully backward compatible</u> effectively DC coupled PIE forward mode that operates with existing Passive (Class 1) readers with modest but useful link budget improvement over typical Passive (Class 1) operation. Fully compatible means to be compatible with fielded readers without hardware or even firmware change. Some additional optional capability can be added through firmware upgrades. Improvements requiring <u>any</u> hardware changes to readers are not recommended for this mode, since that defeats the backward compatibility mission. This mode of operation will allow a typical link budget improvement of about <u>10 dB</u> (it takes advantage of the sensitivity safety margin that exist in current Passive Class 1 readers), or about twice the normal operating range, without too much range for applications where zoning is desired. It is ideal for more simple Semi-Passive (Class 3) products such as

medium range identification (2 to 5 meters) and simple sensors, and may be quickly implemented and ramped up.

2. An optional capability for a sensitive Manchester or effectively AC coupled sensitive PIE mode for use with new generation Semi-Passive (Class 3) capable readers with a greatly improved link budget (approximately 20-25 dB better than passive) and support for optional interference control with reader transmit power level control and optional split band plans. Practical ranges for this option are approximately 10 to 20 meters whether Manchester or AC PIE (for IP reasons). Tags with more advanced design can achieve sensitivities of -50 to -60 dBm in this mode, without use of an LNA, and up to -75 dBm with an LNA. However, these levels of sensitivities with a wideband detector receiver inherently lead to a hostile link environment, hence the need for improved interference control. An improved command set, preambles, and additional features are detailed that support this advanced option. It is ideal for more demanding applications such as long range identification and more advanced sensors with data logging over time.

3. A deliberate plan for a royalty free standard. Accelerated introduction of previously planned (power leveling & world wide roaming) desirable features that may have pending IP reading on them is proposed in the hope that this will encourage disclosure of terms, preferably royalty free. If royalties are demanded, then the standards community should be informed and have the option to try to design around the offending IP. Maxim plans to offer its own necessary IP, including IP needed for optional parts of the standard, as royalty free for reciprocity.

4. A clear forward path to higher level Semi-Passive (Class 3 Plus) (active transmit in tag) and Active (Class 4) (active transmit and narrowband active receive in tag). The command set and features recommended have been designed to be extensible to these modes, and candidate extensions are described (though still incomplete in the first draft of this report). The modes can provide still longer ranges, higher reliabilities, and tag to tag networking.

Sensitive Mode (Manchester) Recommended Change Summary:

Given that the committee approves the philosophy of better performance and deliberate road mapping, then the specific changes we would recommend for the next version of the standard are outlined below.

1. Add the capability to optionally "lock" the tags to the activating reader. This is done by providing an 8 bit Reader ID in the Activation code with a flag to use or not, and then optionally providing this Reader ID as part of global commands. This lock prevents more distant readers from accidentally "reaching in" and controlling tags they are not currently intended to address.

2. Make the capability to use power leveling mandatory for the sensitive mode, providing the necessary features in Semi-Passive (Class 3) tags and readers. Whether an appli-

cation uses power leveling would depend on user based software choice. Support for power leveling leads to several new standard features and commands.

3. Acknowledge and design for the differences between typically DC (power delivery for Passive Class 1) and AC coupled (information delivery, for Semi-Passive Class 3) modes. The command sets to support these modes have distinct differences. DC does not need training preambles or power leveling due to its limited sensitivity, but AC needs preambles, power leveling, and other interference control measures such as flexible sensitivity and data rate control.

4. Commands suggested for modification are: All global commands (to add Reader ID field if locking is in effect), Activate (many new features for more selective wake up, locking, roaming, tag receiver control), Deactivate (more selective and safe), and BroadcastID (modified for smaller optional channel bandwidth to accommodate future expansion to Semi-Active and Active).

5. Suggested new features are: Programmable timers to allow precise and flexible time out of the session flags, which have been incorporated into the suggested power leveling algorithm and into the activate, lower limits on data rates to allow fitting into likely future frequency plans with fine channel steps, programmable tag sensitivity, and programmable tag receiver duty cycles (regular receiver in DC PIE mode, and hibernate receiver in AC Manchester mode).

6. Suggested new commands are: WriteTimer to program the persistence of the Session flags, ReadTimer to read back the state of those flag timers, Rx_Cntrl_3_MAN to allow reprogramming of tag receiver data rate and sensitivity, and Hib_Cntrl_3_Man to allow reprogramming of hibernate mode sensitivity and duty cycle.

The detailed behaviors of these new and modified commands are given in Chapter 3.

After reviewing this chapter, the reader will understand the reasons behind our recommendations.

2 Background: Understanding the Recommendations

2.1 The Goals of this Report

We seek to shed light on the fundamental decisions the standard community now faces with regard to battery support and the road to higher performing RFID. The reader who wishes to really "get it" must understand the impacts of the different performance levels of the general UHF RFID "classes", the link physics, what is possible in circuit design at low cost, the behavior and performance limits of the square law tag receiver (any RF detector based receiver when operating at low RF signal levels), working around the IP problems, and the commercial issues of both backward compatibility and a clear forward roadmap.

A very pertinent example of where explanation is needed is the clear distinction between the sensitivity and pulse width measurement capabilities, and the preamble requirements of, effectively DC and AC coupled tag receivers. This subject is poorly covered in the literature. But, it floats to the very top of the system design in terms of preamble and command set features, and thus must be intimately grasped. For example, the very large sensitivity difference between effectively DC coupled PIE and effectively AC coupled Manchester is not due to the modest 5 dB ideal sensitivity advantage enjoyed by Manchester. It is due to the much larger improvement in sensitivity for a precision demodulation (usually AC coupled) receiver as opposed to a coarsely sliced (usually DC coupled) demodulation. AC coupled or precision sliced PIE can also show outstanding sensitivity (about -50 to -55 dBm without an LNA (Low Noise Amplifier)), though it requires similar preambles for training and command set improvements as does Manchester. Thus, if IP issues related to Manchester are problematic, an AC coupled PIE mode can be substituted. Then, to protect the sensitivity of either mode of AC coupled forward modulation, the system needs improved interference control.

2.2 Definitions, RFID Classes, and Basic Physics

To allow more complete explanation, we need precise term definitions and a basic understanding of the physics based limits of the architectures or classes that can be used in battery supported tags. For the purposes of this report we will be using the following terms.

Coupling: Refers to the baseband (not RF) coupling of demodulated forward link symbols from a driver stage into a comparator or slicer. High sensitivity results when the slicing is precise (the DC on both comparator inputs is nearly identical), since small signals can then drive the comparator.

True DC Coupling: The difference between the midpoint of applied signal and the slicing reference is truly fixed, as with a fixed reference on a comparator input. See the figure below.

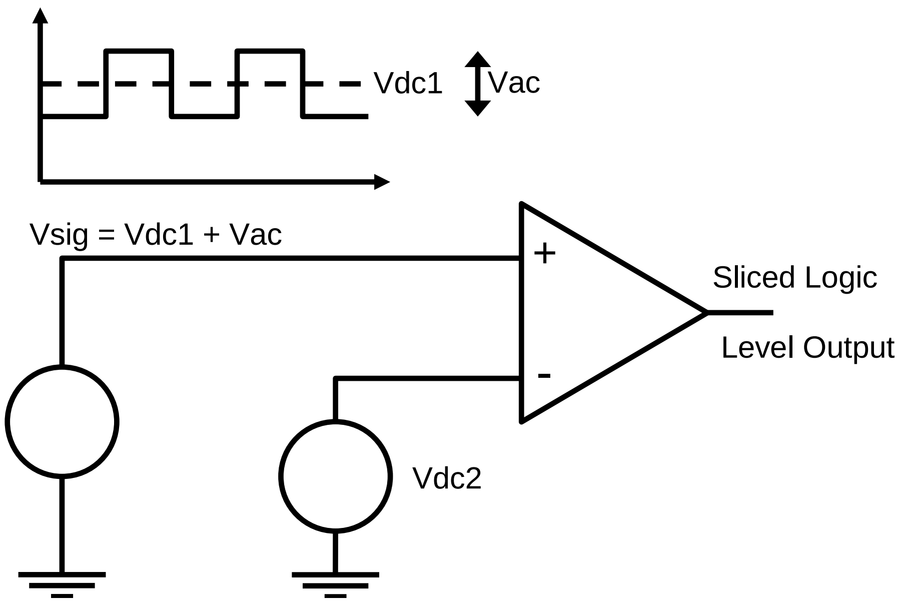


Figure 2.1: True DC coupling. The comparator reference is fixed, and the signal is DC coupled to the other input.

Quasi-DC Coupling: The difference between the midpoint of applied signal and the slicing reference is temporarily fixed during an interval of communications, as with a sample and hold reference on a comparator input. The temporary reference may change between communication intervals, and in a mobile radio link with varying link conditions such change must occur for the link to remain functional. See figure below.

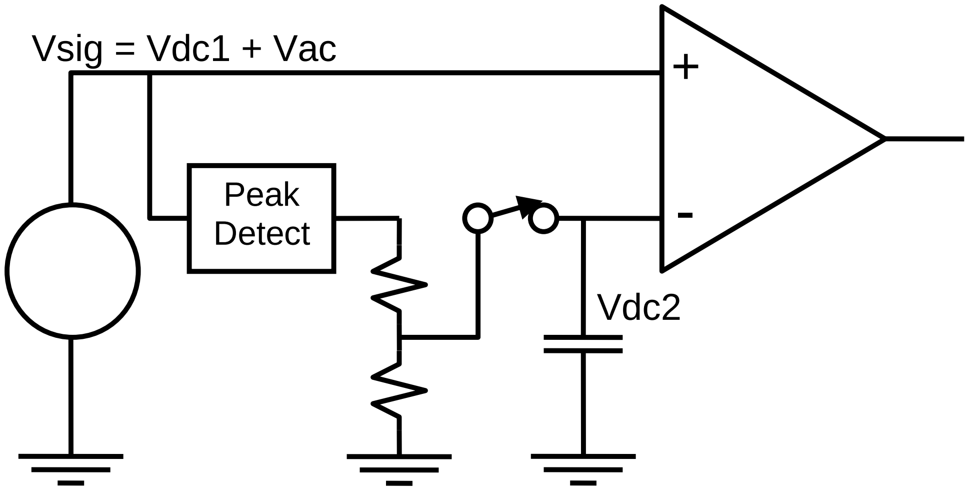


Figure 2.2: Quasi-DC coupling. The peak detect function shown is not meant to imply RF peak detection. It is a baseband peak detection of demodulated symbol peak amplitude. The comparator reference may be temporarily fixed over the duration of a communications interval by capturing an acceptable reference related to the signal at a given moment in time. If the capture is non-linear and "fast", then it may not require special training preambles.

Effectively DC Coupled: Either true or quasi-DC coupling. A feature of effectively DC coupling that is highly relevant to the design of the UHF RFID command set is that it is capable of accurate pulse width measurement without coupling distortion. This capability is presumed in the standard (though not explicitly mentioned) with the use of the special RTcal and TRcal symbols in PIE mode, whose width must be measured in the tag in order to derive the forward and reverse data rates. Effectively DC coupling is adequate for slicing when signal levels are large, which implies that signal is well above noise and that bandwidths may be wide enough for sharp edges where reference placement is not critical. It is thus NOT conducive to high sensitivity in low power and low cost circuitry, though with precision design of tracking references high sensitivity might be achieved. However, such precision tracking will generally require high power consumption in the context of these products, such as op amp based positive and negative peak detectors with bandwidths much greater than the data rate. See figure below.

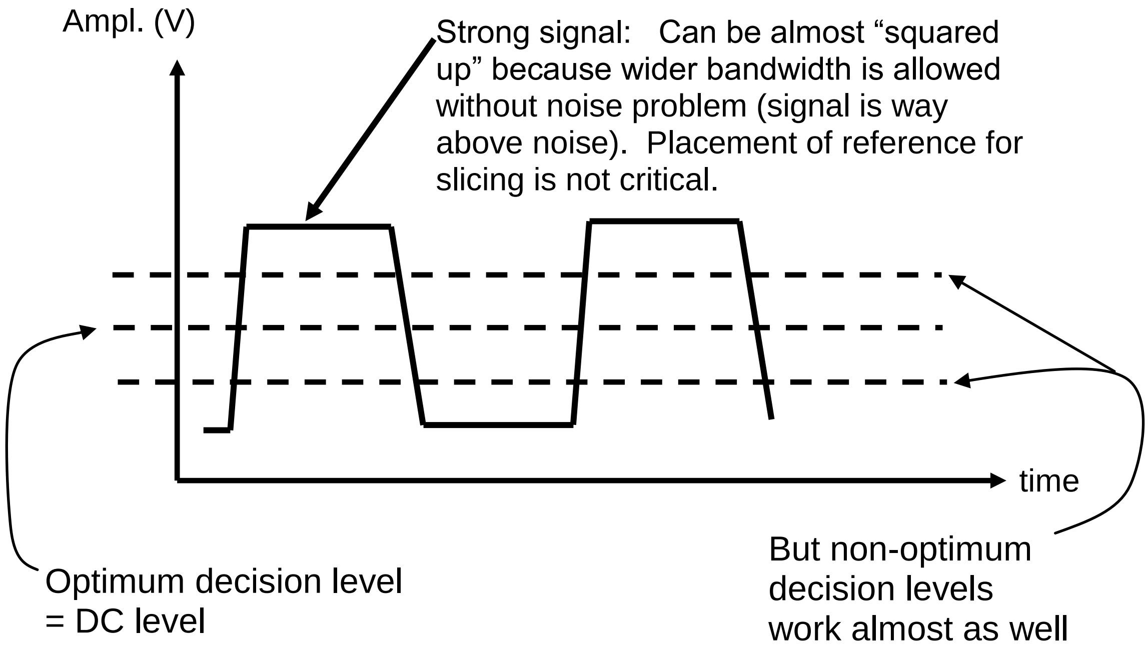


Figure 2.3: Effectively DC coupling is acceptable for relatively large signal swings with sharp edges, since the slicer output is not a strong function of a relatively coarsely placed decision level. In RFID use, it thus tends to less sensitive applications, but can provide for accurate pulse width measurement.

True AC Coupling: Providing a true DC block on the driving side where average level of the difference between the average of the input signal on one input of a comparator and the reference on the other input of the comparator approaches zero in a continuous fashion over time. This difference is constantly moving with short term variations in the DC average of the input signal. The distinguishing characteristics of true AC coupling are that it prevents forward DC flow in the signal path, is linear, that is, it takes time to "train" the AC coupling (in this case, get the DC offset charged onto the capacitor), and that it will continue tracking or adjusting during the communications. The simplest example is a first order RC high pass circuit, as in the figure below.

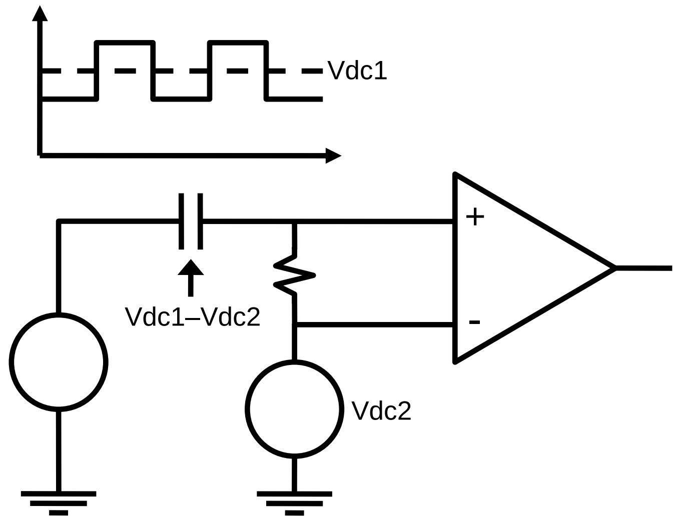


Figure 2.4: True AC coupling with high pass filter. It allows a temporary differential DC term between the two comparator inputs if the signal DC changes, but that difference fades to zero at the time constant of the RC.

Quasi-AC Coupling: Provides the same behavior as true AC coupling in terms of the differential voltage between the comparator inputs, but does so with a low pass filter or low pass analog control system that either adjusts the voltage of the reference input to slowly track the average of the signal, or adjusts the DC content of the signal to match the DC of the fixed reference. A "DC zeroing" control system falls into this category if it is continuous, or into the quasi-DC category if it is intermittent and "frozen" during times of signal demodulation. The only behavioral difference between quasi and true AC coupling is that quasi does allow forward DC flow in signal path. All the other characteristics are the same, and as concerns training requirements via standard preamble design there is no difference. See figure below.

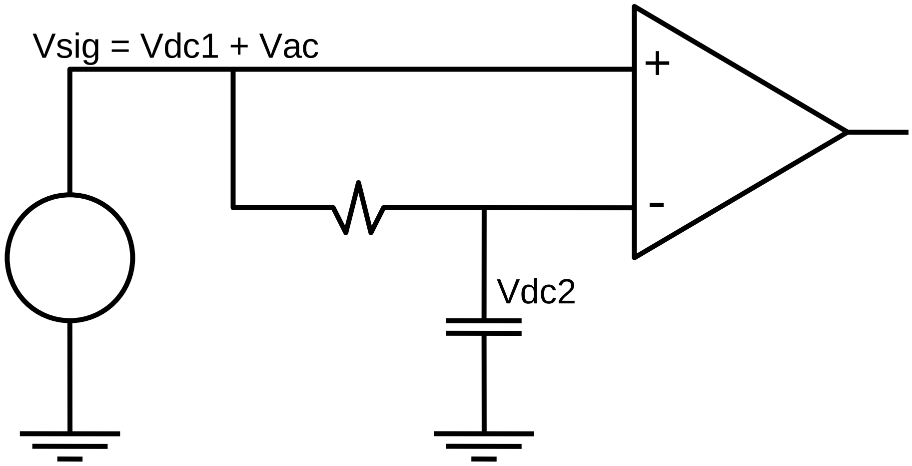


Figure 2.5: Quasi-AC coupling with a low pass filter. It's linear, it takes time to train, and now it is more clearly seen how it continues tracking with a speed limited by a low pass filter function. Note that though DC voltages are applied to both inputs of the comparator by the signal, it is not DC coupling. The differential voltage at the comparator inputs follows the same behavior as the true AC coupled high pass form. The same mathematical behavior can be achieved with a control system that continuously adjusts the reference to track the signal, or adjusts the signal to match the reference.

Effectively AC Coupling: Either true or quasi-AC coupling. AC coupling in general is conducive to high sensitivity by removing DC offsets and thus allowing high gain without saturating gain stages, and by the tracking ability allowing precision control of the decision level such that very small and bandwidth limited (low noise) signals can be successfully sliced. The price paid for these advances is a need to "train" the AC coupling, which takes time consuming preambles. See figure below.

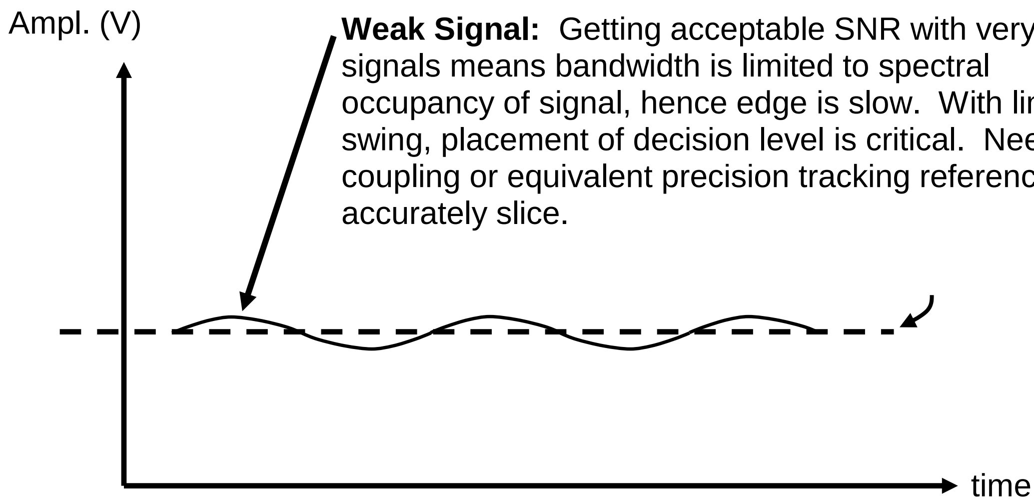


Figure 2.6: AC coupling is conducive to low power high sensitivity by allowing slicing of small, bandwidth limited baseband signals without high precision high power tracking circuitry.

> The term "battery supported" needs to be supplemented by much more specific terms, due to the very large performance differences of various types of battery supported tags.

Passive, Fully Passive, Class 1: All these refer to the use of a detector based receiver with voltage multipliers to power the tag (field powered tag with no battery), with a backscatter based transmitter. In practice these links are "forward link limited", meaning that operating range is usually limited by the tag sensitivity (about -10 to -15 dBm). For a Passive (Class 1) tag sensitivity of -15 dBm, the reader sensitivity need only be about -70 dBm to guarantee (via 10 dB safety margin) that the reader sensitivity is not the limiting factor, which is achieved by competent design despite the presence of the "deafening" carrier needed to provide backscatter. This difference in forward and reverse link sensitivities occurs because the link is asymmetric (inverse square forward link, but inverse 4^{th} return link since "transmit" power at the tag is inverse square with distance, and it fades inverse square again going back.). Free space operating range is about 5 to 10 meters, and practical reliable range is about 1 to 3 meters. This class is currently successfully standardized by EPC and ISO. This link adequate for short range (2 meters) identification functions, but is limited for larger data sets such as logged sensor data.

Key Passive (Class 1) Points for Standard Design: Passive (Class 1) provides a useful level of performance for identification purposes, at minimum cost. However, the Passive (Class 1) tag cannot match up to well designed Passive (Class 1) reader sensitivity, hence the link is "mismatched" and does not reach its full performance. Also, because of the limited sensitivities, only limited interference control is needed. More advanced interference control is not now part of the standard, and for a forward looking standard should be added.

Passive plus Security, or Class 2: The Passive (Class 1) system with additional security features, and also typically with larger memory. There is no battery and the same link behavior exists as for Passive (Class 1).

Semi-Passive, or Class 3: A battery supported tag system with enhanced tag sensitivity, while maintaining use of a tag backscatter transmitter. This eliminates the major weakness of the Passive (Class 1) system, its very limited forward link. However, the physics involved leads to the tag forward link being able to outperform the tag reverse link, as explained below. The link becomes reverse link limited with the burden of link performance being on reader sensitivity. In fact, this class is the most demanding of reader performance, since it requires getting maximum possible reader sensitivity in the presence of the reader also putting out a fairly strong carrier. To achieve the possible performance requires some alert changes in standard design in addition to the outstanding reader design. Explaining these and proposing near optimum methods is the major purpose of this document.

Square Law Receiver: With battery support of the tag receiver, typically including baseband gain but also the option of RF gain, the tag receiver becomes a "square law receiver" for weaker signals. This happens for any non-linear detector type AM wideband receiver that operates via a direct RF to baseband conversion (no local oscillator). The square law transfer function always occurs when the input signal becomes small enough for detector non-linearity to be modeled as 2^{nd} order. Just as a linear transfer function is the limiting behavior for small signal operation at a single frequency, square law operation is the limiting behavior for small signal non-linear operation. In a square law receiver the transfer function is volts out per watts in, or amps out per watts in, which is watts squared out per watts in, hence the name "square law". The sensitivity of a square law receiver is typically limited by baseband noise, not RF noise, since at weak signal levels there is a large conversion loss from RF to baseband (on the order of 30-40 dB).

It is important to understand what performance is possible in a square law receiver in order to competently design a standard using it. It is relatively easy to design an AC coupled or precision reference square law receiver with -40 dBm sensitivity, and with careful design sensitivity can be about -55 to -60 dBm without an RF LNA. With an RF LNA the sensitivity can be improved up to about 15-20 dB, but is limited to an ultimate sensitivity of about -75 dBm (relative to reader carrier plus AM sidebands) in an RFID system because of the wideband RF front end. The noise floor kTB in a 40 MHz bandwidth is about -98 dBm, and leaving a 13 dB SNR for reliable demodulation and a 10 dB noise figure puts sensitivity at -75 dBm. To do better requires a narrowband RF filter. While the square law receiver is thus capable of surprisingly good sensitivity, it suffers the major limits of being "wide open" to interference (selectivity being set by the wide front end RF filter) and having limited dynamic range (due to watts out being proportional to watts in squared). A square law receiver covering 80 dB of input dynamic range must have

160 dB of output dynamic range. This is for practical purposes impossible in a low power receiver in a single dynamic range state, so a sensitive square law receiver requires **multiple dynamic range states**. It also for practical purposes requires AC coupling, automatic gain control, or level adjustment in order to center small signals for data slicing. Thus, if the square law receiver is to perform to its limits, the protocol adopted must allow for AC training preambles and switching of dynamic range states. It is possible to save time in such preambles by selecting the dynamic range state in the hibernate state when receiving the Activation command, and then entering normal mode with dynamic range state already chosen. It is also possible to save more time by settling AC coupling during backscatter times and by non-linear "speed up" of settling during preambles. Options using these methods will be presented later.

Due to the asymmetric backscatter link, it only takes -35 dBm tag sensitivity (at full reader power) for the reader to have to go all the way to the physical limit of about -100 dBm sensitivity (relative to total backscatter at 32 kbps) to "keep up" with the limited backscatter from the tag. A well designed tag sensitivity of -55 dBm finds the reader falling 40 dB or more short of what it needs to keep up. Thus, even with a high quality reader design, the Semi-Passive (Class 3) link is usually reverse link limited. The only exceptions are when the reader forward power is reduced significantly below that used to provide carrier for tag backscatter, when interference well above the noise floor exits, and in the non-ideal case of the tag sensitivity being much worse than it has to be and the reader sensitivity being truly outstanding and operating with a very low reverse data rate.

Key Semi-Passive (Class 3) Points for Standard Design: The tag sensitivity improvement is an important advance, but taking it to its limits with the characteristics of the tag square law receiver requires effectively AC coupling and implementing multiple dynamic range states, which must be accounted for in the protocol. But, once that state is achieved, it is impossible for the weak reverse link to keep up with the now muscular forward link. Making intelligent use of this behavior calls for reducing reader on reader and reader on tag interference with lower forward modulated power than pure carrier used to support backscatter, which strongly implies that power control should be used in Semi-Passive (Class 3). Also implying the need for power control is need for better interference control brought about by the higher sensitivities of both links. Other interference control measures such as optional split bandplans and time coordination should also be used. Finally, the recognition of the immutable limits of a backscatter reverse link, which are not helped by the battery in the tag, implies that the standard should gracefully allow for optional or full time active transmission from the tag for links or applications needing a better link than is possible with backscatter.

Class 3 Plus, Semi-Active: This new class (at least within the context of planned standards) corrects the weaknesses pointed out for Semi-Passive (Class 3). These new terms are proposed to mean the combination of a square law receiver with an active transmitter, typically a fine stepping phase locked transmitter with a transmit power capability on the order of 0 dBm (1 mW). This power level is supportable by a small lithium button cell or thin cell battery. Why fine stepping? Because the tag power supportable with small batteries allows for narrowband (non-hopping) operation under the FCC rules, and the competent system designer does not waste the precious resource of spectrum on wider hopping channels when it can be avoided. This mode allows for a perfect match of the forward and return links, as follows. With an LNA, a well optimized square law tag receiver is capable of about -75 dBm sensitivity. From a +33 dBm reader transmitter the link loss can thus be as high as 108 dB. A well optimized reader receiver without a high power carrier in receive mode and with the 3 dB sensitivity boost of only 2 tag sidebands compared to 4 for backscatter with subcarrier (both allowed by the active tag transmitter) is capable of about -105 dBm sensitivity at 32 kbps. From a 0 dBm tag transmitter the allowed link loss is now 105 dB, an almost perfect match of link capabilities. Another way to quickly verify this matched link condition is to note that the tag sensitivity is about 30 dB inferior to the reader, but the reader matches this with up to about 30 dB more transmit power than the battery powered tag. The best use of this mode would be as an optional capability to Semi-Passive (Class 3), so that the reader can order active replies from the tag when the link loss is too severe for backscatter, or when interference levels are too high for backscatter. When using backscatter, the reader supplies a carrier, but when using the active transmitter in the tag there is no need for reader carrier.

From a reader supplier point of view, Semi-Active Class 3 Plus is an easier reader to design for, as the phase noise and isolation requirements are lower. A top quality Semi-Active reader can be very highly integrated, and thus of minimum high volume cost. A top quality Semi-Passive reader, with its needs for low phase noise and higher isolation, tends to be more discrete and thus more expensive.

Key Semi-Active (Class 3 Plus) Points for Standard Design: Semi-Active (Class 3 Plus) is the simplest RFID architecture that provides a "matched link" under optimum design conditions, and the simplest that can do tag to tag networking. It does so with up to a 40 dB link improvement over the Semi-Passive (Class 3) reverse link and a 60 dB improvement over Passive (Class 1) forward link. It thus has performance to burn compared to the other classes, allowing trade-offs such as tiny tags using electrically small and more selective antennas while still improving on standard Semi-Passive (Class 3), or very low reader power that does not require hopping under FCC rules and thus allows superior frequency plans. This powerful capability can be added to the current standard with minor command set extensions, which will be outlined in this report. If this capability is judged as beyond our current charter, then if the command set proposed is adopted, we at least have a clear path to future adoption of this mode.

> Semi-Active Class 3 Plus is another big step forward that is rather easily allowed for in the standard. The rock solid return link matches the solid forward link, it has better band citizenship, and can often use narrowband channels (avoid hopping) and thus get in quiet spots and make better use of spectrum. **What's not to like?**

5. Active, Fully Active, or Class 4: These terms refer to the use of fully active receivers and transmitters in the tag. With a superheterodyne or direct conversion receiver in the tag, its sensitivity would be approximately -100 dBm at 32 kbps. With a super-regenerative receiver in the tag for maximum battery life, its sensitivity would be about -

90 dBm. Tag transmit power would likely be about 0 dBm, as with Semi-Passive (Class 3 Plus). Compared to Semi-Passive (Class 3) and Semi-Passive (Class 3 Plus), the Active (Class 4) tag system has the significant advantage of selectivity at the tag. Reader on tag interference is much lower for this class than for Semi-Passive (Class 3) or Semi-Passive (Class 3 Plus), and its tag to tag networking capabilities are superior to Semi-Passive (Class 3 Plus).

Key Active (Class 4) Points for Standard Design: Active (Class 4) is a natural for incorporation into 900 MHz (as opposed to 433 MHz) because of the business, regulatory, and physical advantages of 900 MHz. The business advantage is that the customer can do it all under one infrastructure, with tags that operate in lower power modes when possible, but which resort to higher power active when necessary. The regulatory advantage is the much greater spectrum, higher transmit power, and continuous duty cycle allowed at 900 MHz. The physical advantage is the smaller resonant antenna size. For these reasons Active (Class 4) probably has a strong future in 900 MHz RFID, and it is thus desirable for the features and commands of the standard now under development to anticipate active operation. We thus show some possible command structures built upon those proposed here that would allow for Active (Class 4) operation.

> Active (Class 4) is the ultimate RFID form, suited to the most demanding applications, and far more naturally implemented at 900 MHz than any other band. The big deal compared to other classes is that the tag is now frequency selective and much more immune to interference. The greater tag sensitivity allows better tag to tag networking than Semi-Active (Class 3 Plus) and lower reader power that in turn allows narrowband U.S. operation (no hopping).

The figure below documents the function relating required reader sensitivity as a function of tag sensitivity, and vice versa, at the 1 watt reader power level.

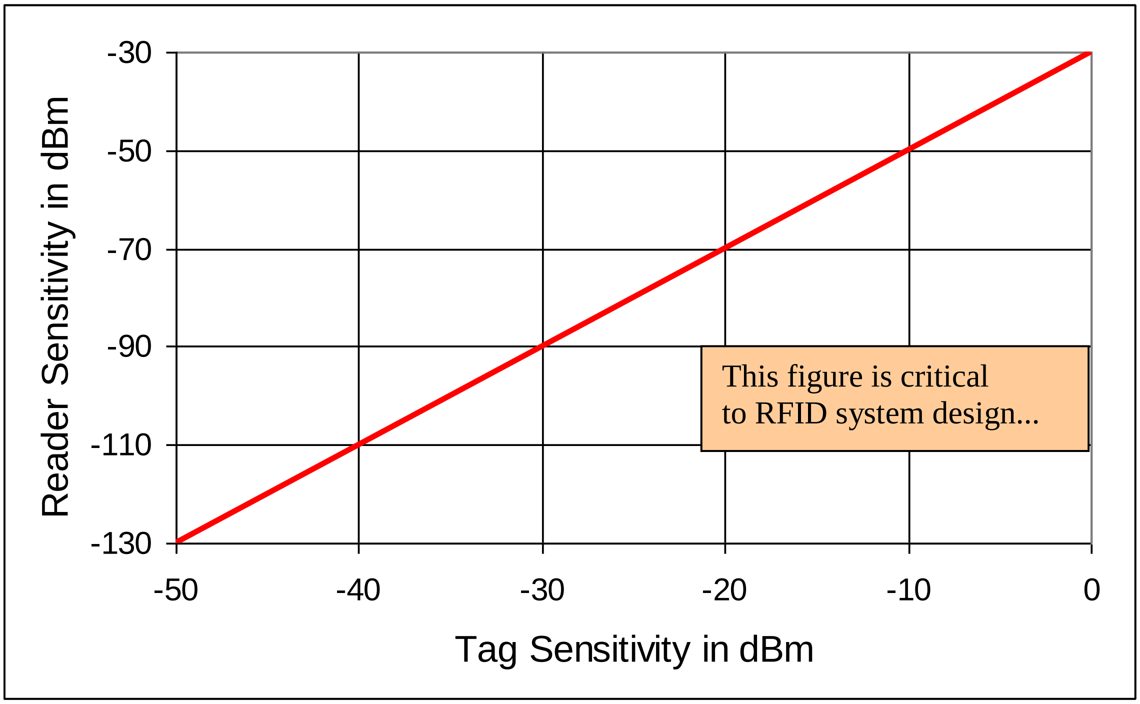


Figure 2.7: The relationship between reader and tag sensitivities to maintain a "matched link" condition where the range of both links is equal. This graph assumes tag duty cycle of 50% and tag backscatter efficiency of 50% also.

The numbers in this table are also critical to RFID system design...

The basic performance numbers concerning the classes defined above that should be considered by the standard design committee are summarized in the table below.

Table 2.1: Key class points summary (tag backscatter is Euro power level, centered at 3 dB inefficiency loss, and per 2 useful sidebands)

	Tag Xmit Power	Tag Sensitivity	Tag Selectivity	Reader Sensitivity	Link Limits & Range
Passive (Class 1, 2)	Backscatter Max -5 to 0 dBm @ 1.5 meters per 2 sidebands Max -18 to -13 dBm @ 5 meters per 2 sidebands	-10 to -15 dBm	Approx 100 to 200 MHz	-70 to -80 dBm	Forward limited by 10 to 20 dB depending on reader sensitivity Practical range 1-2 meters
Semi-Passive (Class 3)	Backscatter Max -24 to -19 dBm @ 10 meters per 2 sidebands	-40 to -60 dBm no LNA -50 to -75 dBm with LNA	Approx 30 to 200 MHz	-80 to -110 dBm	Reverse limited by 0 to 90 dB depending on tag and reader sensitivities. (Only 0 dB if tag is poor and reader is outstanding and at very low reverse link data rate) Practical range 5 to 10 meters at good reliability if standard properly designed.
Semi-Active (Class 3 Plus)	-20 to +7 dBm per 2 sidebands	-60 to -75 dBm with LNA	Approx 30 to 200 MHz	-93 to -113 dBm (ASK or FSK return link)	Approx matched Practical range 20 to 50 meters at good reliability if standard properly designed.
Active (Class 4)	-20 to +7 dBm per 2 sidebands	Approx -90 to -110 dBm	Selectable 25 KHz to 500 KHz	-93 to -116 dBm (assuming PSK return link option)	Reverse limited by approx 30 dB Practical range 20 to 50 meters, but at high reliability and best band citizenship

We have confirmed the Semi-Passive (Class 3) square law receiver sensitivities given above in analysis, simulation, and laboratory measurement. Actually using those sensitivities requires that interference control be introduced into the standard, which in turn requires some new timers and command extensions.

We can't write a good standard without having a clear vision.

2.3 Strategic Questions and Answers

If the decision is taken to add higher performance and a deliberate future option to allow active behavior in the tags, then the following key questions arise:

Key strategic question 1: What is the forward link strategy to be for both excellent Class 3 sensitivity and backward compatibility to Passive (Class 1) readers? What coupling is assumed in the tag receiver? Do we allow for high sensitivity tag receivers with multiple dynamic range states?

Key strategic question 2: What measures should we take, and how well incorporated are they into the standard, for dealing with the clear interference issues of significantly improved sensitivity? For what is not immediately incorporated into the standard, what is the road map for future use?

Key strategic question 3: What is the plan for growth of the command set and accommodation of the need to add the powerful capabilities of Semi-Active (Class 3 Plus) and Active (Class 4)?

Key strategic question 4: How do we keep the standard as royalty free as possible while accomplishing the above? There is possible IP encumbrance, such as further undisclosed pending patents that may read on newer methods such as the Manchester forward link. It is known that there is pending IP on necessary system behavior such as power leveling and regulatory region roaming. Do we ignore these potential hurdles to standard adoption by EPC, or deliberately plan to deal with them?

In light of the above questions, we propose the following answers:

Strategic Answer 1—Forward Link: The clearly best forward link options for the industry and the customers is a hardware and firmware backward compatible DC coupled PIE mode that can be used by the currently deployed generation of Passive (Class 1) readers with some tag sensitivity improvement, and a sensitive AC coupled Manchester mode that can be taken advantage of by upcoming highly sensitive fully Semi-Passive (Class 3) enabled readers. A firmware upgrade to existing readers, allowed by a large fraction of but not all of the fielded readers, can provide for optional features for the DC PIE mode. Note that this preferred option requires that it is made clear that there is NO IP impediment regarding the use of the sensitive Manchester. If there is IP impediment, then we have to consider replacing the Manchester with a sensitive AC coupled PIE that is not as IP encumbered. In that case the command definitions that allow for Manchester can also provide for a sensitive PIE mode with interference control. However, the training for sensitive AC PIE has to take into account the DC content of the PIE symbols.

Strategic Answer 2—Interference Control: The use of highly sensitive tags and readers requires the use of interference control for good reliability. In the reader a receiver of high frequency selectivity is available. This naturally points to the use of optional split band plans (for closed systems) where the more serious interference problem of reader on reader interference is much lower (the readers in the listen mode segment only put out quiet carriers for backscatter support and do not subject each other to nearby forward modulated spectral splatter). The other easily available interference control tool is power leveling, or limiting the reader transmissions (particularly the modulated forward transmissions) to only that needed for a reliable link. We shall provide detailed suggestions to the standard community for split band plans and power leveling, including incorporation into the command sets, which can largely eliminate reader on reader interference.

Time coordination an equally powerful tool that can and should be applied. Spatial separation, including antenna patterning, is also a first order tool that should be formalized in either the standard or in supporting documentation. Both time and space coordination are also effective on limiting reader on tag interference. Since they may be used outside the scope of the standard and do not immediately affect product definition, is not critical that they be captured in standard documentation right now. However, we would propose that they be captured in a standard revision in 2008, perhaps in concert with Semi-Active (Class 3 Plus).

That leaves direct sequence spread spectrum, or code separation, as the only major weapon of multiple access not yet planned for use by the standards community. In our internal investigations we have found ways to use direct sequence to advantage, but so far not to such strong advantage that we can yet recommend it for incorporation in the standard. It is most needed in the forward link due to the interference susceptibility of the wideband tag receiver, but square law receivers require 2 dB of baseband processing gain to get 1 dB of RF interference immunity, hence interference improvement is practically limited to about 5 to 10 dB. We therefore defer the possible employment of direct sequence to a later date.

> The behavioral differences between the backward compatible PIE and the much more sensitive AC coupled option effectively requires significant command set and feature extension.

Strategic Answer 3—Command Set and Preambles: The primary weaknesses in the current command set and preambles are:

1. Lack of clear definition of the roles of PIE and Manchester. Is PIE AC coupled and sensitive, or DC coupled and backward compatible? If backward compatible, is that with no reader software upgrade or requring software upgrade? Since no white papers or articles are so far being published, and the standard deliberately avoids wasting time tutoring, the chance of confusion is high.
2. Inadequate AC training for high sensitivity multiple dynamic range state tag receivers.
3. Limited and non-optimum provision for power level control, which is needed for performance and to flush out pending IP.

4. No planned provision for regulatory region roaming, which is also needed to flush out IP.
5. No planned provision for extension to Semi-Active (Class 3 Plus) and Active (Class 4).

Our recommendation for forward mode strategy is a DC coupled PIE that is backward compatible for Passive (Class 1) readers, with modest increase in tag sensitivity compared to Passive (Class 1) that can take advantage of existing reader sensitivity safety margin, and sensitive AC coupled Manchester to take Semi-Passive (Class 3) to the limits it is capable of. This requires full IP disclosure and assurances of acceptable royalty load. If such assurances are not forthcoming, then our recommendation changes to become sensitive AC coupled PIE to meet the need for a sensitive forward link with minimum IP encumbrance. Since Manchester is the superior mode for communications purposes, we hope the IP situation does not prevent its use.

Our recommended **command set improvements** may be summarized as follows:

1. Add the capability to optionally "lock" the tags to the activating reader. This may be achieved by having the Activation command inform the tags of its identity along with a flag indicating if the tags are to use the identity as a filter on commands the tag received. The global commands would generally have an 8 bit Reader ID field appended IF the lock mode has been selected. Individual commands do not need the lock field because they are addressed by the RN16 they have provided to the reader.

2. Make the <u>capability</u> to use power leveling mandatory for the sensitive mode, providing the necessary features in Semi-Passive (Class 3) tags and readers. Whether an application uses power leveling would depend on user based software choice.

3. To the Semi-Passive (Class 3) Activation command, add fields for locking tags to readers via Reader ID, for activating tags based on Inventory flag state (superior for power level operations), for passing reader transmit power (also enabling to power leveling), geographic region (enabling to tag set up, such as front end filtering), and type specifier (wake up tags of type Semi-Passive (Class 3), Semi-Active (Class 3 Plus), Active (Class 4), or a combination). If the specifier is Semi-Passive (Class 3), the Activation command terminates. If the type specifier is for Semi-Passive (Class 3 Plus), then the Activation command is longer and also specifies tag transmit channel (for PLL programming), transmit power, and modulation mode (a Semi-Active Class 3 Plus tag could transmit ASK, FSK, PSK, or even direct sequence). If the type specifier is Active (Class 4), then the Activation code is longer still and specifies a channel for tag receiver operation and receive modulation mode following full power up. The recommended channel spacing is 25 KHz, allowing high flexibility in future channel plans that may involve a large number of narrowband channels allowed by sensitive tag receivers and active transmit at the tag.

4. For DC coupled PIE, eliminate the optional Activation command, as it is not hardware compatible with existing readers. Provide for battery life enhancement in the DC PIE

case with an optional command made available with only a firmware upgrade that provides for receiver duty cycling.

5. Also make DC PIE Query_BAT an option provided by a firmware upgrade to existing readers. Thus the existing Passive (Class 1) readers would inventory Semi-Passive (Class 3) tags in the same inventory round as passive tags, but with a firmware upgrade those existing Passive (Class 1) readers have the option to inventory Semi-Passive (Class 3) tags in a separate battery supported query round.

6. If sensitive PIE is incorporated, then it must be AC coupled (or effectively AC coupled by AGC level control in the tag), which means that extra long and distorted duty cycle symbols like RTcal and TRcal must be eliminated. That means that forward data rates must be specified within a new AC PIE Activation Code that is functionally identical to the Manchester Activate. The remaining AC PIE commands would duplicate the functionality of the Manchester command set.

7. Given a 13 bit channel specifier for Semi-Active (Class 3 Plus) and Active (Class 4) tags to allow a 25 KHz channel step to cover 200 MHz of spectrum (which should cover all feasible future bands around the world), the reader channel number in the BroadcastID command should be changed to 13 bits also.

8. The high sensitivity that Semi-Passive (Class 3) is capable of, combined with the square law nature of the receiver, means that good AC settling and possible switching of receiver dynamic range state should be allowed for in training and timing acquisition preambles. We thus propose new and longer training preambles, augmented by a new training symbol (the Special One) for sensitive PIE. We also propose optional training with controlled and reduced amplitude steady state carriers for AC training. These steady state training times produce less average reader on reader interference than symbol based training times.

9. Optimum power leveling requires changes in commands and in flag usage from what appears to be currently anticipated. The currently defined DeactivateBAT, needed for group power downs of previously accessed tags, is defined only to control tags based on the Select flag state, and not Inventory flag state. The session Inventory flags are the best flags to use for a tag to indicate that it was successfully read in a lower reader transmit power state and need not be accessed in a higher power state, since they are unique to each session and allow a tag to be in power leveled operation with multiple readers. They also automatically change state upon access, thus eliminating wasted time as compared to using Select commands to set the Select flags. However, for Passive (Class 1) the Inventory flags have very coarse limits on their timeouts (persistence), and these timeouts are not the same for all sessions. We thus recommend accurate programmable timers to set the Inventory flag timeouts, and new commands to conduct this programming. A reader transmit power control algorithm based on extensions to correct these weaknesses is outlined later.

Strategic Answer 4 –IP: This industry does not have the cash flow to support the kinds of royalties that have come to be expected in paid airtime wireless. Our position is thus that a royalty free standard or as close to it as can possibly be developed should be the industry goal. It is therefore our intention for Maxim IP necessary to practice of the standard, including optional parts of the standard, to be offered royalty free in return for reciprocity. To encourage all involved IP holders to state their terms, we propose including desirable features at the earliest possible date in the standard. For example, it is known that there is pending U.S. IP on power control in RFID, and on adaptation to environmental conditions such as regulatory region. For that reason we propose adding improved commands supporting power leveling and regulatory region roaming.

2.4 Usable and Achievable Tag Sensitivities

To our knowledge it has not been presented to the standards community how sensitive a battery supported tag *can* be (electronically), and sensitive it *should* be (before it is too unreliable due to interference). We will address both issues starting with the interference environment.

2.4.1 Interference to the Tag Receiver

The main sources of interference are from within the RFID system itself, from cell phone handsets, and from pager transmitters around 900 MHz. A secondary interfering source is cellular base stations. There are also other possible sources of interference from other powerful emitters such as airport radar and aircraft identification transponders at 1030 and 1090 MHz that have not yet been investigated.

However, while we find these interference sources to be problematic, they are not so severe that tag sensitivity as compared to what is electronically possible should be artificially restricted by the standard. Our recommendation is for the standard to support allowing for full sensitivity and also providing for interference control to preserve that sensitivity.

2.4.1.1 Tag Signal to Interference Requirements

The square law nature of the tag is actually a help in interference. Because the requirement for signal to interference is basically about 12 dB baseband, with the receiver generating 2 dB out per 1 dB in, it only takes about 6 dB of RF input signal Signal to Inteference Ratio (SIR) to achieve 12 of output SIR. This is true so long as the interfering source is not directly co-channel with the desired signal and the tag provides good quality baseband filtering. The tag will provide such filtering if it has been designed for best sensitivity, since baseband noise must be limited.

This may be shown analytically as follows. Let a desired input steady state carrier signal (pure carrier for reasons of simplicity) have a voltage coming out of the tag antenna as follows:

Eq. 2.1: $V_1 = V_{s1}\,Sin(\omega_1 t)$, where the signal has peak amplitude V_{s1}. Then let a lower amplitude interfering signal be given by:

Eq. 2.2: $V_2 = V_{s2}\,Sin(\omega_2 t) = LV_{s1}\,Sin(\omega_2 t)$, where "L" is a "loss" factor between 0 and 1.

Then the total signal is given by:

Eq. 2.3: $V_{Tot} = V_{s1}\left(Sin(\omega_1 t) + L\,Sin(\omega_2 t)\right)$, and

Eq. 2.4: $V_{Tot}^2 = [V_{s1}(Sin(\omega_1 t) + L\,Sin(\omega_2 t))]^2 = V_{s1}^2 [Sin^2(\omega_1 t) + 2LSin(\omega_1 t)Sin(\omega_2 t) + L^2 Sin^2(\omega_1 t)]$

Now apply:

Eq. 2.5: $Sin^2(\omega\, t) = \frac{1}{2} - \frac{1}{2}Cos(2\omega t)$, and

Eq. 2.6: $Sin(\omega_1 t)Sin(\omega_2 t) = \frac{1}{2}[Cos(\omega_1 - \omega_2) - Cos(\omega_1 + \omega_2)]$

When applying these, neglect the higher frequency terms (they are filtered off at base-band). Making these substitutions gives:

Eq. 2.7: $V_{Tot}^2 = V_{s1}^2 \left[\frac{1}{2} + L\,Cos(\omega_1 - \omega_2) + \frac{L^2}{2} \right]$

The cross term will be noticeable if the interference is co-channel, but most of the time it may be filtered off. Also, it must be kept in mind that the detector, being square law (as explained in the section on electronic sensitivity limits), will give an output *current* that is proportional to the voltage squared terms in the input. Thus, the SIR is the *square* of the ratio of the first term to the third term, or:

Eq. 2.8: $SIR = \left[\frac{1}{L^2} \right]^2 = \frac{1}{L^4}$

Recall L is a voltage ratio. For an input RF power difference of 6 dB, L = 2. For this case, the dB SIR would be 12 dB, as expected.

Possible confusion may reduced by defining a power ratio between desired RF signal and undesired RF interference as $L_p = L^2$. Then baseband SIR may be written as:

Eq. 2.9: $SIR(dB) = 10\log\left(\frac{1}{L_p^2} \right)$

The following SIR analyses will assume that interference is not directly co-channel, and that 6 dB of RF SIR leads to an acceptable 12 dB of baseband SIR.

2.4.1.2 Reader on Tag Interference

"Enemy" reader on tag interference will be the statistically most common form of interference that tags will suffer. The graph below shows that interference will typically occur within about 100 meters for full sensitivity well designed CMOS tags where the enemy is at 1 watt with 6 dB antenna gain. Inside this distance time coordination and transmit power control are recommended.

Figure 2.8: Enemy reader signal level as seen by a tag in the main lobe of that reader. The propagation exponent is assumed to be 2.0 at close range and to degrade to 3.0 at 100 meters (a typical indoor behavior).

2.4.1.3 Cellular Handset on Tag Interference

The figure below shows typical handset interference (U.S. case) causing sensitivity degradation within 15 meters for well designed CMOS tags.

Figure 2.9: U.S. cell handset signal level as seen by a tag. A typical handset power of +20 dBm is illustrated, at 849 MHz with a tag front end filtering and antenna total rejection of 26 dB. The propagation exponent is assumed to be 2.0 at close range and to degrade to 3.0 at 100 meters.

2.4.1.4 Cellular Base Station on Tag Interference

The cellular base station can cause interference at longer ranges in the U.S. case, as it is so close to 902 MHz that rejection is practically zero. The figure below illustrates the situation.

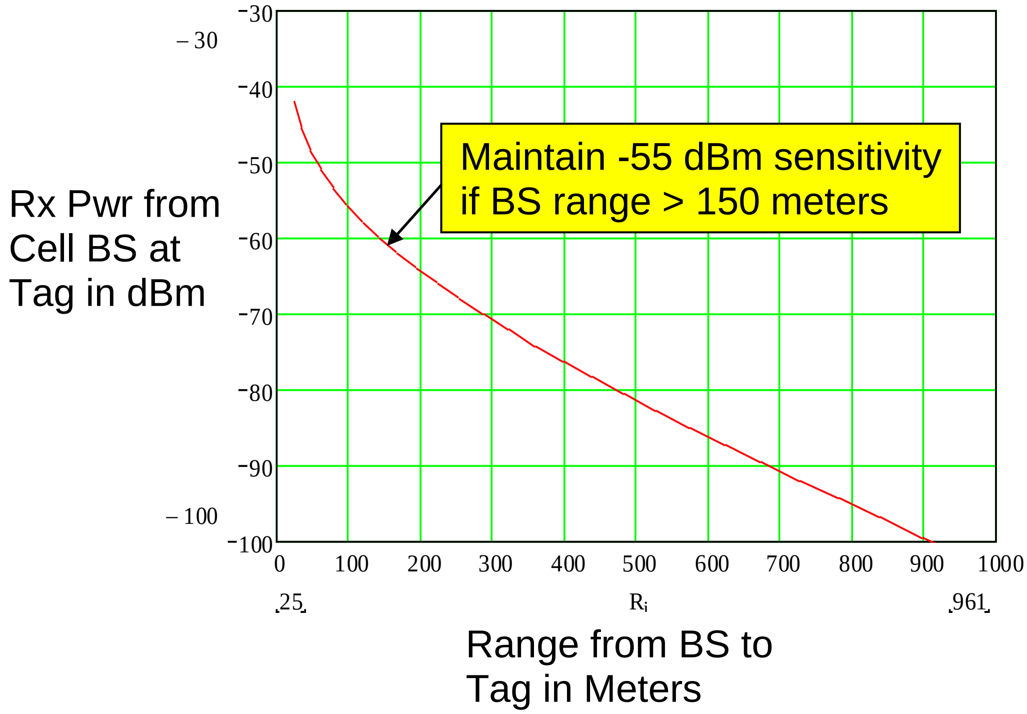


Figure 2.10: U.S. cellular base station typical signal level as seen by a tag. A typical base station power of +20 dBm with 10 dB antenna gain is illustrated, at 894 MHz with a tag front end filtering and antenna total rejection of 3 dB. The propagation exponent is assumed to be 2.0 at close range and to degrade to 3.0 at 1000 meters.

2.4.1.5 Pager System on Tag Interference

Pager interference can be problematic because some pager systems are quite powerful and sometimes quite close to RFID frequencies. Though their usage has been declining due to the prevalence of cellular and PCS, they are still in use in most metropolitan areas. For example, in the United States there are pager systems with multiple bands in the 400-500 MHz range that are not a significant problem, but other systems at 929-930 and 931-932 MHz that typically operate at 250 watts and that can be as high as 3500 watts. The proximity of these frequencies to the 902 to 928 MHz band means that RF filters generally provide little protection. However, the high sensitivity of pager receivers means that typical system design does not lead to unacceptable interference with respect to even well designed Semi-Passive Class 3 tag sensitivities over the great majority of RFID system installations. We investigate the basic physics below with graphs of interference range and a basic interference analysis.

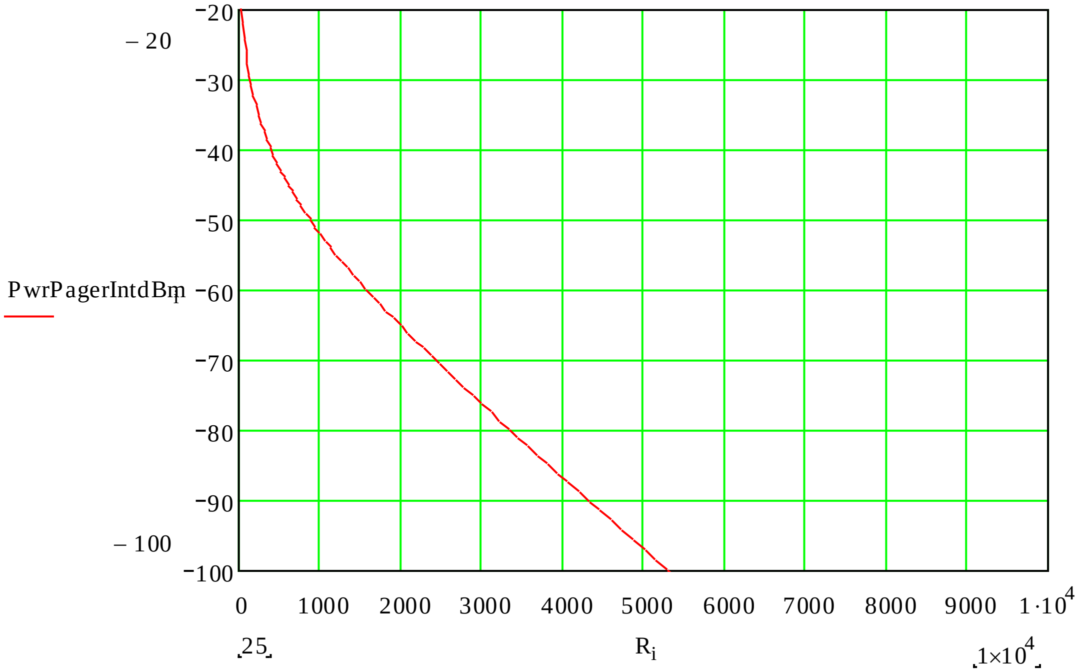


Figure 2.11: U.S. pager interference range with pager power of 250 watts and 3 dB transmit antenna gain, frequency of 929 MHz, propagation exponent of 2 at close range degrading to 4 at 10 km, and 10 dB final penalty (building penetration). Note that for final sensitivity of about -55 dBm, interference can occur for ranges less than about **1.7 km**. The choice of 10 dB building attenuation is explained later.

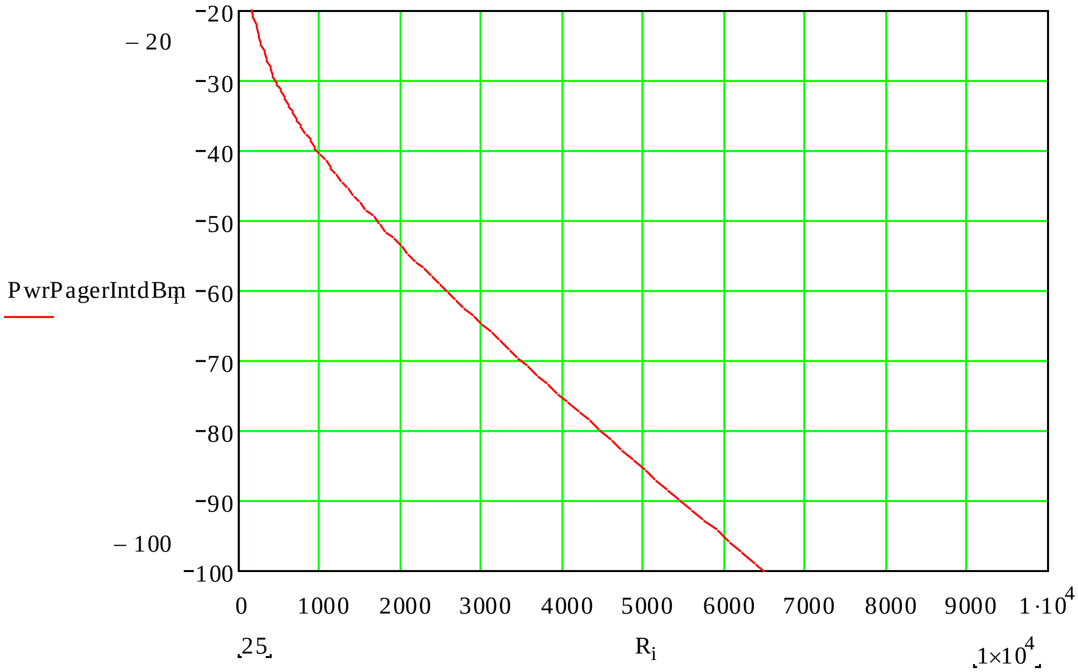


Figure 2.12: U.S. pager interference range with pager power of 3500 watts and 3 dB transmit antenna gain, frequency of 929 MHz, propagation exponent of 2 at close range degrading to 3 at 10 km, and 10 dB final penalty (building penetration). Note that for final sensitivity of about -55 dBm, interference can occur for ranges less than about **2.7 km**.

We therefore note that interference from pager systems is sometimes inevitable. The key question arises as what *percentage* of the time such interference occurs. This question may be given a first order answer by use of the below figure.

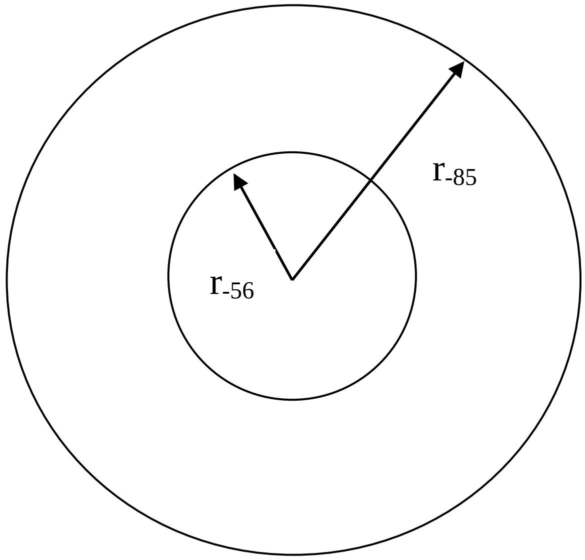


Figure 2.13: A particular case of tag interference range and area and pager coverage area for a particular case. The inner circle covers ranges for which the pager signal is above -56 dBm (which allows interference limited sensitivity to degrade to, and the outer circle is ranges for which coverage is -85 dBm or greater. Pager receiver sensitivity is approximately -110 dBm, so pager system layout will provide for near 100% coverage with some fade margin and overlap, which is assumed here as 25 dB, thus requiring -85 dBm nominal pager signal at maximum range.

In the above figure, assume that the propagation environment is inverse 3.5 with range, which is approximately true in urban environments with a relatively high pager tower. The ratio of receive power at -85 dBm to receive power at -56 dBm is 1.26E-3. Thus:

Eq. 2.10: $\frac{P_{-85}}{P_{-56}} = 1.26E-3 = \frac{Cr_{-85}^{-3.5}}{Cr_{-56}^{-3.5}} = \frac{r_{-56}^{3.5}}{r_{-85}^{3.5}}$, and therefore

Eq. 2.11: $\frac{r_{-56}}{r_{-85}} = (1.26E-3)^{\frac{1}{3.5}} = 0.148$, and for the percentage of area where unacceptable interference occurs we get

AreaRatio = (radius ratio)^2 = 2.2%

The area of interference seems surprisingly low for the strength of the pager transmitter, but when one considers that the nominal sensitivity difference of even well designed battery supported tags and typical pagers is approximately 40 to 60 dB, then it is to be expected.

This example may be generalized as follows:

Eq. 2.12: $AreaRatio = RadiusRatio^2 = PowerRatio^{\frac{2}{n}} = \left(\frac{P_{\lim}}{P_{\text{int}}}\right)^{\frac{2}{n}}$

In the above equation, n is the propagation exponent with distance in the particular environment, $P_{\lim}$ is the typical receive power at the far edge of the pager coverage area, and Pint is the allowable interference level at the tag. Generally, for square law receivers the allowed interference power is about 6 dB below the expected tag sensitivity so long as that interference is not directly on the desired reader transmit channel.

The table below runs up some typical interference percentage numbers over a range of tag sensitivities. No additional protection such as notch filtering of pager bands or time coordination with pager emissions is assumed. For the better sensitivities, such as might be achieved in Semi-Active Class 3 Plus, such extra protection would be desirable. In the absence of such special protection and in the vicinity of pager transmitters, system operation would probably move towards higher reader powers that overcomes the pager interference. Such interference is one of the reasons we will later suggest programmable tag sensitivity.

Table 2.2: Percentage of area interfered with by typical 929 MHz pager operation for a U.S. 902-928 MHz RFID system using wideband tags.

Tag Sensitivity (wideband tag)	Prop Constant	Area Interference Ratio
-10 dBm	3.5	.011%
-20 dBm	3.5	.043%
-30 dBm	3.5	0.158%
-40 dBm	3.5	0.591%
-50 dBm	3.5	2.20%
-60 dBm	3.5	8.21%
-70 dBm	3.5	30.6%

The authors are based in Dallas, Texas, a metropolitan area with a population of about 5 million people within a 60 km radius. In taking 929 MHz pager signal strength measurements around the north Dallas area, which is well covered by pager systems and is commercial and lightly industrial with some residential, we find pager signal strength measurements from around -90 to -70 dBm inside typical commercial building to typically -70 to -50 dBm outdoors to as high as -20 dBm when quite close to a pager tower. The very high power levels are a tiny percentage of the time, and the numbers in general conform to the simple analysis shown. Attenuation inside buildings as compared to right outside is typically 10 to 30 dB, though as much as 40 dB if deep inside a larger building. We used 10 dB as a typical building attenuation factor in the interference range graphs shown above with the thinking that many of these operations occur somewhat on the fringe of the building and not deeply into it.

We conclude that while pager systems are sometimes problematic for the more sensitive range of possible Semi-Passive Class 3 tag sensitivity, that the general interference signal levels are not sufficiently high to justify artificially limiting the goal sensitivity of Class 3 systems at the standard level. The standard should support high sensitivity with features to deal with interference as necessary.

Future Semi-Active Class 3 Plus systems may feature tag LNAs in the search for better tag sensitivity and balanced forward and reverse links. These tags will be electronically limited to about -75 dBm sensitivity. If they try to keep to -70 dBm practical sensitivity they will find themselves suffering from pager interference approximately 30% of the time. In those situations the reader network should operate with expectations of reduced sensitivity, how much being a function of the particular environment. The problem may be somewhat mitigated by time coordination with the pager system, whereby the reader monitors pager emissions and increases its transmit power at times that it detects the pager system is transmitting.

2.4.2 Electronic Limits to Tag Sensitivity

In this section we shall outline the analysis of the basic sensitivity limits of the battery supported tag receiver. The tag receiver architecture assumed here is a wideband detector that directly converts RF to baseband without benefit of a local oscillator. A diode detector is an example of this form. Transistors may also serve as good detectors, in some circumstances better than diodes.

Though these receiver forms are electronically simple, they are not intuitive as to basic operation, at least not in the weak signal case. This is because they are not presented to us in our basic education, since they were dispensed with in the history of radio in the 1920's with the popularization of the regenerative and superheterodyne receiver architectures invented by Edwin Armstrong. Until RFID came along, the main purpose of the detector based receiver from about 1925 forward was as an introductory AM radio project for children (the "crystal" radio depicted in my "Boy's Book of Radio and Electronics", circa 1952). The superhet was such a fundamentally sound invention that it remains the dominant receiver architecture to this day, and analysis of receivers is usually taught with respect to it.

Thus, most engineers presented with a detector or "tuned RF" receiver initially assume it to be a peak detector. This is in fact basically true for passive RFID tags, but not for Semi-Passive tags. The Semi-Passive tag can have a biased detector where the detection mechanism is the non-linearity in the voltage to current function of the device serving to create an RF to baseband frequency conversion. So, the simplest model that can capture this mathematical behavior is a 2^{nd} order model. A signal analysis based on second order frequency conversion is in fact quite accurate, since for a "small" signal any curve can be represented as quadratic over a limited range. Linear models for gain and noise only apply after the basic signal detection has taken place, but for sensitivity analysis such linear analysis is both useful and accurate. These analyses do work and are no challenge to an analog oriented BSEE, but they are not depicted in the crystal radio section of "The Boy's Book of Radio and Electronics", since the math is a little beyond what eager 12 year old boy radio engineers to be are normally capable of.

A key factor in determining sensitivity limits is that in the absence of an RF LNA it is usually baseband signal to noise ratio that limits the sensitivity. Fundamentally this occurs because the loss from RF in to baseband out of even a highly efficient square law detector with -60 dBm RF input power is about 50 dB relative to total carrier plus sideband power in. Thus the baseband power output of about -110 dBm must compete with baseband noise. If the electronic noise floor is 10 dB above thermal noise, then the noise in a 20 KHz bandwidth is about -121 dBm, yielding about 11 dB SNR.

Now, consider the case of a detector based receiver with adequate front end RF gain to overcome the baseband noise limit outlined above. The thermal noise power in a 50 MHz bandwidth appropriate to a U.S. RFID tag is -97 dBm. If the front end filter has 3 dB loss and the LNA has 3 dB noise figure, then the receiver basically has a 6 dB noise figure, but let's call it 7 dB to account for backend noise. The AM modulation mode requires a 3 dB carrier loss, double sideband imposes 3 dB more (note Manchester is not imposing another 3 dB because in this case we are not limited by baseband noise bandwidth, but by RF bandwidth). Thus, the SNR ratio required is approximately 16 dB. We thus note expected Manchester coded AM sensitivity of about -97 dBm (50 MHz floor) + 7 dB (Rx noise figure) + 16 dB (total SNR) = **-74 dBm**. For a European tag with a SAW front end that could be improved to about **-85 dBm**. Those represent the limits of detector based receivers.

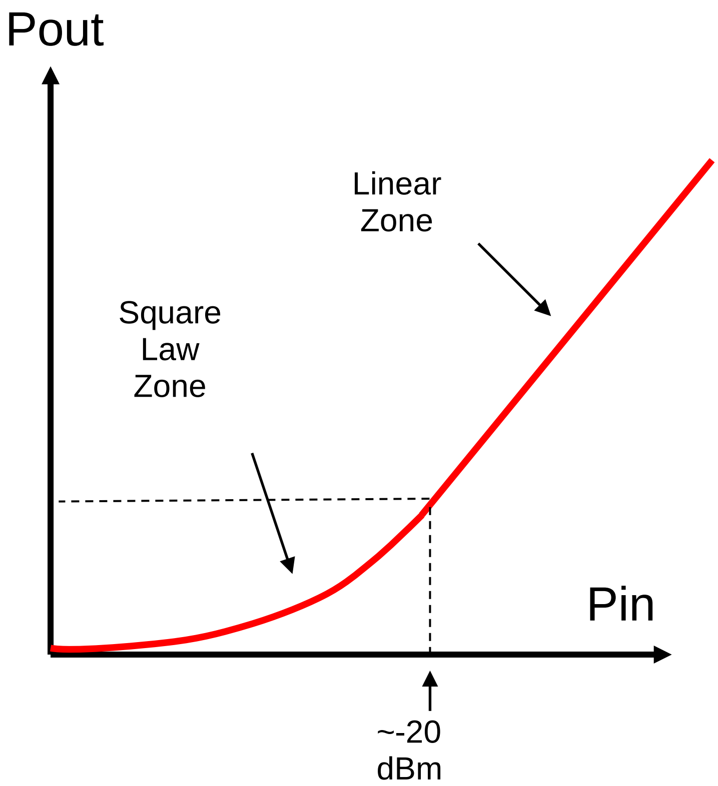


Figure 2.14: The basic square law plus linear transfer function.

The square law receiver may be analyzed for signal harvest as follows. The equation below is the generic Taylor Series expansion of a non-linear function:

Eq. 2.13: $i = I_{bias} + \frac{di}{dv} V_{in} + \frac{1}{2} \frac{d^2 i}{dv^2} V_{in}^2 + ...$

The second order term is the key one. To analyze second order induced RF to baseband transfer we make use of the below identity:

Eq. 2.14: $$V_{in}^2 = \left(V_s\, Sin(\omega t)\right)^2 = V_s^2 \left(\frac{1}{2} - \frac{1}{2}\cos(2\omega t)\right)$$

If we neglect the second harmonic term in this identity and substitute the DC term into the second order term of the Taylor Series, we find for DC current induced by an RF input of carrier peak voltage V_s that:

Eq. 2.15: $$\Delta I = \frac{1}{2}\frac{d^2 i}{dv^2}V_s^2\frac{1}{2} = \frac{V_s^2}{4}\frac{d^2 i}{dv^2} = \frac{P_{in}Z_{in}}{2}\frac{d^2 i}{dv^2}$$

In the above equation, Z_{in} is the impedance environment on the input to the detector and P_{in} is the available RF input power. We generally wish to up transform from the antenna to the detector input in order to get the benefit of passive voltage gain.

For a diode we know that:

Eq. 2.16: $$I_{bias} = i_0\, e^{\frac{V_{in}}{V_T}}$$

where V_T = kT/q. Differentiating twice with respect to Vin gives:

Eq. 2.17: $$\frac{d^2 I_{bias}}{dV_{in}^2} = \frac{I_{bias}}{V_T^2}$$

Substituting this into the expression for harvested DC current above, we get for the diode detector case:

Eq. 2.18: $$\Delta I = \frac{V_s^2}{4}\frac{d^2 i}{dv^2} = \frac{I_{bias}V_s^2}{4V_T^2}$$

So, we have an expression for harvested current that can be experimentally confirmed to be quite accurate. However, in the diode case something goes wrong with making full use of this current. The problem is that the diode has a small signal self impedance, and the harvested current divides to flow through this impedance as well as through a desired load resistance. This is presented in the next figure.

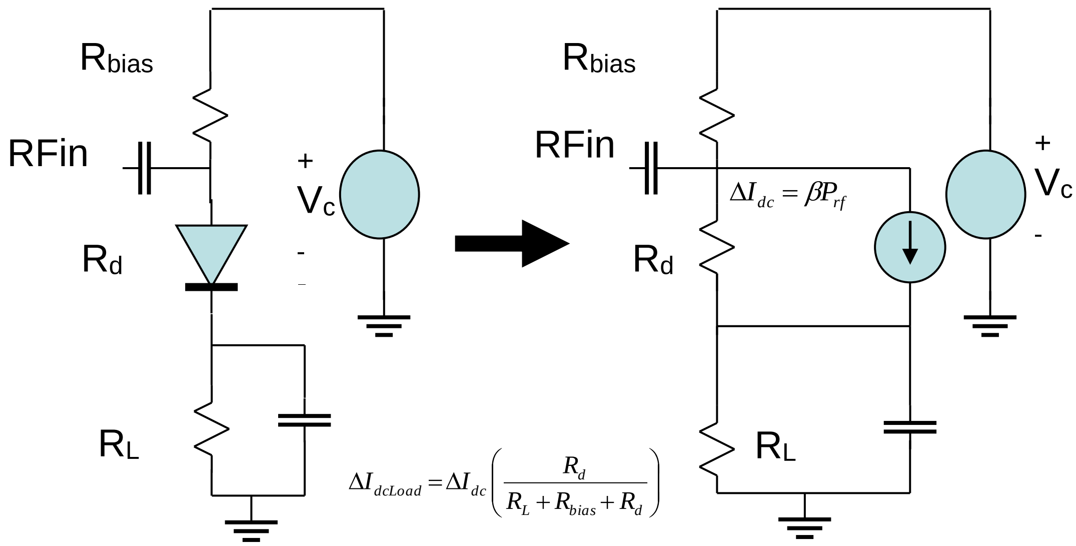


Figure 2.15: The diode detector can be modeled linearly after the detection process in order to determine what fraction of detector current may actually be used.

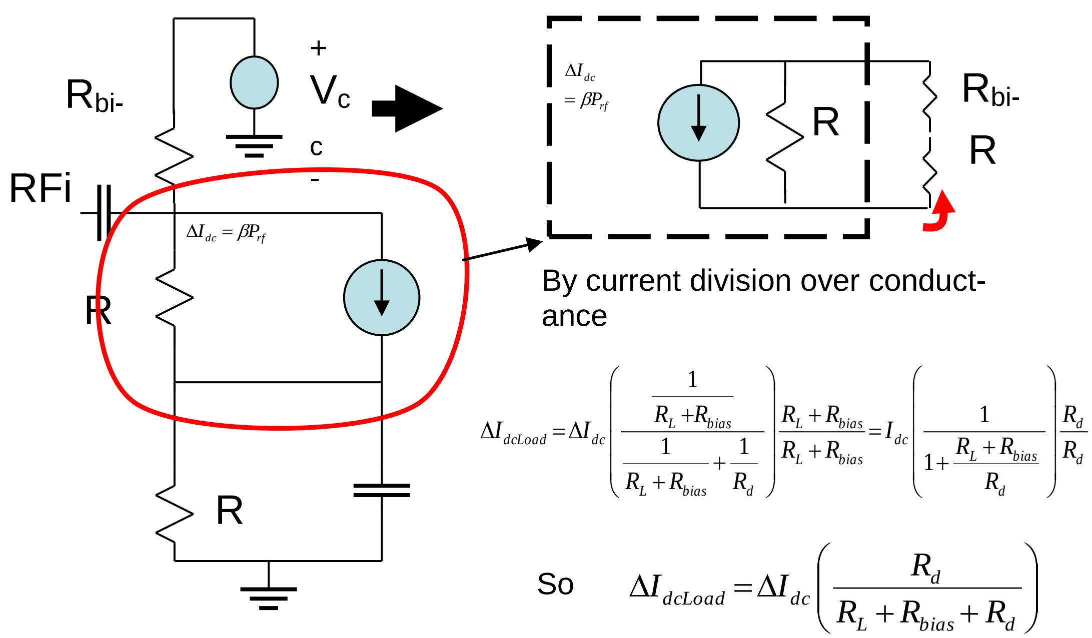


Figure 2.16: The linearized diode detector detailed model further simplified to visualize the current division process.

From Figure 2.16 it becomes clear that the current division problem will noticeably limit harvested current. That problem can be overcome by the use of a transistor-based detector. That idea is depicted in the next figure.

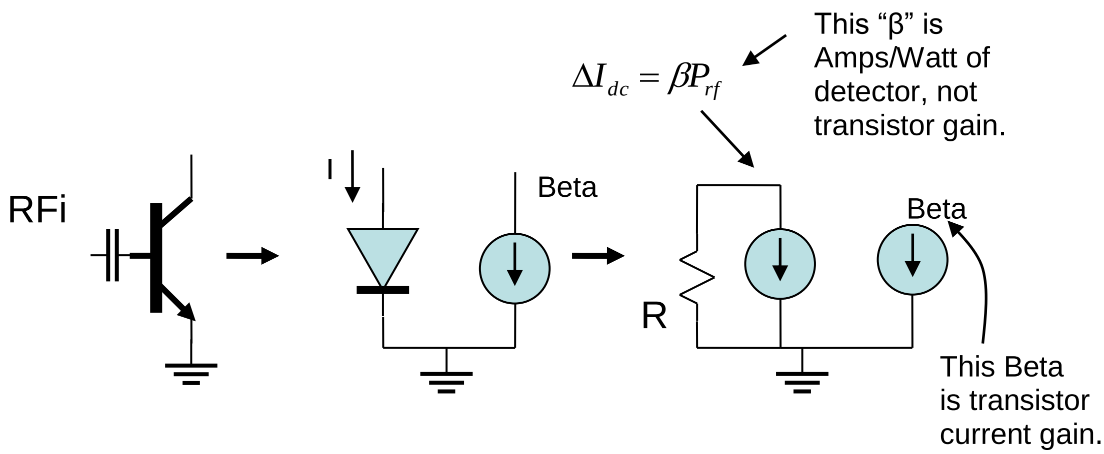


Figure 2.17: The transistor-based detector principle.

The transistor detector can use the trapped current in the BE junction diode and multiply it by transistor Beta. Note that if bipolar transistor is biased at constant collector current, then transistor Beta drops out (see Eq. 2.19).

Eq. 2.19: $$\Delta I_c = \frac{I_{base} V_s^2}{4V_T^2} Beta = \frac{\frac{I_c}{Beta} V_s^2}{4V_T^2} Beta = \frac{I_c V_s^2}{4V_T^2}$$

The advantages of a transistor-based detector are summarized below.

- Turn the disadvantage of harvested current dividing into detector's own impedance into strong advantage by letting that current be the desired current.
- This current can be mirrored, gained, and passed through very high impedance active loads to attain sufficient voltage swing to drive a comparator. For example, a current of only 1 nA may be used to develop adequate voltage to trigger a comparator using an active load impedance of 1 MegOhm:

Eq. 2.20: $V_{out} = \Delta I\ Z = 1nA\ X\ 1Meg = 1mV$

But, to use these small voltages and attain ultimate sensitivity requires fully trained AC coupling and low offset or trimmed comparators. Also, note that from 1mV to 1 volt is 60 dB baseband dynamic range, but only **30 dB RF dynamic range** in square law mode, hence multiple dynamic range states are needed.

We now come to basic analysis of noise limits of this form of detector. Like any receiver, gain can be added to get detected signal up to the necessary amplitude, but in the final analysis this process is limited by the signal to noise ratio. Earlier in this section it was shown that the thermal noise over the wideband RF input bandwidth of the detector limits the sensitivity to about -74 dBm in the case of U.S. tags.

It turns out that the baseband signal to noise will typically limit the tag sensitivity to levels below this RF limit. The tag baseband noise is from much narrower bandwidth than the RF noise, so it is much less. However, the square law nature of the detector means that the harvested signal has much less power than the input RF signal. For example, let input RF signal be -60 dBm peak (-63 dBm average) and let it suffer 3 dB loss in matching and up converting to a 500 ohm impedance level. Then -66 dBm (0.25 nW) in 500 ohms will have a peak RF voltage of 0.5 mV. Plug this into eq. 2.19 with a bias current of 1 uA and a delta I of 9.24E-11 results. If this current is dissipated in a 1 MegOhm load impedance then the baseband signal power is 8.54E-15, which is **-111 dBm**. The input signal has suffered a **45 dB conversion loss** at the detector, and this is despite our harvesting all the current possible. Let this signal be at 32 kbps Manchester and be rather stiffly filtered at 50 KHz baseband noise bandwidth. Just the thermal noise power in 50 KHz is -127 dBm, so the thermally limited signal to noise ratio is 16 dB. If the baseband circuitry lifts the noise floor only 4 dB above thermal, then we are down to 12 dB SNR and we would refer to this receiver as having a sensitivity of about -60 dBm referred to RF peak power. This is in fact quite close to what occurs in carefully designed bipolar circuitry.

While the above very crude analysis is surprisingly close to reality, we can be a little more analytic as follows. We start with a bipolar detector that is mirrored for bias set up as shown below.

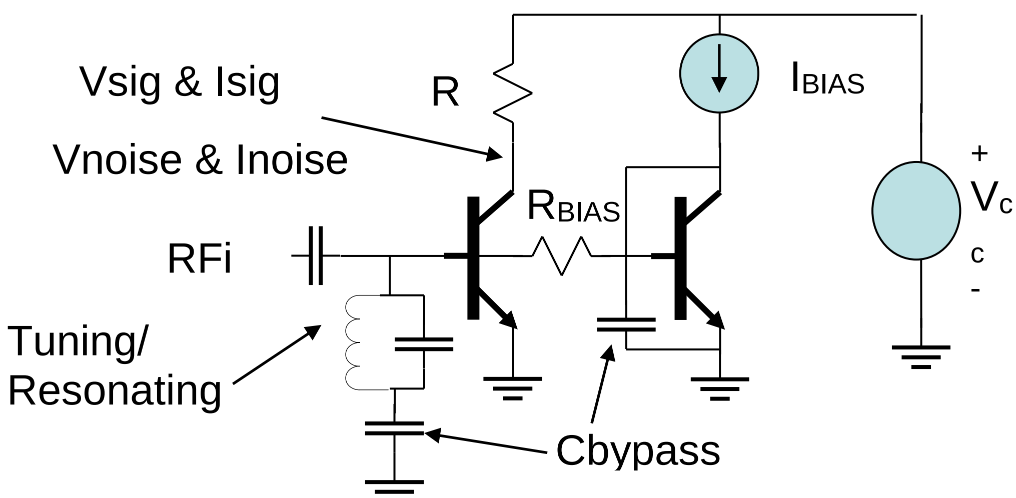


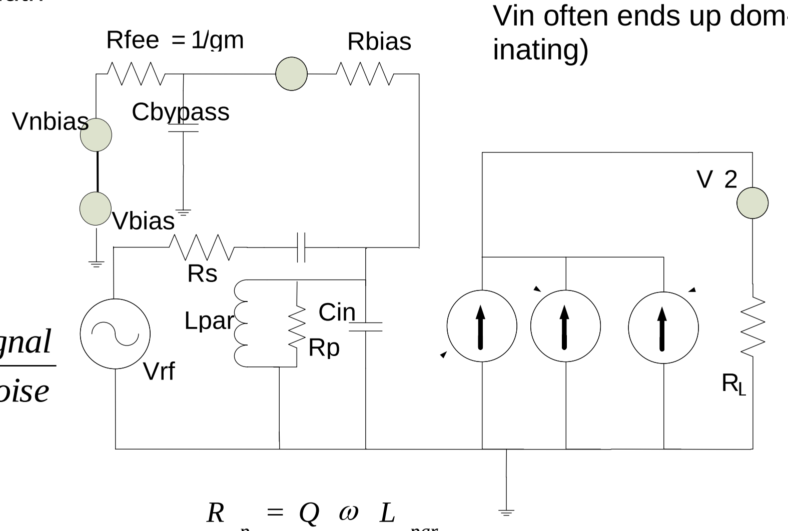
Figure 2.18: Simplified circuit used to perform sensitivity analysis of bipolar detector.

A linear noise model of the above detector is shown below.

Vnbias, Vn1, In2 are all noises over the baseband bandwidth of interest

Vin= Total Voltage Input Noise over band-with of interest (gained Vin often ends up dominating)

$$\frac{S}{N}=\frac{Baseband\_Signal}{Baseband\_Noise}$$



$$R_p = Q\,\omega\,L_{par}$$

Figure 2.19: Transistor-based detector model capturing baseband signal and noise (notice that this model works for any transistor). The three current sources on the right are signal, input noise gained to the output side, and direct output side noise. The signal value is found from square law analysis. The noise values are found from standard noise analysis.

We may come up with deterministic expressions for sensitivity as follows. Based on the circuit on Figure 2.19, the change is the collector current due to a change in the input voltage is given by:

Eq. 2.21: $$\Delta I_c = \frac{I_c V_s^2}{4V_T^2}=\frac{I_c P_{in} Z_{in}}{2V_T^2}$$

In this equation, the input impedance is limited to the following value if the input capacitance is not resonated:

Eq. 2.22: $$Z_{in}=Z_{Cin}\ Parallel\ R_{bias}$$

Or, if the input capacitance is resonated, the input impedance is increased to the following value (assuming impedance up-conversion is well-designed):

Eq. 2.23: $$Z_{in}=R_{par}\ Parallel\ R_{bias}$$

Example of Viability of Sensitivity: Pin = -55 dBm = 3.16 nW, if up-converted to 500 ohms then Vs = 1.78 mV, if Ibias = 5 µA, then harvested current = 0.152 nA, current gain of 8 and Zout of 1 MΩ gives 1.2 mV to drive comparator. This works if noise does not get in the way.

Now, the noise power must be calculated to confirm adequate SNR. The total noise is given by:

Eq. 2.24: $$TotNoise = N_F + GainedNoiseIn = N_F + g_m^2 V_{in}^2 R_L$$

V_{in} is the detector input side noise over BW of interest (often dominated by thermal).

R_n = Effective noise resistance on input side that would generate "Vin" (often only slightly larger than R_{bias}).

N_F is the detector output side noise (for MOS, dominated by channel noise).

R_L= Detector load.

R_b= Data Rate.

Eq. 2.25: $$V_{in} = \sqrt{4KTBR_n} = \sqrt{4KTF_f\ N_{bwf} R_b R_n} \approx \sqrt{12KTR_b R_{bias}}$$

The last approximation applies if R_n is dominated by R_{bias}.

F_f is the "Filter Factor" for extra 3dB bandwidth greater than bit rate R_b needed to pass the signal, usually between 1.5 and 2.0.

N_{bwf} is the effective noise bandwidth increase greater than filter 3 dB BW (F_f*R_b). Total Noise BW = R_b*F_f*N_{bwf}.

N_{bwf} is the increase in noise bandwidth taking into account that the filtering is not "brick wall", and some noise power comes from frequencies greater than filter 3 dB bandwidth. This factor is 1.22 for second order filtering, and 1.57 for first order.

Then, the useful harvest requirement for any transistor leads to:

Eq. 2.26: $$Signal = \frac{1}{2} \Delta I^2\ R_L$$

Eq. 2.27: $$TotNoise = N_F + g_m^2 V_{in}^2 R_L$$

And the signal to noise ratio is:

Eq. 2.28: $$SNR = \frac{\frac{1}{2}\Delta I^2 R_L}{N_F + g_m^2 V_{in}^2 R_L}$$

Solving for ΔI that is required to achieve a desired SNR:

Eq. 2.29: $$\Delta I = \sqrt{\frac{2\,SNR_{req}}{R_L}\left(N_F + V_{in}^2 g_m^2 R_L\right)} = \sqrt{2\,SNR_{req}\left(I_{NF} + V_{in}^2 g_m^2\right)}$$

In the above equation, I_{NF} is detector output side noise current.

If floor N_F is negligible (which it can almost be for bipolar):

Eq. 2.30: $$\Delta I = \sqrt{2\,SNR_{req}\,V_{in}^2 g_m^2}$$

As an example, for a particular transistor plug in expressions for ΔI and Vn, and simply solve for sensitivity. Vin may be thermal OR device noise. Choose SNR = 12 dB for BER = 1E-4.

Equating Eq. 2.21 and Eq. 2.29,

Eq. 2.31: $$\frac{I_c\,P_{in}\,Z_{in}}{2V_T^2} = \sqrt{\frac{2\,SNR_{req}}{R_L}\left(N_F + V_{in}^2 g_m^2 R_L\right)}$$

Solving for sensitivity P_{in}:

Eq. 2.32: $$P_{in} = Sensitivity = \frac{2V_T^2}{I_c\,Z_{in}}\sqrt{\frac{2\,SNR_{req}}{R_L}\left(N_F + V_{in}^2 g_m^2 R_L\right)}$$

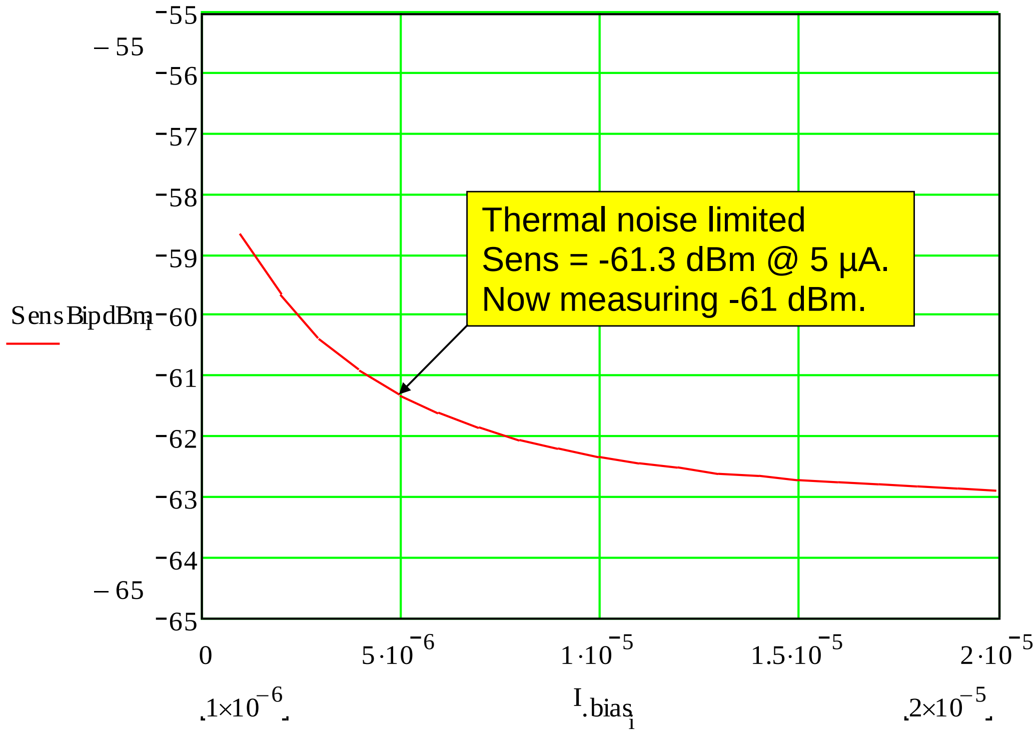


Figure 2.20: Bipolar sensitivity as a function of I_{bias} for Z_{in}=200Ω, R_b=8kbps, and R_{bias}=1.8K Ω.

As a summary on sensitivity:

- Sensitivities better than -50 dBm have been proven for higher data rates, and as good as -61 dBm at 8 kbps for bipolar
- Analysis and simulation of optimized CMOS approx -53 to -55 dBm @ 8kbps (process dependent), degrades 1.5 dB per data rate double (could improve CMOS via LNA)
  - Optimized CMOS about 5 dB over thermal noise limits
- Depending on data rate and sensitivity desired, rx currents are about 2 to 20 µA
- High sensitivity hibernate in range of 5 µA creates need to allow for duty cycling of hibernate mode if best sensitivity is desired
- These sensitivities combined with the square law nature of the receiver typically require multiple dynamic range states and thus longer training preambles than are currently in the standard

The performances discussed may be attained with a receiver architecture based on the fundamental principles captured in the figure below. The major steps involved are:

- Up convert impedance to deliver maximum voltage
- Harvest all the current (which a transistor can do)
- Pass harvested current through a high impedance active load to get usable voltage swing out of tiny currents

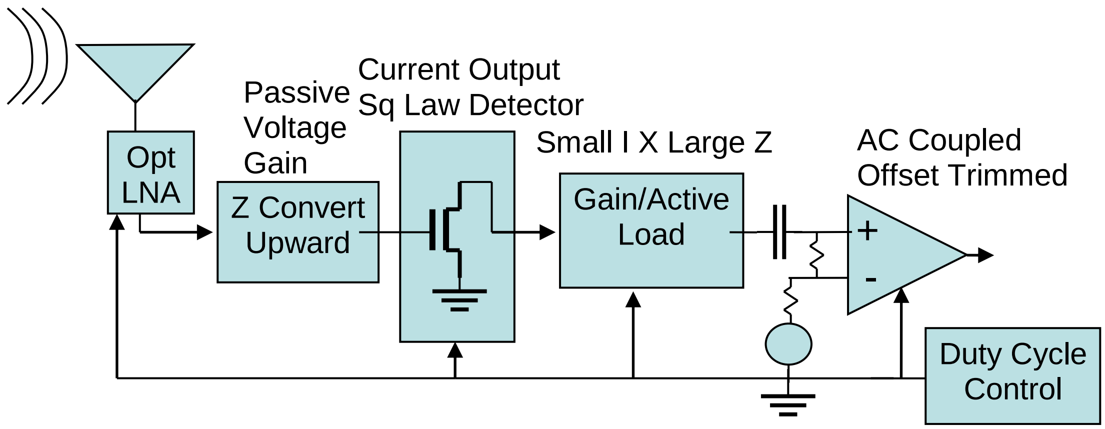


Figure 2.21: Basic maximum sensitivity detector based receiver architecture.

2.4.3 Practical System Ranges Compared to Free-Space Predicted Ranges

The propagation loss given by the Friis formula under free-space conditions can be used to predict the operating range of the system in meters. Since this formula assumes perfect polarization matching and source and load impedance matching at both ends, the predicted ranges are in most cases larger than those that can be achieved in practice. In addition, some fade margin has to be built in for reliability purposes.

We step through the basic analysis of Semi-Passive Class 3 range behavior as follows. From any antenna design textbook (such as “Antenna Theory”, by Balanis) the effective aperture of an antenna is:

Eq. 2.33: $A_{em} = \frac{\lambda^2}{4\pi}\left(meters^2\right)$

The maximum available power at the output of a receive antenna is:

Eq. 2.34: $P_{rec} = W\,A_{em} = \frac{P_{tran}}{4\pi R^2} A_{em}$

Extending this equation to take into account transmit power and antenna gains gives the well known Friis Transmission Equation. For the simplified case of polarization matched antennas and including a degrading term "D" (0 < D < 1) to take into account all sources of signal loss, this equation is:

Eq. 2.35: $$P_{rec} = \frac{P_{tran}\left(\frac{\lambda}{4\pi}\right)^2 G_{tran} G_{rec} D}{R^n}$$

In this equation "n" is the path loss exponent, which is 2 for free space but in practice generally between 2 and 5 depending on the hostility of the link environment. For short range indoor radio a typical value would be 2.5 to 3, while for cellular it is generally about 4. In some special circumstances of reflected power enhancement it may be slightly less than 2, but this should not be counted upon unless the situation is very well controlled.

The Friis equation may be solved for expected range to give:

Eq. 2.36: $$R_{\max} = \left[\left(\frac{\lambda}{4\pi}\right)^2 \frac{D\, P_{tran} G_{tran} G_{rec}}{S}\right]^{\frac{1}{n}}$$

In this equation "S" is the required receiver input power or sensitivity. For cases of typical fade D may be assumed as a random variable, and by characterization of its statistical behavior the receive power and link range for a desired reliability level may be found.

Applying the Friss equation to the RFID forward link case, we may write:

Eq. 2.37: $$P_{rec\_tag} = \frac{P_{tran\_reader}\left(\frac{\lambda}{4\pi}\right)^2 G_{reader} G_{tag} D}{R^n}$$

Now, here is where we diverge from standard radio link analysis to take the backscatter character of UHF RFID into account. The receive power at the tag, with a little modification, gives the tag transmit power, which may in turn give the signal power received at the reader. We obtain an equation by considering how to modify tag receive power to give tag transmit power. There are two major factors involved. First, the power available to backscatter is actually four times the available receive power. This is because when the tag antenna load is shorted for maximum reflection, its total impedance is cut in half, its current thus doubles, and its backscatter power (going as current squared with the same radiation resistance) thus goes up 4X (6 dB). However, there has to be some losses associated with the switching across the antenna. The tag transmit power may thus be written as:

Eq. 2.38:
$$P_{tran\_tag} = \frac{4 d_c \, e P_{tran\_reader} \left(\frac{\lambda}{4\pi}\right)^2 G_{reader} G_{tag} D}{R^n}$$

In this equation "e" is the efficiency associated with the tag switching, generally about 0.5 to 0.8, but sometimes deliberately lower in order to meet European regulatory requirements. The term d_c is the duty cycle associated with the return modulation, generally 50% for ASK. Now, plugging this equation back into the general Friss equation to get receive power at the reader, we obtain:

Eq. 2.39:
$$P_{rec\_reader} = \frac{4 d_c \, e P_{tran\_reader} \left(\frac{\lambda}{4\pi}\right)^4 G_{tran}{}^2 G_{rec}{}^2 D^2}{R^{2n}}$$

Note the key thing that happened with the link exponent—it has doubled. That is because the tag receive/transmit power faded once with link exponent from reader to tag, then fades again going back. So, if the forward link is inverse square (close enough for quite short ranges), then the link is inverse 4th for the reverse link. Note that fade "D" and antenna gain functions also became squared.

Now, solving the above equations for forward and reverse link ranges, we get:

Eq. 2.40:
$$R_{\max\_tag} = \left[\left(\frac{\lambda}{4\pi}\right)^2 \frac{D P_{tran\_reader} G_{reader} G_{tag}}{S_{tag}} \right]^{\frac{1}{n}}$$

$$R_{\max\_reader} = \left[\left(\frac{\lambda}{4\pi}\right)^4 \frac{D^2 \, 4 d_c \, e P_{tran\_reader} G_{reader}{}^2 G_{tag}{}^2}{S_{reader}} \right]^{\frac{1}{2n}}$$

Ideally these ranges should be about equal, since if one is much better than the other then the weaker link breaks the full link. If we set these ranges equal to each other and solve for reader and tag sensitivities in the case of an inverse square forward link, we obtain:

Eq. 2.41: $$S_{reader} = \frac{4 d_c e S_{tag}^{2}}{P_{tran\_reader}}$$

Eq. 2.42: $$S_{tag} = \sqrt{\frac{P_{tran\_reader} S_{reader}}{4 d_c e}}$$

Now these equations are very important to system operation and design, with a profound consequence. Basically, every time an improvement is made in the forward link of one dB, the reverse link must improve 2 dB to keep up. This is not readily noticed for Passive Class 1 systems since the tag sensitivity is only -15 dBm or so, and the reader has no real difficulty holding up its end. But add a battery to the tag and push towards the better possible sensitivities, while trying to keep the reader sensitivity good enough to not limit system performance, and the physical limit of possible reader performance will be reached before the limit of tag sensitivity established earlier. This relationship was graphed earlier in Figure 2.7, which is repeated below.

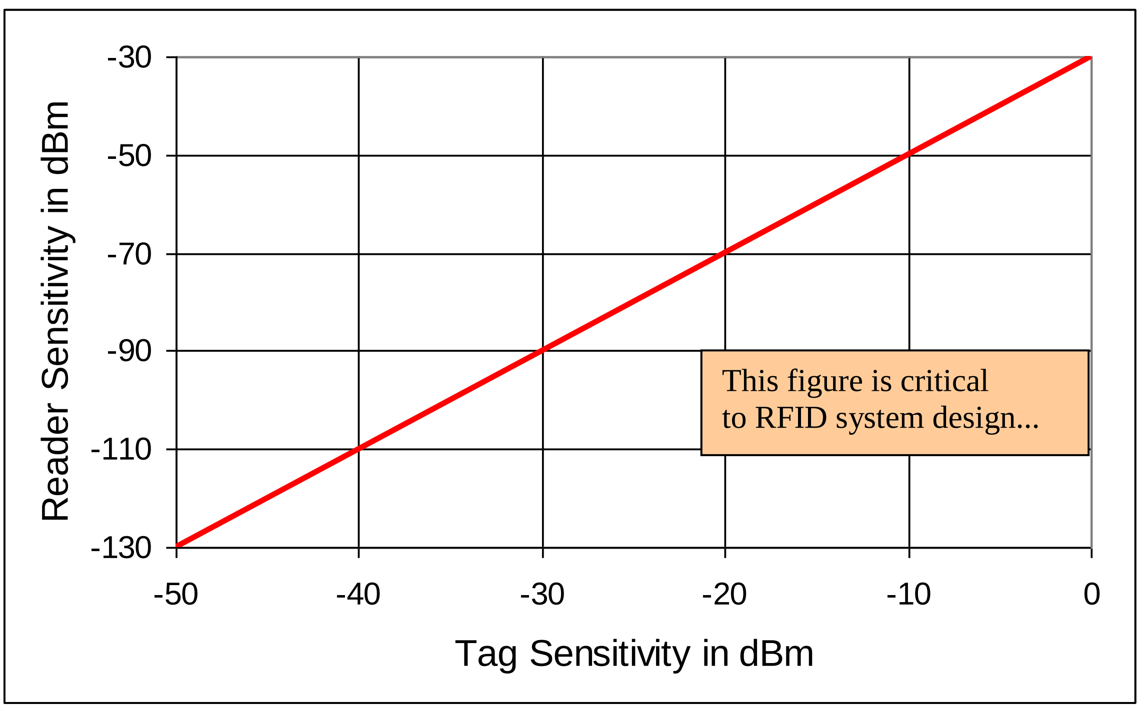


Figure 2.22: The relationship between reader and tag sensitivities to maintain a "matched link" condition where the range of both links is equal. This graph assumes tag duty cycle of 50% and tag backscatter efficiency of 50% also, with reader transmit power of +36 dBm ERP, and with an inverse square forward link.

It is our experience in indoor and terrestrial radio that practical range is generally in the ball park of one order of magnitude down from free space. As a relevant example, see "914 MHz Path Loss Prediction Models for Indoor Wireless Communication in Multi-floored Buildings", by the well known wireless professor Ted Rappaport and his student Scott Siedel, from the IEEE Transactions on Antennas and Propagation, Vol 40, No. 2, Feb. 1992. It is reported there that indoor communications on the same floor averaged over a variety of buildings shows an approximately log normal distribution of signal strength with an average standard deviation of 12.9 dB. To a first order, reliability in a radio link translates to a certain number of standard deviations of safety margin in the link budget. So, if the standard deviation of fade is known, then approximate reliability can be planned for via a simple exercise of statistics. Providing that safety margin for a certain reliability will sharply reduce the apparent range, though in fact free space range was never really there to start with.

A relationship giving range reduction as a function of degrading factor D (which is directly related to reliability through standard deviation of fade) may be quickly found. Recall maximum reader range (since the reverse link will normally be limit for Class 3):

Eq. 2.43: $$R_{\max\_reader} = \left[\left(\frac{\lambda}{4\pi} \right)^4 \frac{D^2\, 4\, d_c\, e\, P_{tran\_reader} G_{reader}{}^2 G_{tag}{}^2}{S_{reader}} \right]^{\frac{1}{2n}}$$

Using this equation for free space reverse link range with $D_1 = 1$ to give $R_{max\_reader1}$ and with $D_2 < 1$ to leave standard deviations of fade to give $R_{max\_reader2}$, we may write:

Eq. 2.44:

$$\frac{R_{\max\_reader2}}{R_{\max\_reader1}} = \frac{\left[\left(\frac{\lambda}{4\pi} \right)^4 \frac{D_2{}^2\, 4\, d_c\, e\, P_{tran\_reader} G_{reader}{}^2 G_{tag}{}^2}{S_{reader}} \right]^{\frac{1}{2n}}}{\left[\left(\frac{\lambda}{4\pi} \right)^4 \frac{D_1^2\, 4\, d_c\, e\, P_{tran\_reader} G_{reader}{}^2 G_{tag}{}^2}{S_{reader}} \right]^{\frac{1}{2n}}} = D_2^{\frac{1}{n}} = (N\,\sigma)^{\frac{1}{n}}$$

In this equation sigma is the linear value of the standard deviation of fade (not the dB value), and N is the number of standard deviations needed for a desired reliability level. This equation directly gives the fraction of free space range that may be covered at the desired reliability level. However, note that it does not take additional practical link "hits" into account, such as antenna orientation and absorption losses.

Now we may run up a table comparing free space and practical range. From the Rappaport article above the nominal standard deviation of fade in an indoor radio link is about 12.9 dB, but we don't expect it to be that bad for Semi-Passive RFID because the range of operation will be a little shorter than they are measuring over. Let us assume it is 7 dB (the best reported by Rappaport is 5.2 dB). Then we get the following required forward link fade margin buffers versus reliability in the reverse link:

Table 2.3: Operating range vs. free space range as a function of system reliability. Ranges are given taking only fade into account, and then also with an additional 10 dB link budget hit for factors such as antenna orientation and material absorption losses.

Reliability	Number of standard deviations "N" needed	Forward Link Margin needed at σ = 7dB	D = N σ	Operating Range/Free-Space Range (fade only / 10 dB more)	Operating Range (meters) (fade only / 10 dB more)
80%	0.85	5.95dB	0.254	50% / 16%	100 / 32
90%	1.29	9.03 dB	0.125	35% / 11%	70 / 22
95%	1.64	11.48dB	0.071	27% / 8.5%	54 / 17
98%	2.05	14.35dB	0.0367	19% / 6%	38 / 12

It is thus clear why a rule of thumb of practical range being about an order of magnitude down from free space is approximately true. However, we point out that the exact numbers here are not really the point. The important issue is that when reliability, practical path loss exponents, and interference are considered, practical range will be considerably reduced from free space range. Thus, at the standard design level, to keep range and reliability both as high as possible, we strongly advocate taking every low cost step that can be taken to preserve sensitivity and maximize interference control.

3 Option 1: DC Coupled PIE and AC Coupled Manchester

This is the preferred option if IP reasons do not get in the way of using Manchester. The Manchester forward link has about a 5 dB theoretical sensitivity advantage over PIE, and in the case of AC coupling necessary for high sensitivity, Manchester has less baseline wander due to each symbol having identical DC content.

3.1 DC Coupled BAT PIE

In order to preserve the value of the infrastructure already deployed in the field, this mode is proposed. This mode offers true backwards compatible operation while moderately increasing tag sensitivity by about 10-15 dB.

3.1.1 DC Coupled PIE Behavior and Design Goals

Since full backwards compatibility is required for this mode, the same preambles used for Passive (Class 1) 18000-6 Type C shall be used. No power leveling is suggested, nor any required firmware update for the readers.

Note on Activation in DC PIE: Though a PIE Activation command option is in the current draft as an option, we recommend it be removed as its implementation is likely to require hardware level changes in the reader, and "compatibility" means no more than firmware level changes. To provide a "compatible" means of preserving tag battery power in the DC PIE case, we propose a new and optional tag receiver duty cycle control command that can be implemented using only a firmware reader upgrade.

Others may prefer that the Activation command for DC PIE continue to exist in an optional form. This is viable, but the problem it introduces is that it tends for force the tag to constantly cycle between modes and not end up saving power anyway. The tag that implements this option in an open system must assume that it may encounter readers which do not, hence it must periodically power up its regular receiver anyway according to the assigned duty cycle. Its battery life is thus <u>shortened</u>, not improved, by the use of the hibernate receiver. But if the tag may count on this mode simply not existing, then it only powers up the regular receiver according to desired duty cycle. The system implementer who desires the best possible battery life simply advances to the more advanced tags that implement a sensitive AC coupled mode with true hibernate receiver, and the associated readers designed to support this mode.

In the DC PIE mode, mild sensitivity improvement suitable to pushing existing readers into their limit is expected. A recommended sensitivity range is between -20 dBm to -25 dBm. The tag receiver dynamic range can then be accommodated in a single dynamic range state. This limited improvement is useful without requiring additional dynamic range states in the tag receiver and without danger of the tag read range being too long for applications that prefer a deliberately limited range.

Passive and DC coupled PIE BAT coexist in the same interrogation round, except when a firmware upgraded reader implements the options DC PIE Query_BAT. In that case the tag may be programmed to operate in either or both types of query rounds.

3.1.2 DC Coupled PIE Command Set

The command set for this mode is exactly the same to that of pure passive tags, since 100% backward compatibility is required by design. The mandatory command set is repeated here for convenience.

Table 3.1: DC coupled PIE command set (only mandatory commands are shown).

DC Coupled PIE		
Command	**Length (bits)**[1]	Code
QueryRep	4	00
ACK	18	01
Query	22	1000
QueryAdjust	9	1001
Select	>44	1010
NAK	8	11000000
Req_RN	40	11000001
Read	>57	11000010
Write	>58	11000011
Kill	59	11000100
Lock	60	11000101

3.1.3 DC Coupled PIE Optional Features

3.1.3.1 Optional DC PIE Commands (req reader firmware upgrade)

The proposed DC PIE features proposed are optional because they are useful but require a firmware upgrade to the reader. Recall that required features are limited to those which existing readers can perform with no changes, optional features only require a firmware

[1] This includes command length plus the parameters length.

upgrade, and that improvements which require hardware level reader changes are limited to the high sensitivity AC coupled modes.

The optional DC PIE commands proposed below redefine the Hibernate concept as consisting of both “Hibernate” with receiver duty cycling and “Sleep” with tag receiver completely off for a significant time. We recommend 3 new commands to perform this firmware based replacement of the Activate mechanism. To cause this new sleep state we recommend a new optional “Sleep” command that puts tags not needed for transactions into a “Sleep” mode. In “Sleep” mode tag receivers are completely off for a timed interval. The mask parameters of the “Sleep” command (choice of tags to leave at 100% duty cycle) are nearly identical to that of the Manchester Activate command. This command is mask controlled (requiring neither flag matching or singulation) and is also sophisticated enough to allow for either keeping a selected group awake or putting selected sub-groups asleep with a parameter for how long to stay asleep. For control of tag receive duty cycle in the new definition of Hibernate, the optional RX_Control_DC command is tag specific using the RN_16 handle, and allows reprogramming of the intervals of receiver duty cycling. The newly proposed Next_PIE command is similar in usage to the Manchester Next, with the function of putting tags asleep right after singulation, and therefore is tag specific also. However, in the PIE mode the distinction between Hibernate and Sleep means that the Next_PIE command needs a timer function that puts tags to sleep for a desired programmable interval. The Next_PIE is similar to the RX_Control_DC command, but without the capability to reprogram tag duty cycling. It could thus be replaced by the RX_Control_DC command if desired, but we have recommended it to keep the operation more similar to Manchester mode.

3.1.3.1.1 Sleep_DC_PIE Command

This optional PIE mode command is needed to enhance the battery life of tags with DC-coupled receivers. Tags with DC-coupled receivers are fully backwards compatible to class 1 readers. Consequently, their receivers wake up for all class 1 command activity, which may unnecessarily consume the tag’s battery.

The optional Sleep_DC_PIE command allows a designated group of tags to ignore all incoming PIE commands for a prescribed time period. That group of tags can then save battery power by turning off their receivers (sleeping) for the prescribed time period.

The Sleep_DC_PIE command addresses groups of tags. As a result, tags shall not provide an RF backscatter response to the command – they ignore all commands for the prescribed time period.

The proposed format of the Sleep_DC_PIE command is as follows:

Table 3.2: Sleep_DC_PIE Command Structure

	Command	**Length**	**Address**	**Mask**	**Polarity**	**Time**	**CRC-16**
# of Bits	8 bits	7 bits	7 bits	96 bits	1 bit	8 bits	16 bits
Description	11010001	Mask Length	Mask Address	Mask Value, up to 96 bits	0: Sleep if mask matches 1: Sleep if mask does not match	Time to sleep. See Table 3.33 (WriteTimer method of counting time)	

Multiple Sleep_DC_PIE commands can be used to incrementally put to sleep multiple groups of tags.

This command does NOT affect any previous tag receiver duty cycle programming. For example, if a tag receiver was set up for 10% duty cycle before receiving a Sleep_DC_PIE command, it would revert to a 10% receiver duty cycle after sleeping for the prescribed time period.

3.1.3.1.2 RX_Control_DC Command

The structure of the RX_Control_DC is shown in the next table.

Table 3.3: RX_Control_DC Command Structure

	CMD ID	**Receiver OFF time**	**Receiver ON time**	**Interrogation Round Partici-pation**	**RN16**	**CRC-16**
# of bits	8	8	4	2	16	16
De-scrip-tion	1101 0000	Number of units of time (each unit is 0.25s) receiver is off. Value 00000000 means receiver is always ON. Special Value 11111111 means infi-nite—or al-ways OFF	Number of units of time (each unit is 0.25s) that the receiver stays ON	00: Both Passive and BAT 01: Only Passive 10: Only BAT 11: On any QueryRep	RN16_handl e	CRC-16

Tags shall reply to the RX_Control_DC command as given below. Since this command can effectively shut down a tag a for long period of time, the reply confirming correct receipt is recommended to be protected by CRC.

Table 3.4: Proposed reply to RX_Control_DC Command.

	RN16	**CRC-16**
# of bits	16	16
Description	RN16_handle	

In addition, if tags implement the receive duty cycle option, it is recommended that a way be provided of forcing them out of this mode. An example would be via a high level of RF power (higher than 12dBm). This might be implemented with a purely passive detector consuming zero DC power.

3.1.3.1.3 Next_PIE Command

The optional Next_PIE command puts a singulated tag to sleep. This is part of the strategy to turn off battery powered tag receivers as soon as possible in order to maximize tag battery life. This command is used on singulated tags.

Table 3.5: Next_PIE Command Structure.

	Command	RN	Time
# of Bits	8 Bits	16	8
Description	1100 1011	RN_16_Handle	Time to sleep. See table 3.32.

Table 3.6: Reply to Next Command.

	RN16	Parity
# of bits	16	1
Description	RN16_handle	Odd parity

The Next_PIE command does NOT affect any previous tag receiver duty cycle programming. For example, if a tag receiver was set up for 10% duty cycle before receiving a NEXT_PIE command, it would revert to a 10% receiver duty cycle after sleeping for the prescribed time period.

3.1.3.1.4 Query_BAT_DC_PIE Command

An optional command to enable orthogonal interrogation rounds, that is, interrogation rounds that only interrogate passive tags or BATs. Notice that this command has the same structure as the pure passive query command, but it has a different command code.

Table 3.7: Query_BAT_DC_PIE Command structure (DC PIE mode).

	Command	DR	M	TRext	Sel	Session	Target	Q	LFF	BLF	RFU	CRC-5
# of bits	8	2	4	1	2	2	1	4	1	4	8	5
Description	11010101	00: DR=8 01: DR=64/3 10: RFU 11:RFU	0000: M=1 0001: M=2 0010: M=4 0011: M=8 0100: M=16 0101: M=32 0110: M=64 0111 to 1111: RFU	0: No pilot tone 1: Use pilot tone	00: All 01: All 10: ~SL 11: SL	00: S0 01: S1 10: S2 11: S3	0:A 1:B	0-15	0: BLF field not used and tag data rate defined through TRCal 1: BLF field used for definition of tag data rate	0000: 64 KHz 0001: 80 KHz 0010: 128 KHz 0011: 160 KHz 0100: 256 KHz 0101: 320 KHz 0110: 640 KHz 0111 to 1111: RFU		

Tag shall reply to the Query_BAT_DC_PIE command in the same way as they to a regular Query command.

3.1.3.2 Proof that Duty Cycling of Receiver Works

In the preceding section, the addition of the command RX_Control_DC is proposed so that the BAT receiver can be duty-cycled in an effort to preserve battery life in the absence of an “Activation Command”. This section presents the mathematical analysis for calculating the probability of missing a Query command[2] due to duty-cycling the receiver, while the DC PIE BAT crosses the field of a reader. Based on the analysis, the probability of missing a Query command are never above 26% for the highly unlikely case of average one Query command per second, but when that average is raised to 10 Query commands per second, most of the time they are below 1e-6. Also, if the BAT is allowed to look for any valid command, the analysis shows that the probability of missing an interrogation round is virtually zero in all cases, even for such low duty cycles as 1%.

3.1.3.2.1 Definitions for Rx Duty Cycling

T_{ON} is the fraction of one second that the receiver is ON, that is, the receiver is able to detect a command, in this case, a Query command, in order to ensure the participation of a DC PIE BAT in an interrogation round. Notice that by definition, this is also the duty cycle of the receiver.

T_{Query} is the time the reader takes to transmit a Query command. Notice that the Query command with parameters has 22 bits (this analysis also takes into account the preamble that precedes the Query command). T_{Query} is related to the forward data rate used in the interrogation round. The forward data rate is determined by the value of Tari, and the length of the PIE data one symbol.

The number of Query commands in one second is a random variable that depends, among other things, on the number of tags, and the transactions for each tag. In this analysis, that random variable is assumed to have a mean of λ_{Query} per second.

A similar Analysis for the case the BAT is trying to decode any valid command is presented later.

3.1.3.2.2 Statistical Reliability Analysis of Rx Duty Cycling

The receiver can only decode commands when it is ON (see Figure 3.1); the time it can successfully decode a Query command is given by T_{ON}-T_{Query}. This is also the probability of successfully decoding a Query command because it is the time period in which the two intervals (T_{ON} and T_{Query}) can overlap completely. If we assume λ_{Query} Query commands per second, the probability of successfully decoding at least one Query command in one second is given by Eq. 3.1.

Eq. 3.1: $$P(decoding\ at\ least\ one\ Query) = 1 - P(decoding\ \ 0\,Queries)$$

[2] Notice the successful decoding of a Query command is the worst case scenario, since the BAT can be made to decode any of the mandatory commands, and therefore, the chances of missing an interrogation round virtually disappear.

Eq.3.2

$$P(decoding\ \ 0\,Queries) = (1-(T_{ON} - T_{Query}))^{\lambda_{Query}} = P(\,failure\ \ in\,1\sec ond)$$

Eq. 3.3: $P(decoding\ at\ least\ one\ Query) = 1-(1-(T_{ON} - T_{Query}))^{\lambda_{Query}}$

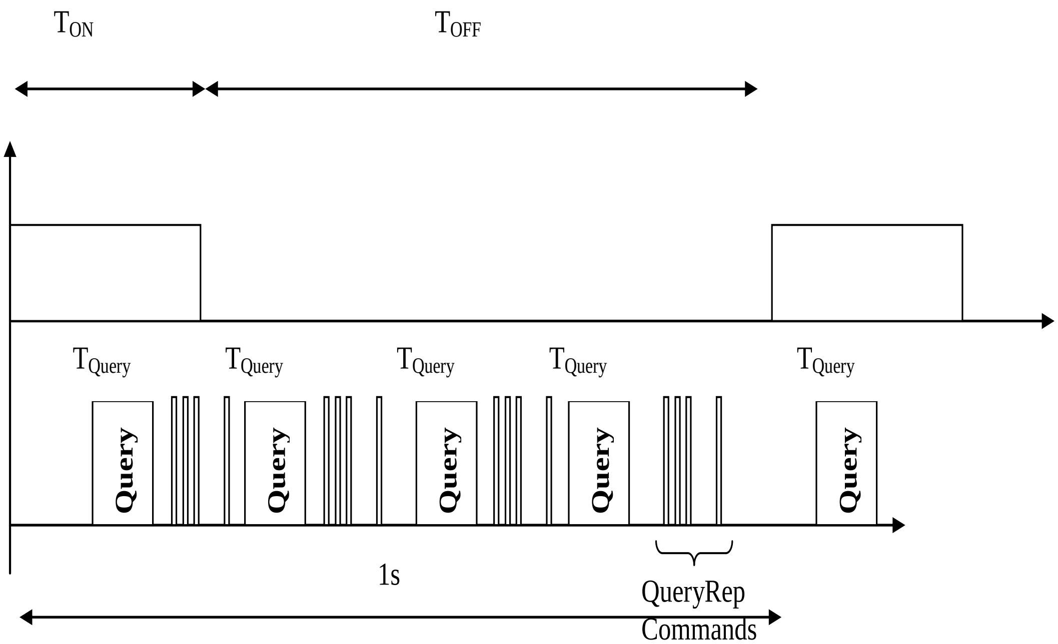


Figure 3.1: Timing Diagram.

Now, if the tag is moving at a speed of *v* m/s, close to a reader, the probability of missing a Query depends on the time the tag takes to get in and out of the reader's field. The size of the reader's field depends on the tag sensitivity. Assuming inverse square propagation conditions, the radius of the reader's field can be found by solving Friis equation, and that is shown next.

Eq. 3.4: $r = \frac{\lambda}{4\pi}\sqrt{\frac{P_{\text{Reader}}G_{\text{Reader}}G_{Tag}}{P_{\text{Received}}}}$

Where λ is the wavelength of the signal, P_{Reader} is the power used by the reader, G_{Reader} is the reader antenna gain, G_{Tag} is the tag antenna gain, and $P_{Received}$ is the power at the tag, which is substituted by the tag sensitivity.

The geometry of that situation is presented in Figure 3.2.

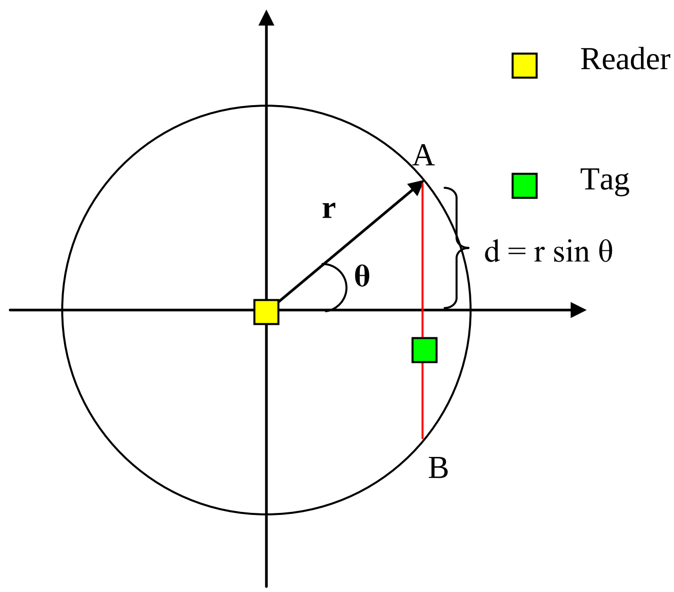


Figure 3.2: Geometry of reader and tag.

In this situation, the tag enters the circle of influence of the reader at point A and exits at point B. The distance AB and the speed of the tag determine the time the tag spends within the circle of influence (assuming a straight line movement). In this case, the time in seconds is given by the following equation.

Eq. 3.5: $t = 2r\sin(\theta)/v$

The probability of failing to decode a query in *t* seconds is the given by the modification of Eq. 3.3 and it is shown next.

Eq. 3.6: $P(decoding\ at\ least\ one\ Query) = 1 - (1 - (T_{ON} - T_{Query}))^{t\lambda_{Query}}$

3.1.3.2.3 Rx Duty Cycling Examples

Table 3.8 presents the parameters and the values used in the following examples.

Table 3.8: Parameters and values used in examples.

Parameter	Value
P_{Reader}	1W
G_{Reader}	6dB
G_{Tag}	-2dB
f_c	915MHz
Tag sensitivity	-25dBm
v	6mph
T_{ON}	10% and 25%
Tari	6.25µs and 25 µs
PIE data one duration	1.5Tari
λ_{Query}	1 and 10

With the values of Table 3.8 and Eq. 3.4, the value of the radius of the circle of influence of the receiver is 23.31m. Proposing values of θ such that the tag passes at r/3, r/2, and 2r/3 from the reader, the respective values of time are 16.39s, 15.06s, and 12.96s. The results are given in the tables below for two different values of λ_{Query}. In the case of λ_{Query} equal to 10, the values are always above 97% success rate. For values of λ_{Query} greater than 10, the success rate is effectively 100%.

Table 3.9: Probability of successfully decoding at least one Query command (λ_{Query}=1).

	Tari=6.25μs		Tari=25μs	
time	T_{ON}=0.1s	T_{ON}=0.25s	T_{ON}=0.1s	T_{ON}=0.25s
16.39s (θ=70.53°) r/3	0.82142	0.99100	0.81919	0.99086
15.06s (θ=60.00°) r/2	0.79452	0.98679	0.79217	0.98660
12.96s (θ=48.19°) 2r/3	0.74383	0.97585	0.74131	0.97557

Table 3.10: Probability of missing all Query commands (λ_{Query}=10).

	Tari=6.25μs		Tari=25μs	
time	T_{ON}=0.1s	T_{ON}=0.25s	T_{ON}=0.1s	T_{ON}=0.25s
16.39s (θ=70.53°) r/3	3.29e-8	0	3.73e-8	0
15.06s (θ=60.00°) r/2	1.34e-7	0	1.50e-7	0
12.96s (θ=48.19°) 2r/3	1.21e-6	1.11e-16	1.34e-6	1.11e-16

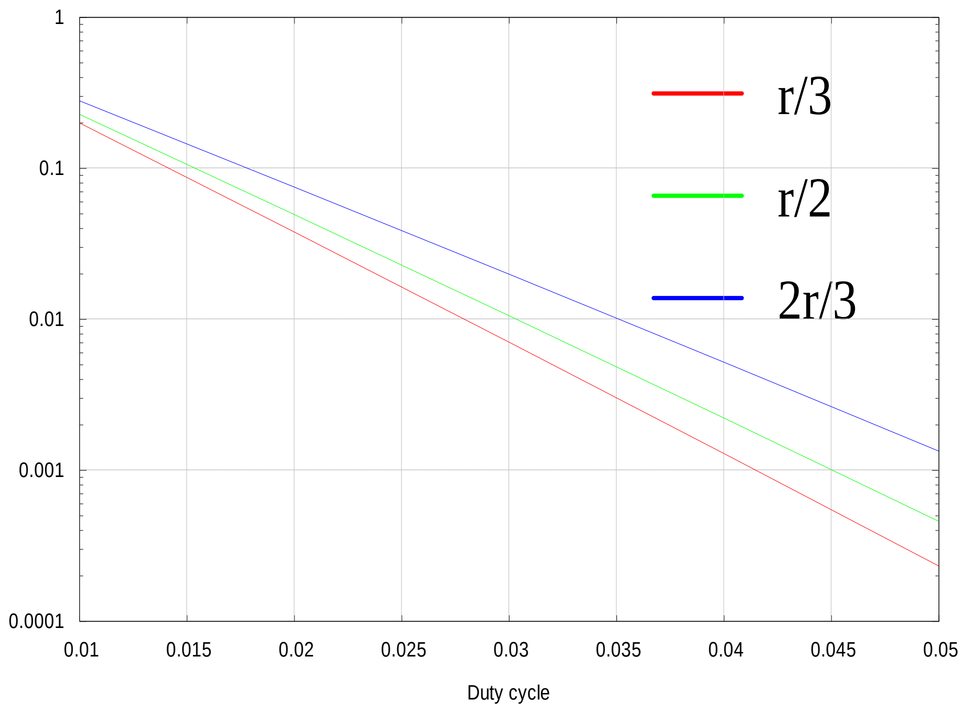


Figure 3.3: Probability of failure to detect a Query vs. duty cycle for λ_{Query}=10, Tari=6.25µs.

3.1.3.2.4 Enhancements to Rx Duty Cycling

Up to this point, the proposed duty-cycling technique has been shown to miss no more than 26% of the Query commands for the outlined conditions. The duty-cycling concept can be made much more effective (i.e. drive the duty cycle down while maintaining a negligible probability of missing an interrogation round) if the BAT is made to decode any command within the mandatory list (there are currently defined 11 mandatory commands). With this enhancement, a BAT will stay ON if it decodes successfully any valid mandatory command, and not only Query commands.

To simplify the analysis of this enhancement, we will concentrate in the most used command in an interrogation round, namely, QueryRep. If we assume an average number of Queries in a second, the number of QueryRep commands in an interrogation round is a random variable that depends on the value of Q used in the Query command for that particular interrogation round. If we assume that an average of $\lambda_{QueryRep}$ QueryRep commands are sent over the air for each interrogation round, Eq. 3.6 with λ_{Query} substituted by $\lambda_{Query} \cdot \lambda_{QueryRep}$ gives us the probability of successfully decoding a QueryRep command. Since there are an average of λ_{Query} Query commands a second, and $\lambda_{QueryRep}$ QueryRep commands per round, the total average of QueryRep commands in a second is $\lambda_{QueryRep}$ λ_{Query}. Also, the number of bits of a QueryRep command is 4, plus the frame-sync. For this analysis we set $\lambda_{QueryRep}$ at 64. With the value parameters presented in Table 3.8, the resulting probabilities of missing all QueryRep commands are presented next.

Table 3.11: Probability of missing all QueryRep commands (λ_{Query}=1, $\lambda_{QueryRep}$=64).

	Tari=6.25µs		Tari=25µs	
time	T_{ON}=0.1s	T_{ON}=0.25s	T_{ON}=0.1s	T_{ON}=0.25s
16.39s (θ=70.53°) r/3	1.09e-48	9.77e-132	1.39e-48	1.31e-131
15.06s (θ=60.00°) r/2	8.80e-45	4.56e-121	1.10e-44	5.98e-121
12.96s (θ=48.19°) 2r/3	1.21e-38	2.67e-104	1.47e-38	3.37e-104

Table 3.12: Probability of missing all QueryRep commands (λ_{Query}=10, $\lambda_{QueryRep}$=64).

	Tari=6.25µs		Tari=25µs	
time	T_{ON}=0.1s	T_{ON}=0.25s	T_{ON}=0.1s	T_{ON}=0.25s
16.39s (θ=70.53°) r/3	0	0	0	0
15.06s (θ=60.00°) r/2	0	0	0	0
12.96s (θ=48.19°) 2r/3	0	0	0	0

Please notice that the value of the probability of successfully decoding at least one QueryRep command is 1.0, this means that ***there is no penalty to pay for duty-cycling the receiver*** if the BAT wakes up and tries to decode a QueryRep command, and if it detects such command the BAT stays up and listens for the next Query to be able to participate in the following interrogation round.

Since the numbers shown in Table 3.11 and Table 3.12, show a probability of successfully decoding a QueryRep of virtually 1.0, we can decrease the duty cycle to about 1% to maximize battery life, and at the same time have very low (if not zero) probability of missing an interrogation round. The numbers for a duty cycle of 1% (i.e. T_{ON} equals 0.01s) are presented next. Notice that since the numbers are so small, we decided to present the probability of missing all QueryRep commands instead of the probability of successfully decoding at least one QueryRep command. This is the probability of failure instead of the probability of success.

Table 3.13: Probability of missing all QueryRep commands (λ_{Query}=1, $\lambda_{QueryRep}$=64).

time	T_{ON}=0.01s	
	Tari=6.25µs	Tari=25µs
16.39s (θ=70.53°) r/3	2.84e-5	3.55e-5
15.06s (θ=60.00°) r/2	6.67e-5	8.19e-5
12.96s (θ=48.19°) 2r/3	2.54e-4	3.03e-4

Table 3.14: Probability of missing all QueryRep commands (λ_{Query}=10, $\lambda_{QueryRep}$=64).

time	T_{ON}=0.01s	
	Tari=6.25µs	Tari=25µs
16.39s (θ=70.53°) r/3	3.46e-46	3.23e-45
15.06s (θ=60.00°) r/2	1.74e-42	1.35e-41
12.96s (θ=48.19°) 2r/3	1.14e-36	6.72e-36

From the numbers in the preceding tables, it can be seen that the BAT that listens to QueryRep commands is virtually assured to engage in interrogation round even at 1% duty cycle.

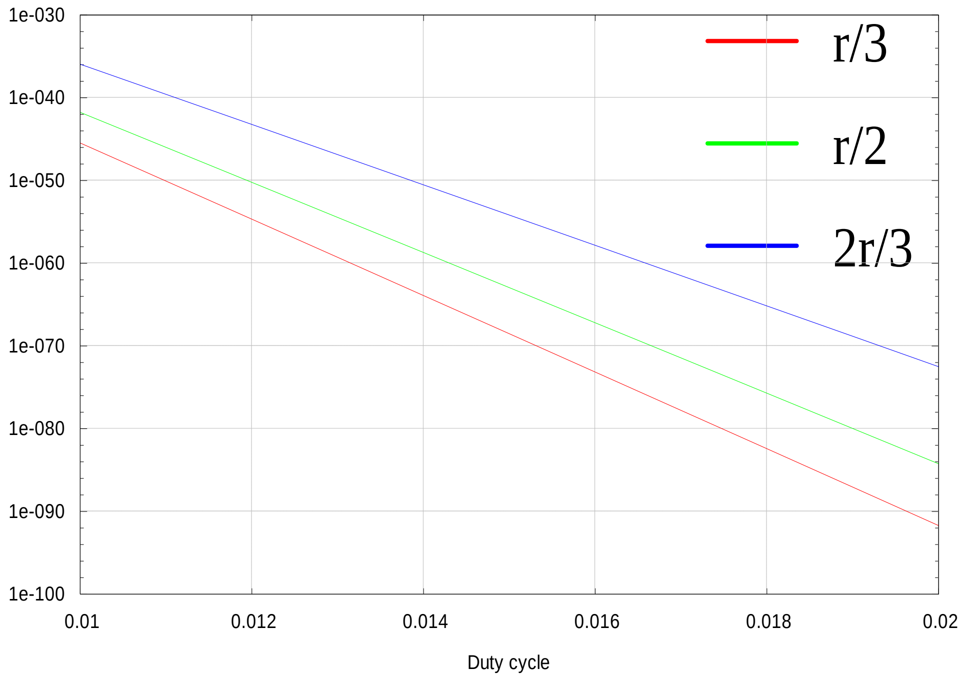


Figure 3.4: Probability of failure to detect a QueryRep vs. duty cycle for λ_{Query}=10, $\lambda_{QueryRep}$=64, Tari=6.25μs

3.2 AC Coupled Manchester

For the purposes of this section, AC coupled Manchester is assuming a high performance level that approaches what is physically possible.

3.2.1 AC Coupled Manchester Behavior and Design Goals

There are several requirements on preambles to be used in more sensitive battery supported tags. These include:

1. The need to train the AC coupling that is necessary for high sensitivity, which is a 50% level for optional Manchester.

2. Since the tag receiver dynamic range is large (around 80dB), the low cost constraint mandates the use of at least two dynamic range windows or states. The preamble for the activation command shall allow time for the proper selection of such dynamic range window.

3. To provide a frame marker indicating that AC training is complete. This is necessary since any timing information extracted by the tag during training can be skewed by the fact that the training is not complete and the DC average of the received modulation is still moving.

3.2.2 AC Coupled Manchester Preambles and Training

3.2.2.1 Asymptotic training

Asymptotic training refers to the fact that the training average voltage level is set to that of the desired AC coupling voltage level, in this case 50%. In that way, the voltage in the AC coupling *asymptotically* approaches the desired voltage.

This kind of training takes out the extra complication of calculating the training time for each individual circumstance a tag might be in (i.e. initial AC coupling voltage value and dynamic range state). The price paid for this convenience and reliability is the extra time it takes. But, if sufficient time is provided, *it always works* despite multiple dynamic range states and uncertainty as to the starting state of the AC coupling or AGC.

3.2.2.1.1 AC Coupled Manchester Asymptotic Preamble Analysis

The use of an "Activation" command at a low data rate, as now exists in the draft standard, allows a low power receive mode in a "Hibernate" state. The Activate command sets up the higher power higher data rate tag receiver used in the fully operational or "Normal" mode. This command shall include an AC coupling suitable training preamble. This preamble provides for time to adjust the dynamic range of the tag receiver and for AC coupling training that is essential to good sensitivity in the tag receiver.

Note that good training without using excessive time requires that the high pass corner of the AC coupling in the tag be specified with respect to the data rate or T_{bit} used. The choice of AC coupling corner depends on tolerance for sensitivity degradation due to baseline wander and willingness to spend die area on capacitance. Let N_c be defined as the Normalized cutoff factor of AC coupling high pass, or the fraction of $1/T_{bit}$ for the 3 dB corner of the high pass coupling. Baseline wander for N_c = 0.1, 0.03, and 0.01 is shown in Figure 3.5 (a)(b)(c).

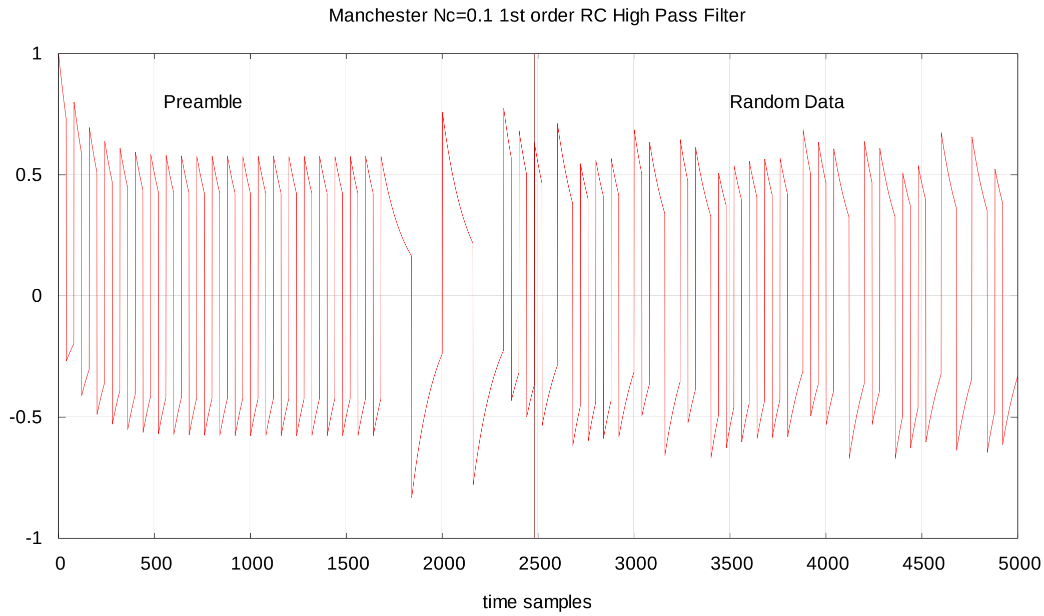


Figure 3.5 (a): Manchester AC settling and baseline wander for normal command preamble N_c=0.1 (voltage at the output resistor of the RC highpass filter)

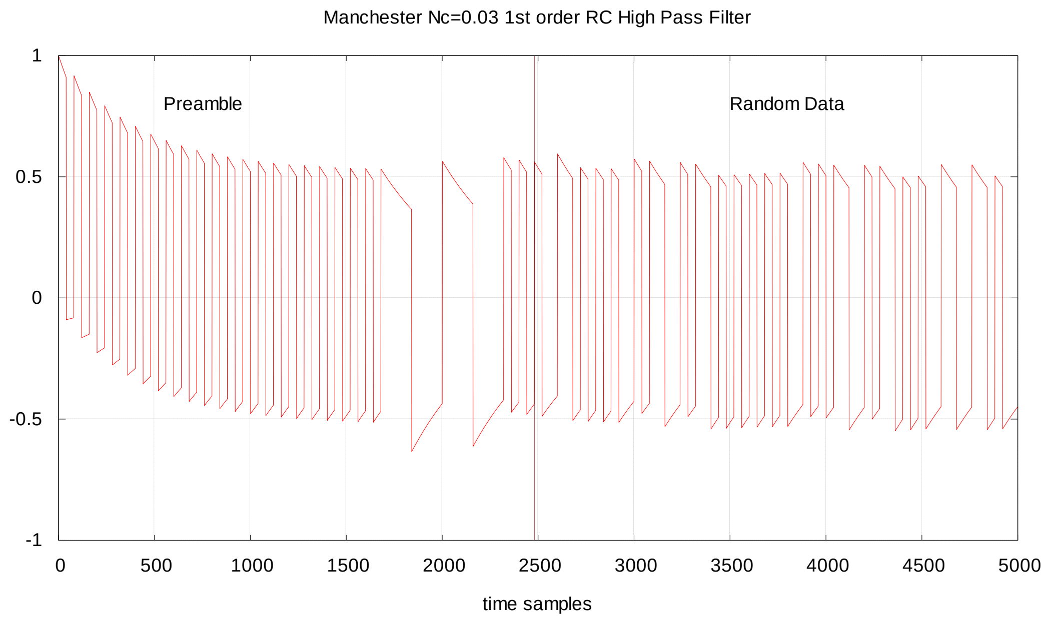


Figure 3.5 (b): Manchester AC settling and baseline wander for normal command preamble N_c=0.03 (voltage at the output resistor of the RC highpass filter)

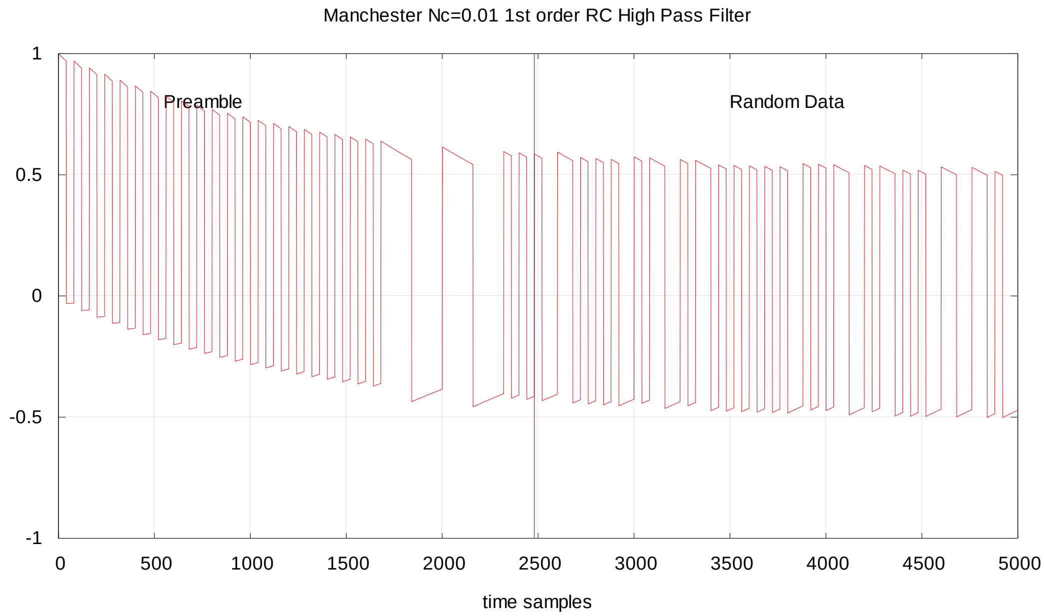


Figure 3.5 (c): Manchester AC settling and baseline wander for normal command preamble N_c=0.01 (Voltage at the output resistor of the RC highpass filter)

As a compromise between these**, a normalized cutoff of 0.03 is recommended**. This value provides an acceptable signal to wander ratio. Thus the corner frequency in Hz of the AC coupling is given by:

Eq. 3.7: $f_c = \frac{N_c}{T_{bit}}$

The time constant of single order AC coupling is given by:

Eq. 3.8: $\tau = \frac{1}{2\pi f_c} = \frac{T_{bit}}{2\pi N_c}$

The charge state on AC coupling (starting from zero volts) is given by:

Eq. 3.9: $\frac{V_{out}}{V_{in}} = 1 - e^{\frac{-t}{\tau}} = S_F$,

where S_F is the "Settle Fraction", such as 0.98. Solving for time t to get settled and substituting Eq. 3.9 gives:

Eq. 3.10: $t = -\tau \ln(1 - S_F) = \frac{-T_{bit}}{2\pi N_c} \ln\left(1 - S_F\right)$

Utilizing the proposed N_c value of 0.03 along with a settling factor of 98% in Eq. 3.10 results in a training time of 20.8 T_{bit}. These factors also apply to normal mode, where it is assumed that the tag switches its AC coupling time constant to allow for reducing training time in seconds appropriate to the typically faster data rates of normal mode.

3.2.2.1.2 Manchester Activation Command Asymptotic Preamble Options

Option 1: Following the preceding design procedure, the AC coupling part of the first option for a preamble consists on 21 leading ones at 8 kbps. As mentioned before, the activation command preamble needs to provide time for the tag receiver to adjust its dynamic range, that time is set to two time constants, or another eleven {1} Manchester symbols. The second part is an interrupt or framing flag that indicates the end of the AC training. This flag consists of two Manchester ones at 2 kbps. Correct reception of the flag portion moves the tag from the hibernate state into the code search state (the state used to receive and interpret the activation code). The third part is two Manchester symbols {1,1} at 8 kbps used to finalize timing acquisition in the condition that AC training is known to be complete and that accurate time measurement may be made. This preamble is followed by the activate command code, which is sent using 8 kbps Manchester. The preamble is shown in the below figure.

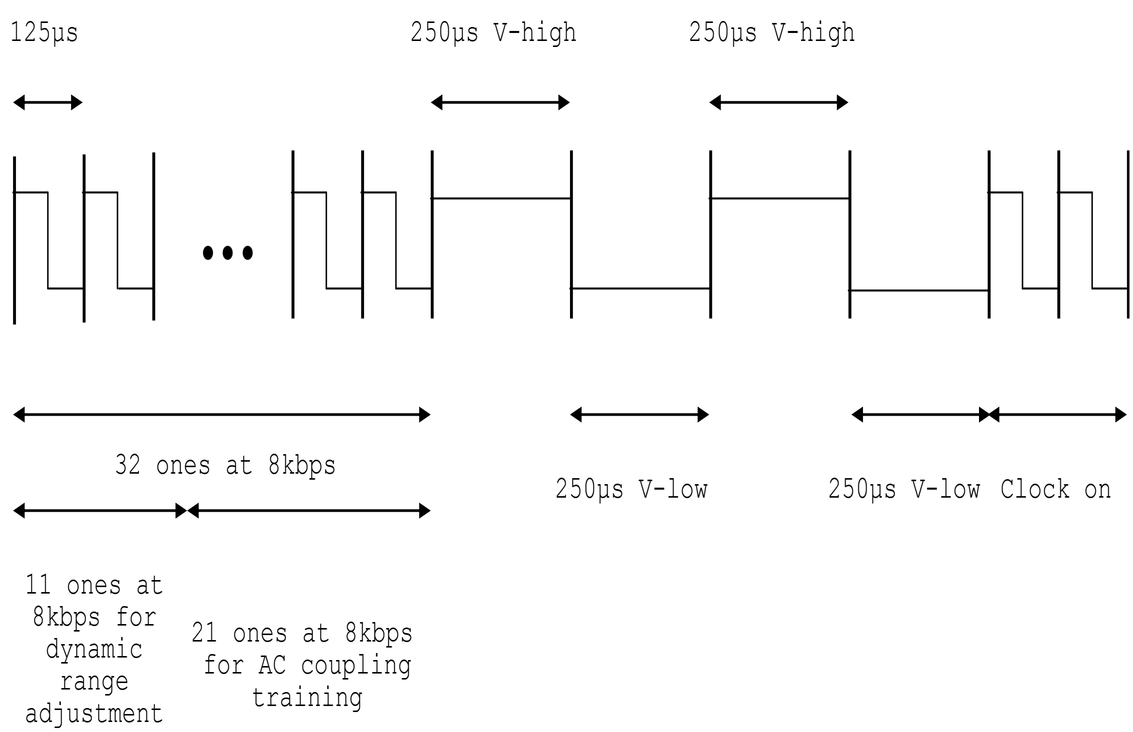


Figure 3.6: Option 1 Activation Command asymptotic preamble.

Notice that the value of N_c is 0.03 of the data running at 8kbps or equivalently, N_c is 0.12 of the data running at 2kbps, but as Figure 3.5(b) shows, it does not introduce unacceptable baseline wander.

Option 2: Since readers which implement a sensitive AC mode are assumed to have precise control of transmit power, this capability may be used to create a training preamble that creates less spectral splatter. This method is to replace the 32 leading ones with a steady state carrier transmitted at 50% of the carrier power used at a particular time (see section 3.2.4). Selecting the same settle fraction S_F, and a cutoff factor N_c of 0.03 as recommended above would indicate that a carrier time of 21 T_{bit} should settle AC coupling, plus 11 extra T_{bit} (two time constants) for initial dynamic range state adjustment. The preamble contains the same frame and timing markers as in the case above, and is shown in the figure below.

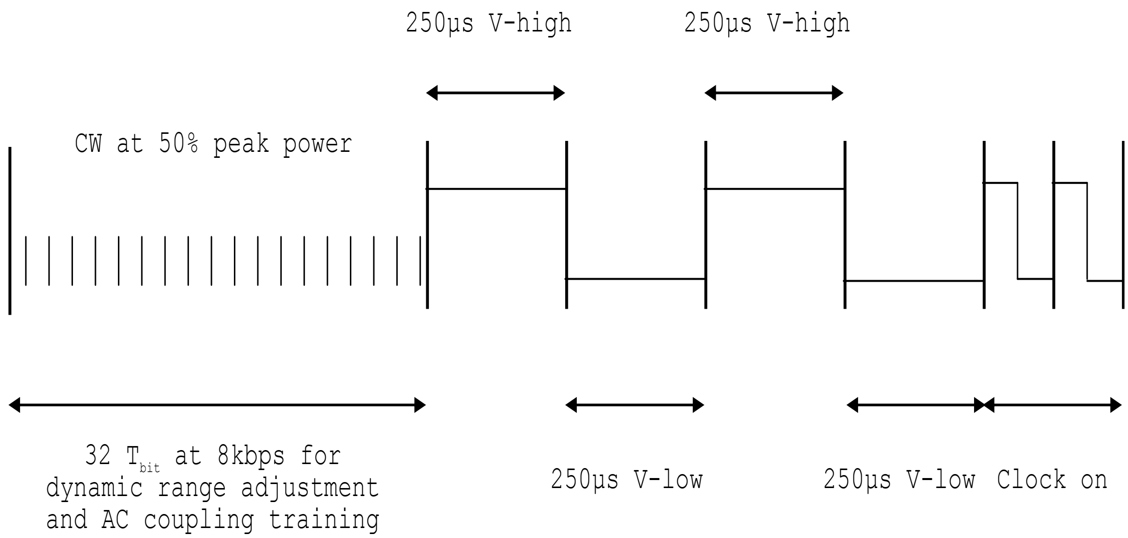


Figure 3.7: Option 2 Manchester Activation command asymptotic preamble.

This preamble lasts for 42 T_{bit}. The reader to reader interference reduction is 76.2% when compared to the regular preamble.

3.2.2.1.3 Manchester Normal Mode Asymptotic Preamble Options

Non-linear circuit design in the tag can likely shorten normal mode preambles. But, for this section we are suggesting preambles for the simpler case of linear training in the tag and the tag being allowed the option of changing its dynamic range state on every T/R turn around. This assumption is safer, and it is more reliable at low to moderate battery supported tag densities. A density can arrive where the channel is choking due to the combination of density and long preambles, at which time shorter preambles would be desirable. We defer that case to another section.

Option 1: The first option, based on symbol training, for a forward link normal preamble is shown in Figure 3.8. It contains thirty two Manchester one symbols (eleven for dynamic range adjustment and twenty one for AC coupling training) at the data rate specified in the activation command for AC coupling training and initial timing acquisition, followed by a framing flag of two Manchester ones at one fourth of the data rate indicated in the activation command, followed by two more Manchester symbols {1,1} at the data rate specified in the activation command for final timing acquisition, and finally by the beginning of normal data symbols.

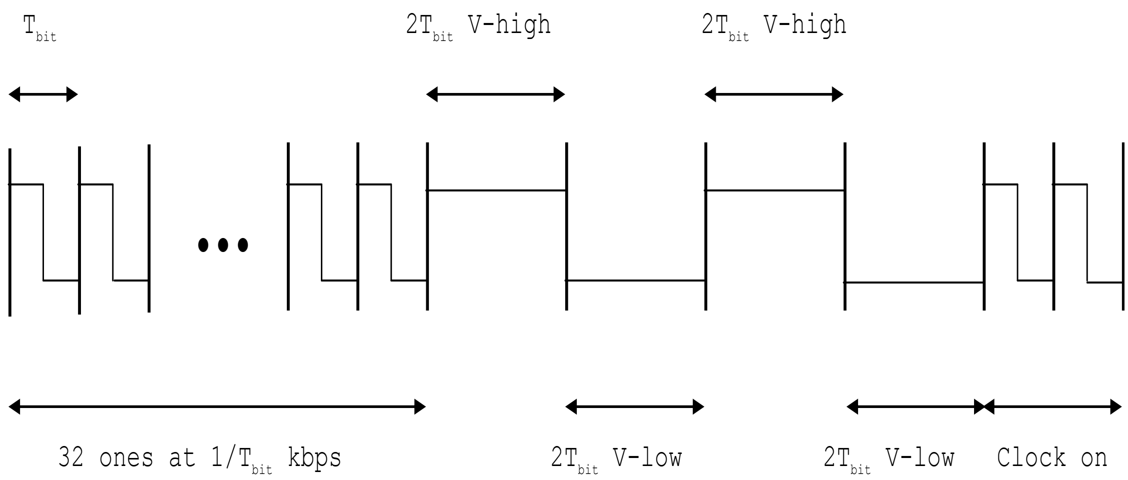


Figure 3.8: Option 1 for normal command preamble in the asymptotic training case.

Option 2: Since readers which implement a sensitive AC mode are assumed to have precise control of transmit power, this capability may be used to create a training preamble that creates less spectral splatter. This method replaces the 32 leading ones with a steady state carrier transmitted at 50% peak carrier power used during modulation. The optional normal command preamble is shown in Figure 3.9.

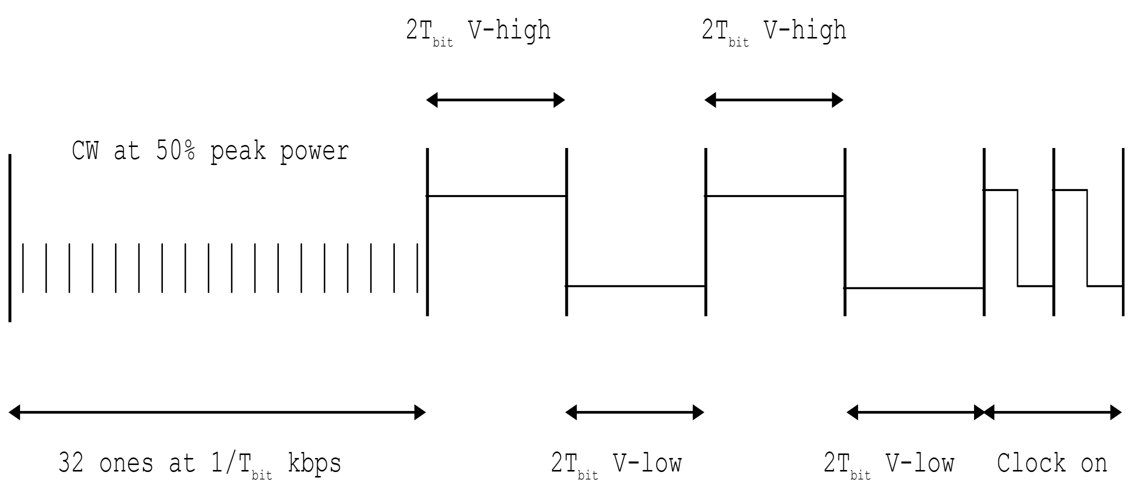


Figure 3.9: Option 2 Normal Command preamble asymptotic training.

This optional preamble reduces the reader to reader interference time during the preamble process by 67.7%.

3.2.2.2 Overshoot Training

Overshoot training refers to the fact that the input training voltage (the driving source) is set temporarily lower or higher than the desired AC coupling voltage (in this case 50%), then changed to the final desired value at about the time that the training should be hitting the desired value. This is effectively a non-linear training that can shorten the training time. This kind of training to shorten the preamble is assumed in the Feb 2007 CD, as shown (but not described) in section P.2.2.5 Reader to tag preamble. The two Tbit low times of Fig. AMd.2-6 are to quickly discharge the "too large" charge that the reader carrier (during backscatter) has left on the AC coupling of tags in receive mode.

That simple fact leads to significant conclusions about the system is operating:

1. The tag receiver is not shifting between dynamic range states, because if it was, the step function this sometimes introduces can be in conflict with the overshoot target training.

2. There is not significant power leveling or use of low reader forward link power, because if there was, there are times when other readers have controlled the charge on the tag AC coupling, and it is not in a state to be accurately quick charged by the particular time assumed.

For this kind of training to work, the reader has to reliably be in command of the AC coupling charge state of its own tags. If the tag "takes charge" by implementing a dynamic range state change, or if an "enemy" reader takes charge, then the desired reader does not know the starting point and cannot accurately control the "quick charge".

We are thus struggling to make good use of this possibility. Every scheme we have tried has had some operational hole or circumstance where it fails. We are still working on it, but are not optimistic for reader controlled quick charging to be reliable in the case of highly sensitive tags with multiple dynamic range states and power leveling in effect. It may be that we have to resort to non-linear behavior in the tag itself. This is a promising path, but we are not yet ready to give "hard numbers" with precise preambles.

When using reader based overshoot or quick charging, factors to be accounted for include the following. Both Manchester symbols (i.e. {0,1}) have the same average voltage, and so they are only suitable for asymptotic training. Also, normally in Semi-Passive power leveling the forward link reader transmission operates at lower power than the reverse link supporting reader carrier (recall Semi-Passive is reverse link limited). There is thus commonly a need to create a low going overshoot to fast settle AC coupling from the too high value left on by reverse link operation to a lower value suitable to the forward link operation. Thus, the general technique is based on transmitting zero-power (i.e. turning off the transmitter) for a period of time to quick charge to the necessary level, followed by a period at the desired level in order to finalize the training. The low period of time (in units of T_{bit}) is governed by a simple RC charge or discharge given in Eq. 3.5 and Eq. 3.12, respectively.

Eq. 3.11: $t = \frac{-1}{2\pi N_c} \ln(1 - V_{desired})$

Eq. 3.12 $t = \frac{-1}{2\pi N_c} \ln(V_{desired})$

3.2.2.2.1 Activation Command Overshoot Training

TBD.

3.2.2.2.2 Normal Command Overshoot Training

TBD.

3.2.3 AC Coupled Manchester Command Set

3.2.3.1 Existing Manchester Command Set

The current CD Manchester command set is shown below. The "Global" commands are issued by readers to all tags that are listening at a given time. They are more dangerous to use in Semi-Passive (Class 3) and higher because the higher sensitivity of the tags and the use of power leveling creates much higher odds of a more distant reader accidentally commanding a tag and interrupting its communications with the desired reader.

Table 3.15: Current CD Manchester **mandatory** command set. We include Activate even though its "command code" is effectively the signature of its unique preamble.

Command	**Length (bits)**[3]	**Code**	**Comments**
Activate	NA	NA	Effectively mandatory.
QueryRep (Global)	4	00	Counts down random counter in Ready state.
ACK	18	01	Causes tag to transmit XPC/EPC in Reply, and transition to Acknowledged.
Query[4]	4	1000	PASSIVE form of begin new query round. Selective as to flag state and session, sets up return link (tag transmitter)
QueryAdjust (Global)	9	1001	Respins random slot counter.
Select (Global)	44	1010	Resets flags.
NAK (Global)	8	11000000	Resets tag in higher states back to Arbitrate.
Req_RN	40	11000001	Causes tag to send new RN, can cause state change.
Read	57	11000010	Read single word.
Write	58	11000011	Write single word.
Kill	59	11000100	Permanently disable a tag, though recommissionable tags can be brought back to life.
Lock	60	11000101	Locks memory against writes, locks passwords against reads and writes. Read, Write, Kill, and Lock are already defined as well protected via CRC-16.

Note that Query is now defined as Mandatory and Query_BAT as optional.

[3] This includes command length plus the parameters length.

[4] We shall recommend that a passive Query NOT be mandatory or even optional. A required Query forces the tag to be able to operate with a dead battery, which has large and sometimes undesired process and design impact.

Table 3.16: Current CD Manchester **optional** and unused command set.

Command	**Length (bits)**[5]	**Code**	**Comments**
Access	8	11000110	Provide password to specific tag via RN and move from Open to Secured.
Block Write	8	11000111	Write a block of data. CRC-16.
Block Erase	8	11001000	Erase a block of data. CRC-16.
Block Permalock	8	11001001	Lock a block of data against new writes. CRC-16.
Deactivate	8	11001010	Command battery tags in Ready state to go to Hibernate based on SL flag. Global, can be dangerous. CRC-16.
Next	8	1100 1011	Commands individual singulated tags back to Hibernate using RN.
Query_BAT	8	11001100	Battery supported Query that sets up round based on SL and Session flag, provides return link setup and Q. Note that it has Reader ID, but that currently tag does not USE ReaderID. Note protection = CRC-5 (needs improving). Also, the CRC-5 is inadequate.
Broadcast ID	69	11001100	Provides 32 bit reader ID, antenna #, power, and channel. Primarily this information is for other readers.
RFU	8	Codes 11001110 to 11011111	
Reserved for Custom Commands	16	1110 0000 0000 0000 to 1110 0000 1111 1111	
Reserved for Proprietary Commands	16	1110 0001 0000 0000 to 1110 0001 1111 1111	
Extended Commands	16	1110 0010 0000 0000 to 1110 1111 1111 1111	

[5] This includes command length plus the parameters length.

3.2.3.2 Proposed Manchester Command Set

Problems with the existing command set include:

- Query is mandatory, possibly implying that battery tags must be able to operate in a passive mode when batteries are dead, and that the primary reader round set up should be via Query instead of Query_BAT. Also, the standard passive Query does not specify return link parameters via data field. Instead, it assumes the use of special TRcal symbol, for which pulse width measurement is distorted by AC coupling.
- Adequate control of power leveling is not provided.
- Prevention of accidental reader access is not provided for. Such accidents become much more prevalent with sensitive tags and power leveling, since the desired reader may be at a low power state when a neighboring reader is at a high power state.
- Allowance for possible future expansion to higher level classes is not provided for. For example, the channelization does not allow for future narrowband channels that are highly likely in Semi-Active and Active tags. Also, forward and reverse data rate minimums are not sufficient for these future narrowband plans.
- No command set provisions are made for regulatory roaming.

Basic recommendations for an improved Manchester command set thus include:

- Make power leveling capability mandatory for the sensitive AC (nominally Manchester) mode. Then provide command set and feature improvements that allow for convenient power leveling.
- Making Query_BAT a mandatory feature, since readers operating Manchester are assuming battery power tags.
- Elimination of a plain Query in Manchester even as an optional feature. A pure passive fall back for a battery supported tag in the event of battery failure is to use DC PIE, since that mode is inherently able to communicate power to the tag. Also, pulse width measurement for data rate commanding is simply not suitable for AC coupling.
- Make provision for optional "locking" of tags to the reader that wakes them up in order to prevent access by other readers. Accidental access of tags by more distant readers is also provided by use of programmable sensitivity in the tag and by time coordination between readers. This is especially critical when power leveling is being used.
- A forward data rate lower limit of 4 kbps is suggested. This requires modification of the Activation and Query_BAT commands, and leans towards alteration of the Manchester "violation" from being 4X symbol time to 2X symbol time.
- For reverse data rate increase divider M from maximum of 64 to maximum of 256 to allow lower reverse data rates with higher subcarriers.
- Make provisions for regulatory roaming via activation command.
- In general, it should be recognized that the Semi-Passive (Class 3) link in the case of excellent tag sensitivity is a hostile link. Thus there is an increased need for

flexible link control (such as receiver sensitivity and data rate programming) and more recommended use of the safer CRC-16 as opposed to the CRC-5.

The optional locking of tags to the activating reader is implemented by the Activation command including a flag indicating if locking is to be observed by the tags and providing an 8 bit field identifying the reader. The global commands would then have the Reader ID appended when locking is in use.

The table below summarizes the recommended mandatory commands for Manchester mode, and the following one summarizes the recommended optional commands. The following sections explain modifications to commands and recommended new commands. For reader convenience we include descriptions of all commands that are used in the recommended power leveling algorithm, even though some of those commands have not changed (such as Next). Commands that we have not recommended a change to and that are not used for fundamental air interface operations are not repeated here. The reader is referred to the current CD for definitions of those commands (such as block read and write commands).

Table 3.17: Proposed Manchester **mandatory** command set. Commands necessary to power leveling operations are recommended as mandatory. Global commands have the option to be locked to the activating Reader.

Command	Length (bits)[6]	Code	Comments
Activate (Modified)	NA	NA	Extended to allow for wake up based on Class of tag and Session flag for power leveling, provide short reader number to tag for optional "locking" of tag to reader, provide regulatory region, and detailed tag receiver set up.
QueryRep (Global) (Modified)	4 or 12	00	Counts down random counter in Ready state.
ACK	18	01	Causes tag to transmit XPC/EPC in Reply, and transition to Acknowledged.
QueryAdjust (Global) (Modified)	26 or 34	1001	Respins random slot counter.
Select (Global) (Modified)	44 or 52	1010	Sets flag states.
NAK (Global) (Modified)	8 or 16	11000000	Resets tag in higher states back to Arbitrate.
Req_RN	40	11000001	Causes tag to send new RN, can cause state change.
Query_BAT_MAN (Global and Modified)	54	11010101	Battery supported Query that sets up round based on SL and Session flag, provides return link setup and Q. Note that it has short Reader ID as required field. Protection increased from CRC-5 to CRC-16.
Deactvate_BAT_MAN (Global and Modified))	30 or 38	11001010	Command battery tags in Ready state to go to Hibernate improved to be based on SL and/or Session flags. Global, can be dangerous.
Next	24	11001011	Commands individual singulated tags back to Hibernate using RN.
WriteTimer **(New)**	36 or 52	11001101	Allows reader to program new timer values for proposed programmable timers associated with each Session flag. Flexible and accurate persistence is needed in power leveling operations.
ReadTimer **(New)**	43	11001110	Allows reader to read back current timer state. Read and Write timers are mandatory with power leveling capability mandatory.
Broadcast ID (Modified)	69	11001100	Provides 32 bit reader ID, antenna #, power, and channel. Modified to allow for finer channels and for inclusion of short ID.
Read	57	11000010	Read single word.
Write	58	11000011	Write single word.
Kill	59	11000100	Permanently disable a tag, though recommissionable tags can be brought back to life.
Lock	60	11000101	Locks memory against writes, locks passwords against reads and writes.

[6] This includes command length plus the parameters length.

Table 3.18: Proposed Manchester **optional** and unused command set.

Command	**Length (bits)**[7]	**Code**	**Comments**
Access	8	11000110	Provide password to specific tag via RN and move from Open to Secured.
Block Write	8	11000111	Write a block of data.
Block Erase	8	11001000	Erase a block of data.
Block Permalock	8	11001001	Lock a block of data against new writes.
Rx_Cntrl_3_Man **(New & Global or Individual)**	8	11001010	This command allows the reader to reprogram the data rate and sensitivity of awake tags. It is planned to have a flag for global or individual applicability.
Hib_Cntrl_3_Man **(New & Global or Individual)**	8	11001011	This command allows the reader to reprogram the sensitivity and duty cycle of the hibernate mode receiver. It is planned to have a flag for global or individual applicability.
RFU	8	Codes 11001110 to 11011111	
Reserved for Custom Commands	16	1110 0000 0000 0000 to 1110 0000 1111 1111	Custom commands may be used in the field, but are restricted to use after tag singulation and reader determination that the tag supports the custom command.
Reserved for Proprietary Commands	16	1110 0001 0000 0000 to 1110 0001 1111 1111	Proprietary commands are vendor specific test commands, and are not to be used in the field.
Extended Commands	16	1110 0010 0000 0000 to 1110 1111 1111 1111	

[7] This includes command length plus the parameters length.

3.2.3.2.1 Manchester Activation Command (Semi-Passive Class 3) (Modified)

The proposed Activation command provides all the information provided in the current draft and adds new information for Class of tag, detailed wake up based on either don't care or status of Session and Inventory flags (for improved power level control), the regulatory region of operation (allowing optimum tag set up, such as adjustment of front end filtering), reader identification and power (for optional control of backscatter power), and more data rate options. Additional data rate options are recommended in order to allow for fitting forward and reverse modulation into narrow channels that will likely be used in future Semi-Passive (Class 3 Plus) and Active (Class 4) tags. The general structure is shown in the figure below.

Preamble	Target (9 bits)	Length (7 bits)	Address (7 bits)	Mask (0 to 96 bits)	Rx Set Up (8 bits)	Reader Info (17 bits)	RFU (8 bits)	CRC (16 bits)

Figure 3.10: Proposed Manchester Activation Command structure.

A tag optional CRC-16 has been appended. The reader would send it, but the tag has the option of doing bit by bit decoding and rejecting the activation on the first non-matching bit, or finishing the packet and running the CRC. The CRC does not help for the case when a bit error makes the tag receive a non-matching mask, since with or without the CRC the tag still does not wake up. But, the CRC does help reject false wake ups when a bit error causes a mask match, or reject errors in set up.

The Target subfield communicates the Class of tag to be woken up, and flags and their states that shall be used to authorize wake up. Note that Session and Inventory flag use are repeated as control parameters in the Query_BAT_MAN command used after wake up. The reader has the option to wake up based on one state of Inventory flag and use that state in a query round, or to use a Select command to change Inventory flag status, and then perform a query round based on this new Inventory flag status.

Table 3.19: Candidate Semi-Passive (Class 3) Manchester Activate Target Field description.

	Class	**SL Use**	**Match SL**	**Session**	**Inventory Flag Use**	**Match Inventory**
# of bits	3	1	1	2	1	1
Description	000: all types 001:Semi-Passive (Class 3) 010:Semi-Passive (Class 3 Plus) 011: Active (Class 4) 100: RFU 101: RFU 110: RFU 111: RFU	0: Don't care about SL state 1: Do care about SL state	0: Activate if SL 0 and other conditions met 1: Activate if SL 1 and other conditions met	00:S0 01:S0 10:S2 11:S3	0: Don't care for Inventory state 1: Do care for Inventory state	0/A: Activate if Inventory 0/A and other conditions met 1/B: Activate if Inventory 1/B and other conditions met

The new Reader Info field provides information as to reader identity, whether the tag is to reply to only the activating reader or not after wake up, and the regulatory region of operation.

Table 3.20: Candidate Manchester Activate Reader Info Field description.

	Reader ID	**Reader Lock**	**Region Field**
# of bits	8	1	8
Description	Reader ID code	0: Tag allows any reader to access 1: Tag only allows this reader to access	Specifies a region in which the tag operates. Precise interpretation TBD.

The Rx Set Up field informs the tag of the forward data rate to be used and the approximate tag sensitivity range for the tag to respond to. Note we have recommended extending the forward data rate control field from 3 bits to 4 bits in order to accommodate the likely future frequency plans using narrowband channels. The new recommendation of controllable tag sensitivity reflects the engineering realities that the tag square law receiver may be physically capable of sensitivities better than -60 dBm, but that there are situations where such good sensitivity is not desired. If the tag cannot meet the commanded sensitivity range (such as the common case of tag that has not been designed for best case sensitivity), then it will provide its best sensitivity.

Table 3.21: Candidate Rx Set Up Field description.

Rx Set Up	**Forward Data Rate**	**Tag Sensitivity**	**RFU**
# of bits	4	2	2
Description	0000: 4 kbps 0001: 6 kbps 0010: 8 kbps 0011:12 kbps 0100: 16 kbps 0101: 24 kbps 0110: 32 kbps 0111: 48 kbps 1000: 64 kbps 1001: 96 kbps 1010: 128 kbps Others RFU	00: 0 to -20 dBm (nominal -10 dBm, like Passive (Class 1)) 01: -20 to -40 dBm (nominal -30 dBm, simple CMOS design) 10: -40 to -60 dBm (nominal -50 dBm, advanced CMOS design) 11: Better than -60 dBm (nominal -70 dBm, advanced CMOS design plus RF LNA)	Additional flexibility might be desired in the future, such as finer trims to sensitivity.

Notice that for the special case of a forward data rates of 4kbps and 6kbps, the preamble for the normal commands needs to be altered in the case of channel spacing of 25 KHz. The new preamble contains the Manchester violations that only last as much as a regular symbol, instead of two times as much for data rates above 6kbps. The preamble for the 4 and 6 kbps cases is shown in the following figure.

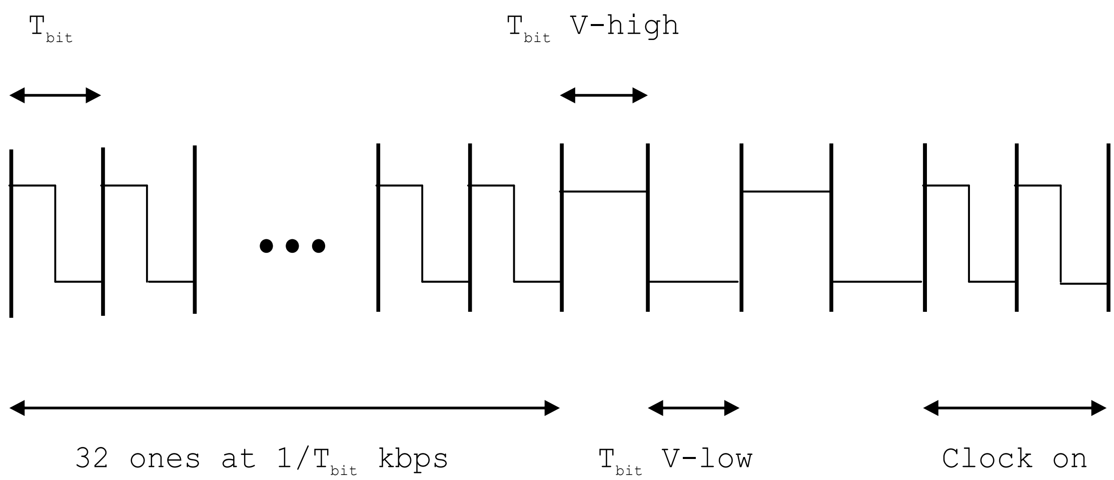


Figure 3.11: Normal command asymptotic preamble for forward data rates of 4kbps and 6kbps. These low data rates require that Manchester violations be at one half the data rate instead of one quarter, unless lower AC coupling corners are allowed for.

3.2.3.2.2 Query_BAT_MAN (Modified)

The methods by which data rates to and from the tag are controlled are fundamentally related to the coupling mode of the tag receiver, and thus to the sensitivity of the tag receiver. Note that in order to prevent the use of the Passive (Class 1) special timing symbols RTcal and TRcal that are not suitable for AC coupling, the forward (RT) and reverse (TR) data rates are commanded. The forward data rates are commanded in the Manchester Activate command. The reverse data rates are commanded in Query_BAT_MAN command. The command structure is presented in the next table.

Table 3.22: Query_BAT_MAN Command structure.

	Command	RFU	BLF	M	TRext	Sel	Session	Target	Q	Reader ID	CRC-16
# of bits	8	4	4	4	1	2	2	1	4	8	16
description	11010101		0000: 64 KHz 0001: 80 KHz 0010: 128 KHz 0011: 160 KHz 0100: 256 KHz 0101: 320 KHz 0110: 640 KHz 0111: 1280 KHz (Note 1) 1000 to 1111: RFU	0000: M=1 0001: M=2 0010: M=4 0011: M=8 0100: M=16 0101: M=32 0110: M=64 0111: M=128 1000: M=256 1001 to 1111: RFU	0: No pilot tone 1: Use pilot tone	00: All 01: All 10: ~SL 11: SL	00: S0 01: S1 10: S2 11: S3	0:A 1:B	0-15	Always included	

Note 1: The 1280 KHz link frequency is optional. A tag that does not support 1280 KHz link frequency that receives a command to use 1280 KHz will ignore the Query_BAT_MAN command. Also, since T_{pri} is defined as 1/BLF, and T_2, the interrogator response time, is required to be between $3T_{pri}$ and $20T_{pri}$, for the optional BLF of 1280 KHz T_2 needs to be changed to be between $3T_{pri}$ and $40T_{pri}$.

3.2.3.2.3 Deactivate_BAT_MAN (Modified)

An important intended use of the deactivation commands is likely to be in power level controlled systems, where different power levels are used, and tags reply based on the state of a flag or memory value. It is desired that nearby tags that were successfully inventoried in a lower power state do not respond to a higher power command or activation. This requires that the Activate command be modified to be selective as to the state of the Select and Inventory Flags. The Deactivate_BAT_MAN to be described here allows for similar deactivation based on the state of either Select flag, a desired Inventory flag, or both.

The modified command Deactivate_BAT_MAN contains the fields of the command Deactivate in the current draft, plus a session field, plus a Match Inventoried field, and Operation field. The modified command acts as a global command, since it does not use a handle. This improved command may thus be used in power leveling operations to put tags that were inventoried at a lower power level back to Hibernate as a group if they are woken up by a subsequent higher powered Activation command, or if they were inadvertently left awake if they missed a Next command to put them back to Hibernate. The command structure is presented in the following table.

Table 3.23: Deactivate_BAT_MAN command structure.

	CMD ID	**SL Use**	**Match SL**	**Session**	**Inventory Use**	**Match Inventoried**	**Reader ID**	**CRC**
# of bits	8	1	1	2	1	1	8	16
Description	1100 1010	0: Don't care for Match SL 1: Do care for Match SL	0: ~SL 1: SL	00:S0 01:S0 10:S2 11:S3	0: Don't care for Inventory 1: Do care for Inventory	0: ~Inventoried 1: Inventoried	Included only if Reader locking is in effect.	

The tag shall not reply to the Deactivate_BAT_MAN command.

3.2.3.2.4 Next (unchanged)

We have not recommended a change to this command, but repeat its definition as it is fundamental to air interface operation. The Next command puts a particular singulated tag back to Hibernate after the reader is done with it in the inventory process, and is ready to move on to singulation of the next tag by counting their random counters down to zero. Since it acts on a particular tag, the tag's random number handle is used to address it.

The tag replies to the Next command with its RN16 handle to let the reader know that it received the command and is going to sleep.

Table 3.24: Manchester Next Command structure.

	CMD ID	RN
# of bits	8	16
Description	1100 1011	RN16_handle

The tag reply to the Next command is presented in the following table.

Table 3.25: Reply to Next Command.

	RN16	Parity
# of bits	16	1
Description	RN16_handle	Odd parity

3.2.3.2.5 Manchester Broadcast ID (Modified)

The only proposed changes from the current draft are to increase the number of bits used in the channel field and to include the short reader ID. This is because we are proposing to leave room for future Semi-Passive (Class 3 Plus) and Active (Class 4) extensions where narrowband channels are used (such as 25 KHz channel steps), thus requiring more bits. The use of 13 bits can perfectly specify the existing channels while allowing future channelization to cover any channel plan describable with 25 KHz steps and within a 200 MHz total range. That step and range should cover any feasible plan anywhere in the world in the band of 830 to 1030 MHz.

Table 3.26: Proposed Broadcast ID Command.

	CMD ID	Long Reader ID	Short Reader ID	Antenna	Power	Channel
# of bits	8	32	8	8	8	13
Description	1100 1100	MAC address	Same 8 bit field for local Reader ID used for Reader-Tag locking	Antenna number	2's complement -64 to +63.5 dBm in 0.5 dB step	Channel #

As is now described in the current draft, there is no tag response to a Broadcast ID command.

3.2.3.2.6 QueryRep (Modified)

The only change to this command is to include the optional short Reader ID if tag to reader locking is in effect.

Table 3.27: Manchester QueryRep Command structure.

	CMD ID	**Session**	**Short Reader ID**
# of bits	2	2	8
Description	00	00: S0 01: S1 10: S2 11: S3	Included if locking is in effect.

The tag reply to the Manchester QueryRep Command is presented in the following table.

Table 3.28: Proposed reply to Manchester QueryRep Command.

	RN16
# of bits	16
Description	RN16_handle

3.2.3.2.7 QueryAdjust (Modified)

The only change to this command is to include the optional short Reader ID if tag to reader locking is in effect.

Table 3.29: Manchester QueryAdjust Command structure.

	CMD ID	**Session**	**Q**	**Short Reader ID**	**CRC-16**
# of bits	4	2	4	8	16
Descrip-tion	1001	00: S0 01: S1 10: S2 11: S3	Q value from 0 to 15	Included if locking is in effect.	

The tag reply to the QueryAjust command is presented in the following table.

Table 3.30: Reply to Manchester QueryAjust Command.

	RN16
# of bits	16
Description	RN16_handle

3.2.3.2.8 Select (Modified)

This command is only modified by the addition of the short Reader ID if tag to reader locking is in effect. The short Reader ID is inserted before the CRC so that the CRC may apply to it as well. There is no reply to the Select command.

Table 3.31: Proposed Manchester Select Command structure.

	CMD ID	**Target**	**Action**	**Mem-Bank**	**Pointer**	**Length**	**Mask**	**Trun cate**	**Short Reader ID**	**CRC 16**
# of bits	4	3	3	2	EBV	8	Varia-ble	1	8	16
De-scrip-tion	1010	000: S0 001: S1 010: S2 011: S3 100: SL 101: RFU 110: RFU 111: RFU	See CD, Table 200	00: RFU 01: UII 10: TID 11: Us-er	Starting Mask address	Mask Length	Mask Value	0: En 1: Dis	Includ-ed if locking is in effect.	

3.2.3.2.9 NAK (Modified)

The NAK command sends a tag to arbitrate from any state except ready or killed, in which case the command does nothing. The only recommended change is to append the short Reader ID in the case of Locking being in effect. There is no tag reply.

Table 3.32: Proposed Manchester NAK Command.

	Command	**Short Reader ID**
# of bits	8	8
Description	11000000	Included if locking is in effect.

3.2.3.2.10 WriteTimer (New and Required)

A total of four new commands are being proposed in order to enable power leveling and to provide tag receiver control. The two new power leveling commands are used to Write and Read programmable timers associated with each session (note that the tag shall maintain an individual timer per session). The programmable timers control the persistence of the inventoried and SL flags on a dynamically adjustable basis. The default timer value prior to first programming shall be 1.0 seconds (10 decimal). Notice that the persistence of the SL and the inventoried flags are equal, and therefore no target field (i.e. SL or Inventoried flag) is included in the commands.

This command may act on a global or individual basis. This allows groups of tags to be programmed when embarking on an application mission, and for readers to modify timers used in power leveling based on particular circumstances. The operation of the timer is to precisely control the persistence of the Semi-Passive (Class 3) and higher inventory flags. When the timer has timed out, it resets the Inventory flags from a state where the tag does not respond to Activate commands with Do Care on inventory flag control to a state where the tag will respond to this Activate. This controlled action of not waking up allows tags inventoried in a low power state to avoid accidentally waking back up to the same reader that just inventoried them in a lower power state. Tags with other opposite Inventory flag state have not been yet inventoried, and they do wake up. For further explanation see the power control section.

The following table shows the proposed implementation of the WriteTimer command.

Table 3.33: WriteTimer Command structure.

	Command	**Flag**	**Scope**	**Value**	**RN**	**CRC-16**
# of bits	8	3	1	8	16	16
Description	11001101	000:S0 001:S0 010:S2 011:S3 100:SL Others: RFU	0: Global 1: Individual	See dedicated table	RN16_handle (not sent if Scope is Global)	

The Scope field determines if the command shall be executed by all tags in the current inventory round and session or if only a specific tag shall execute the command. If the scope is set to global, the RN field shall be ignored by the tags.

Tags shall not reply to a WriteTimer command if the scope is global, but shall reply as below if the scope is individual.

Table 3.34: Proposed reply to WriteTimer Command (only if scope is individual).

	RN16	**Parity**
# of bits	16	1
Description	RN16_handle	Odd parity

In case that a particular tag receives the WriteTimer command in error, it shall ignore the command.

The following table is suggested as interpretation of the 8 bit values for timer operation. The overlap between timer ranges is suggested as a circuit design convenience, where the order of magnitude switching of timer controls are kept separated. Suggested accuracy requirement is 10% at 25 deg C and 20% from -40 to +85 deg C. Competent circuit design should typically reduce variations to less than half those tolerances, or to near zero if crystal timing is used.

Table 3.35: Value Field interpretation.

Code or Range (Decimal)	**Interpretation**	**Comment**
0	Does not time out	Flags remain as set until reset by a Select command.
1 to 100	100 mS to 10 sec in 100 mS steps	Most commonly used range.
101 to 200	1 to 100 sec in 1 sec steps	
201 to 255	10 sec to 550 sec in 10 sec steps	Max timer of 9 minutes and 10 seconds

3.2.3.2.11 ReadTimer (New and Required)

This command acts only on an individual basis. The purpose of this command is to allow a reader to see how a previous reader has set up the controlled persistence of a tag. Even if a tag has an Inventory flag state that has not timed out and allowed the tag to be activated when using Inventory flag to control wake up readiness, any reader can if necessary wake up any tag by setting Inventory flag control to a Don't Care state when the reader transmits an Activate command. This allows for future flexibility in the design and implementation of more advanced power leveling and interference control algorithms.

The following table presents the implementation of the ReadTimer command.

Table 3.36: ReadTimer Command structure.

	Command	**Flag**	**RN**	**CRC-16**
# of bits	8	3	16	16
Description	11001110	000:S0 001:S0 010:S2 011:S3 100:SL Others: RFU	RN16_handle	

A tag shall respond to the interrogator with the programmed maximum value of its persistence timer (the time to be measured at the beginning of timer activation) and the current remaining time before timer expiration. The following table presents the implementation of the tag reply to a ReadTimer command.

Table 3.37: Tag response to ReadTimer command.

	MaxValue	**CurrentValue**	**RN**	**CRC-16**
# of bits	8	8	16	16
Description	Initial value	Current value (at time of ReadTimer decode in tag)	RN16_handle	

3.2.3.2.12 Rx_Cntrl_3_MAN (New and Optional)

The reprogrammability of the tag to different forward data rate and sensitivity are desirable features in the interference limited environment of more sensitive Semi-Passive (Class 3) tags. This command may be individual, in which case a tag is addressed via RN16, or global, in which case the short Reader ID replaces the RN16. Two RFU bits are recommended. The table below is the recommended structure.

Table 3.38: Rx_Cntrl_3_MAN Command for reprogramming of tag normal receiver mode parameters.

	Command	**Scope**	**Forward Data Rate (kbps)**	**Sensitivity**	**RFU**	**Reader ID or RN**	**CRC-16**
# of bits	8	1	4	2	2	0 or 8 or 16	16
Description	11001010	0: Global 1: Individual	0000: 4 0001: 6 0010: 8 0011:12 0100: 16 0101: 24 0110: 32 0111: 48 1000: 64 1001: 96 1010: 128 Others RFU	00: 0 to -20 dBm (nominal -10 dBm, like Passive (Class 1)) 01: -20 to -40 dBm (nominal -30 dBm, simple CMOS design) 10: -40 to -60 dBm (nominal -50 dBm, advanced CMOS design) 11: Better than -60 dBm (nominal -70 dBm, advanced CMOS design plus RF LNA)		RN_16 handle if scope is individual. Reader ID if scope is global and locking is in effect. Nothing if scope is global and locking is not in effect.	

If the scope of the Rx_Cntrl_3_Man command is global, then there is no tag reply. If the scope is individual, then the tag shall reply as below.

Table 3.39: Tag reply to Rx_Cntrl_3_MAN Command if Scope = Individual

	RN16	**Parity**
# of bits	16	1
Description	RN16_handle	Odd parity

3.2.3.2.13 Hib_Cntrl_3_MAN (New and Optional)

This new and optional command allows for increased battery life by providing duty-cycling of the hibernate receiver and programmable sensitivity. The programmable sensitivity also provides greater system adaptability with environmental variation such as variable noise floors.

Table 3.40: Hib_Cntrl_3_MAN command structure.

	Command	**Scope**	**Sensitivity**	**Receiver OFF time**	**Receiver ON time**	**RFU**	**Reader ID or RN**	**CRC-16**
# of bits	8	1	2	8	4	2	0 or 8 or 16	16
Description	11001011	0: Global 1: Individual	00: 0 to -20 dBm (nominal -10 dBm, like Passive (Class 1)) 01: -20 to -40 dBm (nominal -30 dBm, simple CMOS design) 10: -40 to -60 dBm (nominal -50 dBm, advanced CMOS design) 11: Better than -60 dBm (nominal -70 dBm, advanced CMOS design plus RF LNA)	Number of units of time (each unit is 0.25s) receiver is off. Special Value 11111111 means infinite	Number of units of time (each unit is 0.25s) that the receiver stays ON		RN_16 handle if scope is individual. Reader ID if scope is global and locking is in effect. Nothing if scope is global and locking is not in effect.	

3.2.4 Manchester Power Level Control

The general benefit of power leveling is to reduce interference by not using unnecessarily high reader power levels. This general concept is extensively used in cellular and other dense wireless systems. Reader on reader interference is particularly troublesome in Semi-Passive in forward mode because the readers are extra sensitive as compared to passive systems. Co-channel and even adjacent channel transmission at higher powers can cause interference at great distances. This is why “split band plans” that separate the forward and reverse links into separate band segments would also be of great benefit. In the most troublesome case of readers interfering with other readers when they are trying to listen to weak tag backscatter, in the split band plan case that interference is not spread out by forward modulation (it is a quiet carrier only for backscatter) where it overlays tag sidebands, and the excellent selectivity of the reader may then be used to reject the enemy reader carrier. So, in the absence of such split band plans, the use of power leveling is even more important. Based on the extended command set, a common algorithm usable for both the single and dense reader cases may be implemented.

The general principle of the algorithm is to wake the tags up using a series of scaled lower power to higher power Activation commands. For each wake up at a given power level, an inventory round is conducted. We refer to these as “mini-rounds”, where a set of mini-rounds are used to reach out to full range and complete a full round. Each mini-round addresses tags in a “ring” of range. The global commands, such as Activation call, Select, Query_BAT, and QueryRep, used in each mini-round are approximately tailored to what the tags that in ring actually need, with the approximation becoming better if more mini-rounds are used to build a full round. During each mini-round the reader accesses tags within that ring, reading and writing them as necessary, then putting them back to hibernate. See the figure below for an illustration of the geometry.

Current Command Set Possible Implementation: Breaking the service area up into the mini-round rings requires that tags accessed in the inner rings not participate in the outer mini-round rings (they temporarily resist new Activates or accesses). This may be accomplished under the current command set and Inventory flag persistence, where the normal “power up” state of the Inventoried flag, state A, is interpreted to mean “Needs Reading”. The temporary state of “persistence”, state B, is interpreted to mean “Has Already Been Read”. So, tags in inventory state A are the ones accessed via Query command. The problems are:

1. Tags activation does not use Inventory state. So, with any method, tags are going to be woken up unnecessarily, or they are going to have to be left awake. In either case, battery life is wasted, and the tags may accidentally catch an unintended command from another reader.
2. The persistence times are different for the different sessions and are very loosely specified, so the non-participation time of the already accessed tags is widely variable. To assert some control over these flags being in “Don’t Read Me” state B, the reader may use the Select command to reset them all back to A at the end of an Inventory round, but this command may also accidentally reach out and act on more distant tags (some semi-passive tags are quite sensitive).
3. There is no reader to tag locking.

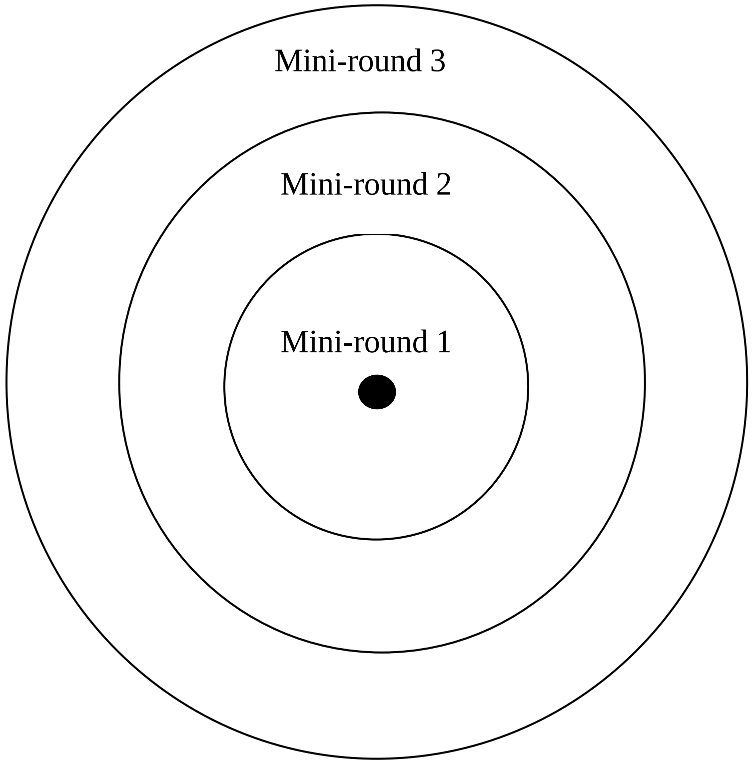


Figure 3.12: The "mini-round" power leveling concept. The inner rings use lower reader power than the outer rings. Three mini-rounds are presented for illustrative purpose, as in practice any number of mini-rounds can be used.

Using the current command and feature set, a first algorithm based on Inventory flag that seems to be implementable is as follows: The reader first sends an Activation command at a low power, waking up nearby tags based upon mask, but not upon Inventory state. So, all Inventory states wake up. The reader needs the tag to be in Inventory flag state A to address them. The reader must assume that flag persistence has expired and the tag has set its Inventory flag to state A, because if this mini-round is a higher mini-round of one inventory round, then this reader has just set that tag's Inventory state to B and should not reprogram it. The reader then issues a Query_BAT for the reader's assigned Session and with a don't care on Select state. It inventories and accesses the nearby tags as follows. As each tag is accessed its Inventory flag changes state (to B, meaning it has been accessed) upon the QueryRep or QueryAdjust following its reply. On this same QueryRep another tag may reply with its RN16, which is noted by the reader. But, before the reader deals with the new tag it first puts the tag it last accessed back to Hibernate by sending the Next command with the RN16_handle of the last accessed tag (not the new tag). This saves a little battery power even though the tag will wake back up for the next mini-round. At the end of the mini-round, a new Activate wakes these back up. But, they do not participate in the Query round because their session state is still B.

Note the problems with this process. The reader must trust the tags to come up in a particular Inventory state, which is not 100% reliable due to other readers. Also, the timeout period when the tag does not participate is poorly controlled and not flexible to take into account variable conditions.

Another algorithm is possible based upon adding the use of the Select flag, as follows: The reader first sends an Activation command at a low power, waking up nearby tags based upon mask, but not upon Inventory state or Select state. But, the reader may now put tags with a Select flag state that is now defined to mean "Have Been Read" back to sleep using the Manchester Deactivate command. This command puts all tags to hibernate that are in a chosen select state (we momentarily defer saying how the tags got in that select state, but we'll get to it shortly). Tags in the other Select state are still awake. The reader then issues a Query_BAT for the reader's assigned Session and a state of Inventory flag (normally A) AND for this chosen value of Select. It inventories and accesses the nearby tags as follows. As each tag is accessed its Inventory flag changes state (normally to B, meaning it has been accessed) upon the QueryRep or QueryAdjust following its reply. At this point the reader desires to have the Select flag also change state, since it is using Select as its criteria for mini-round participation and it does not want this tag to participate in the next mini-round. It does this by sending a Select using the mask field to target this particular tag and reset its Select flag (The Select command is not really selecting anything. It should be called something like "FlagProgram", since that's all it does. The Query command really "selects" tags based on flag state.) Now the Next command with the RN16 of the tag whose Select flag was just changed may be used to send that tag to Hibernate. Subsequent tags are handled until all those in the mini-round have been serviced. At that point all the tags that have been serviced in this mini-round have had their Select flag set to the state that means "Have Been Read." A new mini-round may now be instigated with a new Activate, which wakes up the new farther tags as well as the closer tags that were just handled. But, the reader may then put the closer tags back to sleep using the Deactivate command with the Select flag. The tags still needing access in the new mini-round remain awake, and the process repeats.

Note that if it cannot be counted upon for the Inventory flag to have been in state A upon mini-round entry, then the mini-round may be repeated with Inventory flag state B. This does not re-read any just read tags because all those have their Select flags set to the state that means "Have Been Read".

This algorithm is superior to the first algorithm, but it still has problems:
1. A small problem is that using the Select command with individual addressing is slow.
2. A possible small problem is that the use of the Select command for individual programming sends the tag to Ready state, and is not a given that the tag will still respond to the Next command to immediately go to Hibernate (the tag has been "de-singulated" by going to Ready, so should it still respond to an individual RN16 address?). If this problem occurs, it does not kill the algorithm. It costs battery life by leaving the tag awake until the deactivate early in the next mini-round.
3. A significant problem is that the Select flag is a shared resource between all readers and sessions, hence its usage for mini-round lock out prevents other readers from incorporating this tag into another Query round. If the Inventory flag were used as the mini-round lock out, it is unique to each session, leaving open the chance for a tag to partici-

pate in another reader's inventory round just as soon as it has been dealt with by the first reader, and long before the first reader's total round is completed.

4. It has the same limits of poor timer accuracy, which is endemic in the existing specification. The timers are long enough to stay locked out during a round, but they sometimes are TOO long. For example, under the current CD the Select flag state while energized is indefinite. Since Semi-Passive tags have batteries they are always "energized". Now, if "energized" is defined to mean "in a reader field", then their high sensitivity in a high interference environment may also keep them "energized" most of the time. Thus, the Select flag state that means "Have Been Read" can "stick" for a long time under the current specification, so that the tag cannot be read by a reader using power leveling. To guarantee reading these tags, the reader would have to do a non-power leveled Query round where the Select flag criteria is "Don't Care".

Thus, we have recommended the timer based flag timeouts and new commands described below.

New Command Set Implementation: Our proposal for most conveniently allowing power leveling operations across multiple sessions and without undue flag "sticking" is to put session timer based lock outs on Activation. As each tag is dealt with, it is put back to hibernate state with a flag specific timer running that temporarily prevents that tag from waking back up when new Activates (for the next mini-round) are sent based on that Inventory flag. The timer period may be programmed to suit the environment the tag is in (tag density, tag data rates, amount of tag data read out, everything that affects mini-round duration). All the session flags would have precise timers that can be the same or different based on local system design. If the reader wants to wake that tag back up out of sequence (for example, to reprogram its timer because the full round is taking longer than expected), it can wake it back up by using the other Session flag state or Don't Care in the Activate command. This perfectly defined and reliable control, specific to the local environment, is the fundamental reason why we have recommended accurate reprogrammable timers be implemented for the Inventory and Select flag persistence for Semi-Passive tags that implement the high sensitivity option. These timers are not reprogrammed in the lower sensitivity DC PIE mode, and for simple lower cost tags that only implement the DC PIE mode, they are not even designed in. For higher sensitivity tags there is normally additional functionality (such as sensor logging over time) and often crystal based timing available, and the cost of these timers is transparent.

Now, we might design a system such that during long individual tag accesses the reader tailors its power to what that specific tag needs. But, we would also need a command such as "Get_Tag_Sens_Margin" that allows the tag to report how many dBs of sensitivity margin it has at the current reader power level in order to allow the reader to adjust forward link power (the reader can tell by itself how many dB of reverse link margin it has, and so adjust its backscatter power). For the present we are recommending a simple system where the reader keeps a constant forward power in each mini-round (thus not needing that tag sensitivity margin command), but allowing a variable reverse power. Since the Semi-Passive link is usually reverse link limited, the reader will normally transmit a higher power in the reverse link, thus requiring tag AC coupling retraining on each T/R switch anyway. Therefore, the reader can employ variable backscatter for each tag (thus reducing reader on tag interference) without additional complexity.

New Command Set Algorithm Description: With the proposed timers and command set, the recommended algorithm is as follows.

The reader first sends an Activation command at a low power, using the Reader to Tag Lock option, waking up nearby tags of the desired type and Inventory flag state. Because of the accurate timers now used to control Inventory flag state, it is much safer to assume that tags have timed out and have their Inventory flags set to a state that means "I need to be read." The reader then issues a Query_BAT_MAN for the reader's assigned Session. It inventories and accesses the nearby tags as follows. As tags count to zero, they reply and desired read and write operations are conducted. When the reader has completed such operations, it may optionally reprogram the flag timer if there has been a change in environment rendering change desirable. At the conclusion of reader access, the reader sends a QueryRep or QueryAdjust to get to the next tag, and the Inventory flag of this tag changes state (to B, meaning it has been accessed and should not reply until reset to A by either Select command or internal timer). On this same QueryRep another tag may reply with its RN16, which is noted by the reader. But, before the reader deals with the new tag it first puts the tag it last accessed back to Hibernate by sending the Next command with the RN16_handle of the previous tag (not the new tag). That last tag then goes to Hibernate with its Inventory flag set to B, and it stays in B until timing out or until awoken and reprogrammed.

When the reader has stepped through the 2^Q-1 QueryReps needed for this "mini-round", it repeats with QueryAdjust and a smaller Q if there were collisions leaving a few tags left unread in that particular mini-round. When there are no collisions, it is ready to step up to the next power level, and it issues a new Activate command at a higher power level, thus waking up more distant tags of the desired type. Recall that the Activate command has been extended to allow selective activation based on Inventory flag state, so that the tags just inventoried in the lower power mini-round will not wake up. The inventory process is then repeated with this new set of tags. The reader knows the timeout period and earlier low power level of the tags it has put back to Hibernate, and if the total length of the round approaches the flag reset time it reverts to low power, wakes those tags back up with Inventory flag state set to their current state or "don't care", and resets their timers. This reset may be done individually with a new singulation mini-round, or globally with a scope flag option on the write timer command. It then reverts to higher power and completes the round.

Note that each reader in its own session has the option of setting the <u>Select</u> flag (not the session Inventory flag) via a Select command to a state that all readers would interpret as "Tag was read by another reader and does not need to be re-read", if this is allowed in a particular application. The other readers have the option making use of this setting by using one of the two "do care" states of the Select flag control field in the Query_BAT_MAN command. Tags that don't need to be inventoried can be screened out with this effectively "extra" flag. So, while the original inclusion of both Select and Inventory flags in passive systems was done as a compromise to parties that favored only one, this feature is now very useful for extending the functionality of Semi-Passive tags.

This algorithm based on the proposed command extensions, new commands, and new timer features for Session flags seems to avoid almost all the problems noted for the existing command set. The only weakness noted is that the selective activation based on Inventory flag state does presume that the Inventory flag is in the correct state meaning “Read me”. It is possible that another reader could have left a tag with abnormally long timeout such that the Inventory flag has not reset to the “Read me” state. But, this is not really an algorithmic problem, but one of correct system design. The software for the particular installation must make proper use of the available flexibility to set the Inventory flag timer to a functional value for the particular system or application. It is certainly much more reliable and less error prone than the existing fixed and very coarse time out.

Note that even if tags were somehow set with excessive timers, the reader can test for this situation and recover with the flexibility of this extended command set. One way is to send a single Activate command at a high power using the other Inventory flag state (the normally “Don’t read me” state) or a don’t care, waking up all the tags in its service region, and then using Select to reprogram all of them to the “Read me” state. The Reader then reverts to its low power transmit state for its first mini-round, and completes a normal round. The only problem with this recovery method is that it can reach out pretty far and wake up and reprogram Inventory flags of tags that are actually closer to other readers. It performed with reader locking and if the other reader is repeating use of the same session (it’s quite far), those tags are temporarily locked out of their own readers, at least until their own reader recaptures them with its own activate. If performed without reader locking, then those tags are in the “read me” state and might get read when they did not need to. But, accidentally reading a tag an extra time is not a disaster. It’s missing tags that is a real problem.

The need to test for this possibility is one of the reasons for including a “ReadTimer” command. Readers can then test for what is going on in the larger system around them.

A flowchart showing a possible interrogation round is presented in the next figure. Notice that the specific relationship between P_i and P_{i+n} is implementation dependent and nothing is recommended regarding such relationship other than $P_i \leq P_{i+n}$ for a positive n. P_{max} is defined as the maximum allowed reader transmit power.

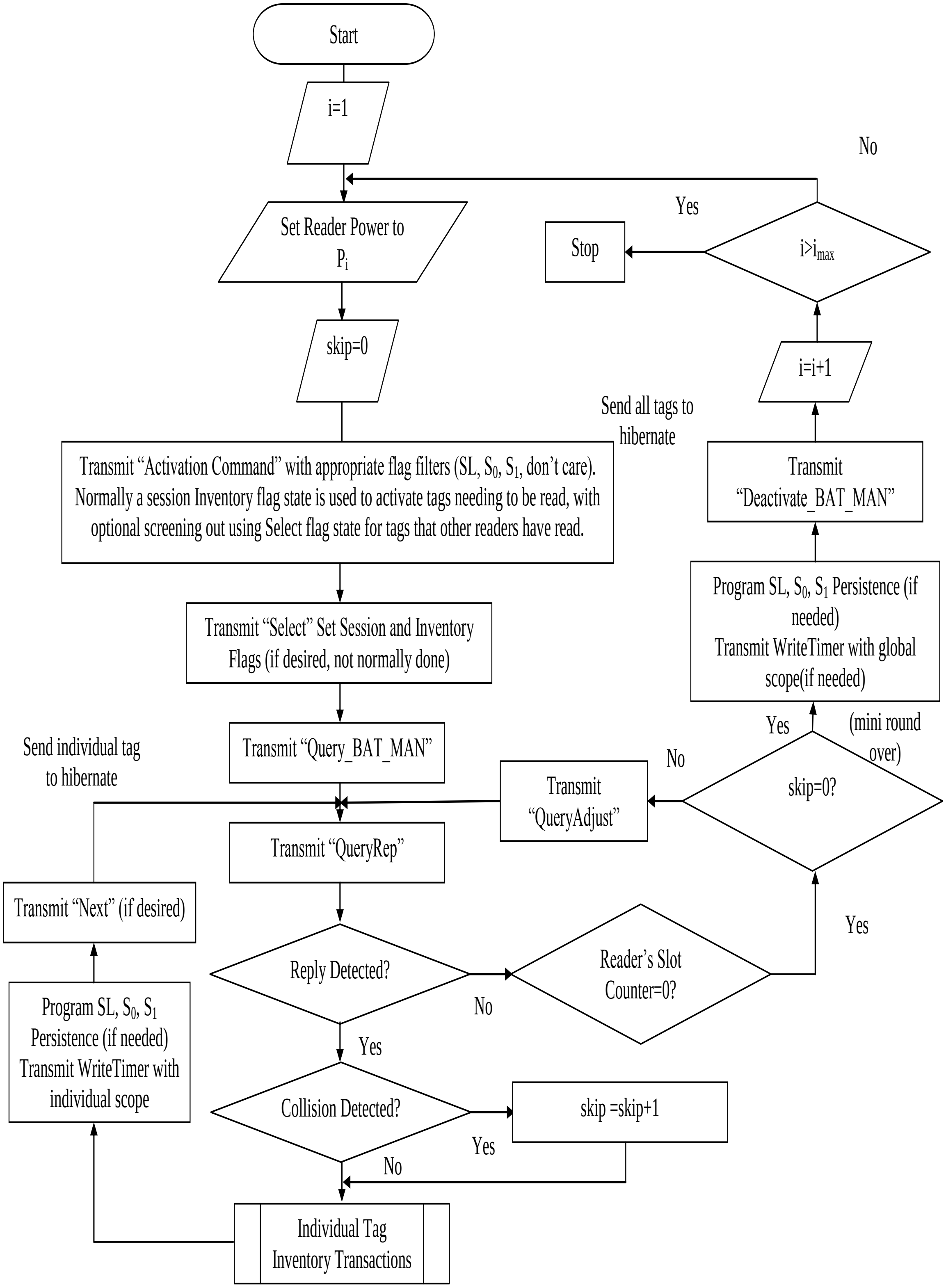


Figure 3.13: Power leveling flowchart.

4 Option 2: DC Coupled PIE and AC Coupled PIE

4.1 DC Coupled BAT PIE

In this case the DC PIE option remains the same, so please refer to section 3.1 for detailed information on this mode.

This option is only recommended if IP difficulties prevent adoption of Manchester as the sensitive forward link, which is the superior forward link mode for square law receivers in battery supported tags. If necessary, AC PIE can be implemented with about 5 dB link budget degradation, and some increase in baseline wander that can cause additional degradation if long strings of zeroes or ones occur. This baseline wander can be up to 20% of the reference (average) value of the data string, which is approximately a 1.5 dB link budget penalty. The total PIE penalty of approximately 6 to 7 dB can be tolerated (though it reduces power leveling range) since for Semi-Passive (Class 3) it is the reverse link that limits the system. However, this loss would be noticed in the case of Semi-Passive (Class 3 Plus).

The AC PIE command set is nearly identical to the Manchester based command set. It has the same requirements of eliminating pulse width measurement as a means of communicating data rates, providing for reader power level control, and providing an Activation command with a planned evolution to Semi-Passive (Class 3 Plus) and Active (Class 4).

4.2 AC Coupled PIE

4.2.1 AC Coupled PIE Behavior and Design Goals

There are several requirements on preambles to be used in more sensitive battery supported tags. These include:

1. The need to train the AC coupling (slicer reference level) that is necessary for high sensitivity, which is a level greater than 50% for PIE.

2. Since the tag receiver dynamic range is large (up to around 80dB without an RF LNA), the low cost constraint mandates the use of at least two dynamic range windows. Therefore, the preamble for the activation command should allow time for the proper selection of a dynamic range state.

3. To provide a frame marker indicating that AC training is complete. This is necessary since any timing information extracted by the tag during training can be skewed by the fact that the training is not complete and the DC average of the received modulation is still moving.

4. To provide for timing information allowing symbol synchronization. In the case of PIE this means providing both the Tari (zero time) and the multiple of Tari that is used for a data one. That may be reduced to providing a “pivot” that provides the tag information on the dividing line between zeroes and ones. This timing information is provided after AC training (right after the flag indicating end of training) when the tag training is known to be completed and high accuracy is assured.

4.2.2 AC Coupled PIE Preambles and Training

4.2.2.1 Asymptotic Training

Asymptotic training refers to the fact that the training average voltage level is set to that of the desired AC coupling voltage level. In that way, the voltage in the AC coupling asymptotically approaches the desired voltage.

4.2.2.1.1 AC Coupled PIE Asymptotic Preamble Analysis (General Case)

Historically, the reason to have a variable data-one symbol has been to enable readers to provide more power to purely passive tags. In the case of Battery Assisted Tags, this is no longer a necessary feature. Since BATs are likely to use AC coupling, eliminating long symbols helps in reducing the AC coupling capacitance and required training time, therefore, the duration of the data-one symbol should be fixed to the minimum allowed (i.e. 1.5Tari). If we define the duration of the data-one symbol as L_1 (in units of Tari, not seconds), and if we assume an equal number of data-zero and data-one symbols, it can be shown that the average fractional power contained in the PIE waveform is given by Eq. 4.1

Eq. 4.1: $D_c = PIE\ duty\ cycle = \frac{L_1}{1+L_1}$

Using L_1=1.5, D_c is 0.60. This means that the correct level for the slicer reference, or level of AC coupling training, is for PIE 60% of the peak signal level. Assuming the simple case of linear circuitry, the training should be designed to provide for to asymptotically approach the level D_c by the end of the training time.

Note that good training without using excessive time requires that the high pass corner of the AC coupling in the tag be specified with respect to the data rate or Tari used. The choice of AC coupling corner depends on tolerance for sensitivity degradation due to baseline wander and willingness to spend die area on capacitance. Let N_c be defined as the Normalized cutoff factor of AC coupling high pass, or the fraction of 1/Tari for the 3 dB corner of the high pass coupling. Baseline wander for N_c = 0.1, 0.03, and 0.01 is shown in Figure 4.1(a)(b)(c). As a compromise between these, a normalized cutoff of

<u>0.03 is recommended to be standardized.</u> This value provides a "nominal" signal to wander ratio of about 25 dB, though naturally the ratio that occurs at each point in time has a statistical variation associated with how many symbols of the same time have occurred immediately prior to the time point in question.

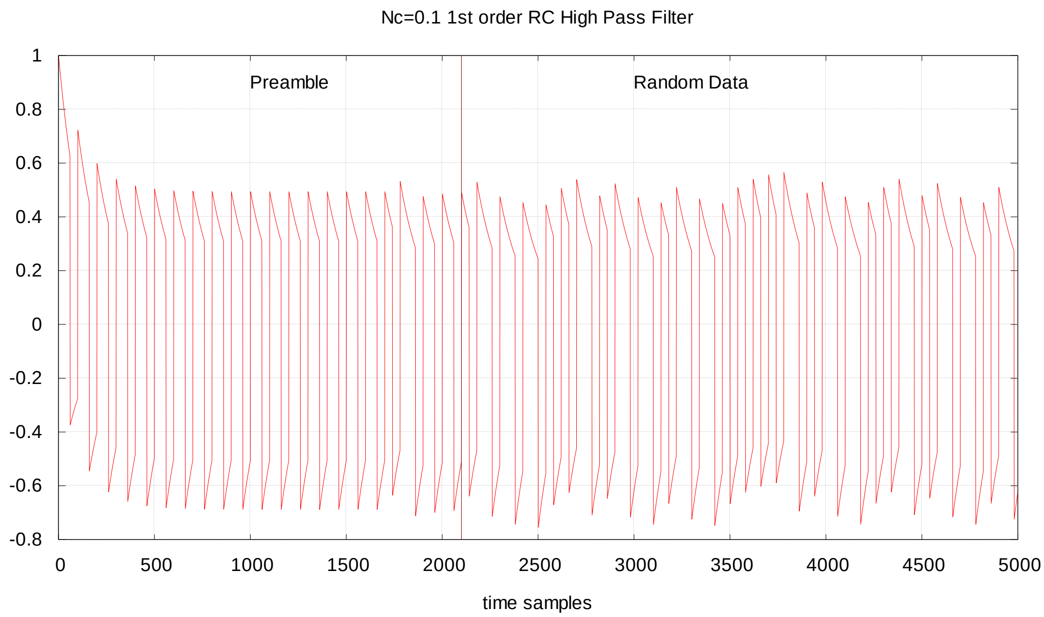


Figure 4.1 (a): AC settling and baseline wander for N_c=0.1 for a particular case of random data. The wander is excessive.

Nc = 0.03 is recommended for standardization.

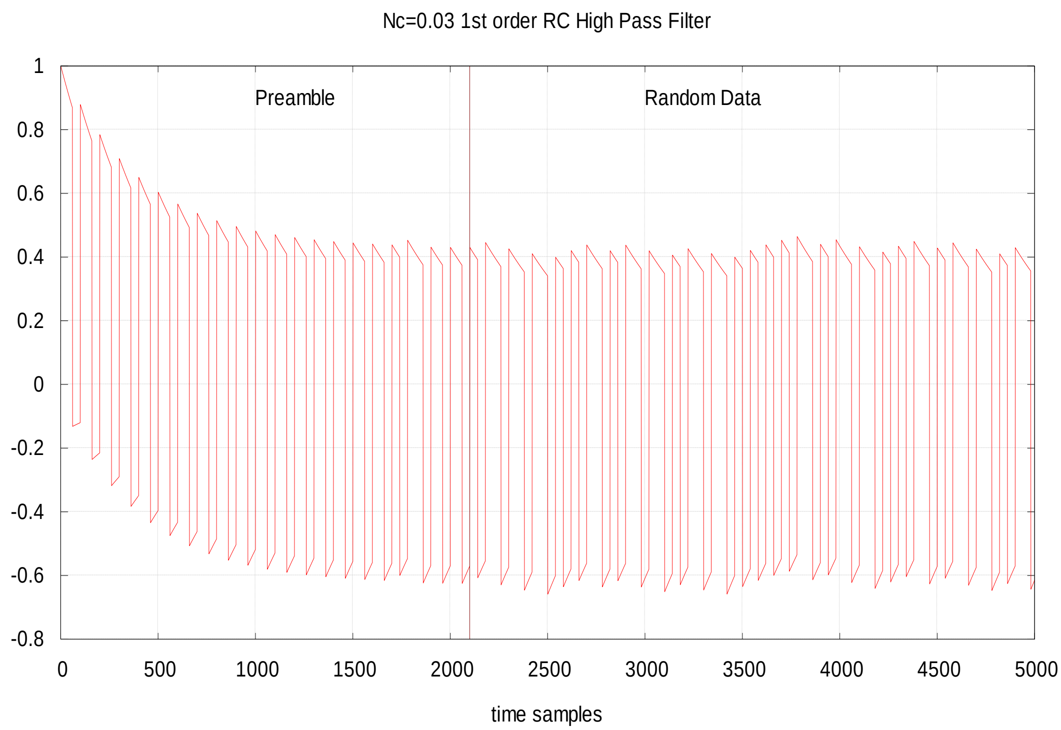


Figure 4.1 (b): AC settling and baseline wander for **N_c=0.03**. This is the **recommended case** for standardization.

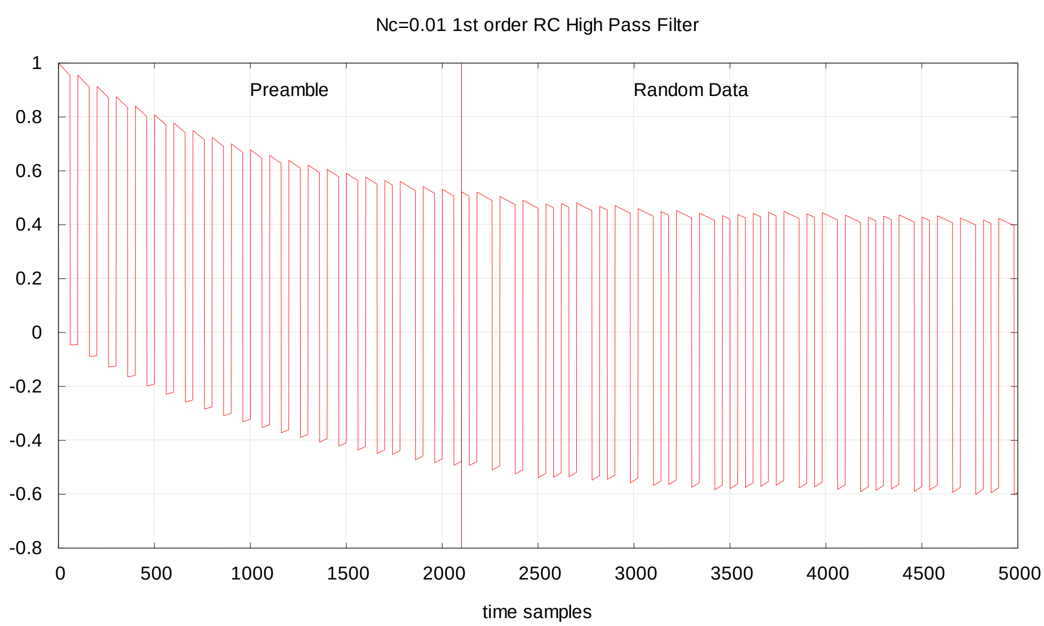


Figure 4.1 (c): AC settling and baseline wander for N_c=0.01. This is better than it has to be, and slower to train.

AC coupling training may be performed by two basic methods. The first is to use symbols with an average equal to a 50% mix of zeroes and ones. The second way is with a steady state carrier of power equal to that average. The second method has the advantage of not generating nearly as much spectral splatter and thus reader on reader interference during its time of transmission, since it has a single edge coming on and from then only spreads by its phase noise.

Using standard PIE symbols, a viable training sequence is a sufficiently long series of alternating data-zero and data-one symbols (i.e. 0101 … 0101). However, a slightly superior training sequence is to define a "special one symbol" (denoted as 1') with duty cycle equal to a 0101 … 0101 sequence. A sequence of these special ones will have less baseline wander than a 0101 … 0101 sequence, and each symbol also provides timing information for distinguishing between PIE zero and PIE one (its duration is equal to the "pivot time"). The duty cycle of the 1' is given in Eq. 4.2. The duration of the high part of the special one symbol is defined here as "x", and Eq. 4.3 gives its relationship to L_1 and Tari.

Eq. 4.2: $D_{cx} = \frac{x}{x + Tari/2}$, and this must equal D_c, therefore:

Eq. 4.3: $x = L_1 \cdot Tari/2$ (where Tari is in units of seconds).

Thus the corner frequency in Hz of the AC coupling is given by:

Eq. 4.4: $f_c = \frac{N_c}{Tari}$

The time constant of single order AC coupling is given by:

Eq. 4.5: $\tau = \frac{1}{2\pi f_c} = \frac{Tari}{2\pi N_c}$

The charge state on AC coupling (starting from zero volts) is given by:

Eq. 4.6: $\frac{V_{out}}{V_{in}} = 1 - e^{\frac{-t}{\tau}} = S_F$,

where SF is the "Settle Fraction", such as 0.98. Solving for time t to get settled and substituting Eq. 4.6 gives:

Eq. 4.7: $t = -\tau \ln(1-S_F) = \dfrac{-Tari}{2\pi N_c} \ln\left(1-S_F\right)$

Utilizing the proposed N_c value of 0.03 along with a settling factor of 98% in Eq. 4.7 results in a training time of 20.8 Tari. If a sequence of special ones is used each of length 1.25 Tari (one length of 1.5 Tari to be used), then 17 special ones are needed to provide the necessary training time. These factors also apply to normal mode, where it is assumed that the tag switches its AC coupling time constant to allow for reducing training time in seconds appropriate to the typically faster data rates of normal mode.

4.2.2.1.2 AC Coupled PIE Activation Code Asymptotic Preamble Options

As mentioned before, the preamble also has to allow time for the tag receiver to adjust its dynamic range window. Because dynamic range state choice does not require complete AC settling, two time constants of the AC coupling corner is generally adequate.

Option 1: The preambles marking an Activation Command in PIE hibernate mode consists of 26 symbols of special duration (1’). This 9 of the 1’ symbols for dynamic range adjustment, and 17 of the 1’ for AC coupling training, followed by a frame marker consisting of two bits (0,1), followed by a timing marker consisting of two special ones. The introduction of the special one symbols as opposed to a 0101 … 0101 training sequence reduces baseline wander. The duration on high (x) of the special one symbol is set so that the charge on the AC coupling is set to the average of the incoming bit stream (assuming equal density of zeros and ones), which is 60% with the one symbol being of length 1.5 Tari. The frame marker is needed since some early bits in the AC coupling period may be missed in the demodulator due to inadequate AC coupling charge, and even later bits have inadequate accuracy for pivot time capture. In reality, only the first bit (zero) of the frame marker serves that purpose, and the following one symbol is for DC balancing purposes. The timing marker after the frame marker is needed to convey similar information as the now unused RTcal symbol that is eliminated to optimize performance with AC coupling. Since it follows the frame marker the full charging of AC coupling of specified $N_c = 0.03$ is assured, and the tag measurement of pivot time equal to the length of these two symbols may be trusted. The preamble structure is presented in Figure 4.2 for the case of a preamble to the Activation Command. It must be assumed in this preamble that the AC coupling is completely discharged—the receiver is coming up from a “cold” state and must adapt from that state to the incoming signal strength level.

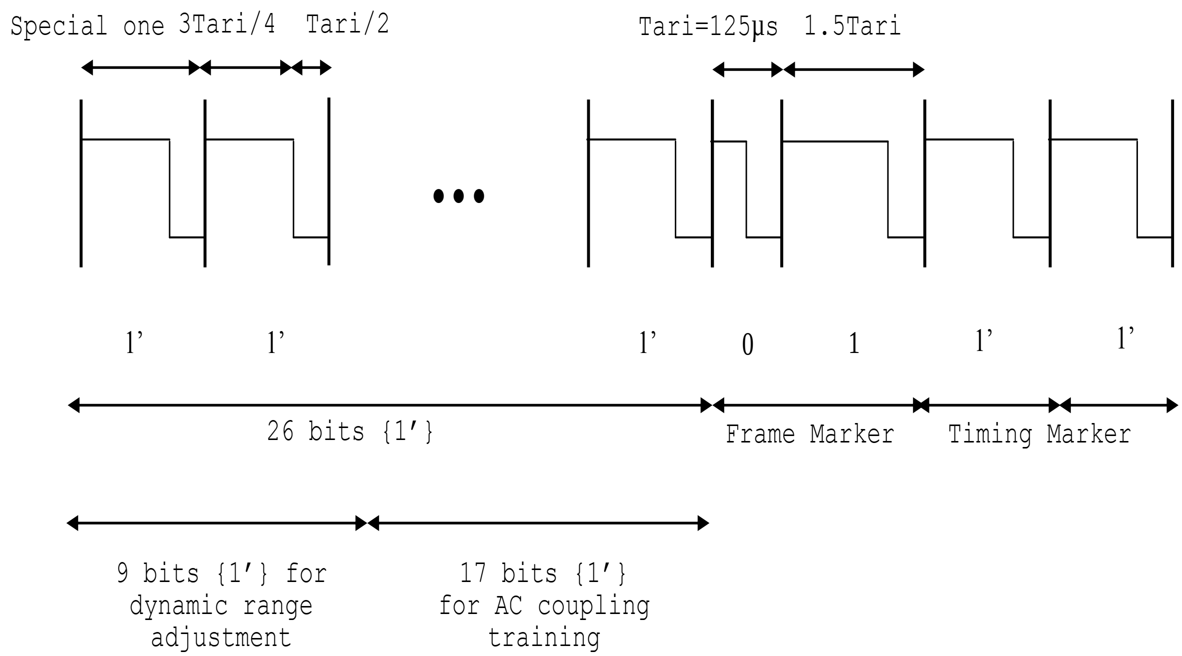


Figure 4.2: Option 1 for preamble of the Activation command, using symbol based training. The particular symbol used is the new "Special One" with length equal to the pivot time and low time equal to 0.5 Tari.

Note that a desirable feature of the preamble in an AC coupled system is avoiding extra long symbols that deviate strongly from the typical symbol length, such as the RTcal and TRcal symbols used in the passive PIE mode. The use of such long symbols would require placing the AC corner even lower and also providing rebalancing of the training charge to compensate for their duty cycles that are significantly different from typical symbols. It is therefore recommended that the battery supported PIE mode not use the RTcal and TRcal symbols for determination of forward and reverse data rates, respectively. Instead Tari and forward data rate after activation will be specified as part of the activation sequence, and reverse link frequency, mode, and data rate will be specified as part of the Query_BAT_AC_PIE.

Option 2: Since readers which implement a sensitive AC mode are assumed to have precise control of transmit power, this capability may be used to create a training preamble that creates less spectral splatter. This option for AC training replaces the 26 special ones with a steady state carrier with power at DC fraction of the peak carrier power used during modulation. Selecting six time constants (as found from Eq. 4.7 with a settling factor of 98%, 2 time constants for dynamic range adjustment and 4 time constants for AC coupling training) and a cutoff factor N_c of 0.03 as recommended above would indicate that a carrier time of 32 Tari should approach best performance. The preamble contains the same frame and timing markers as in the case above, and is shown in the figure below.

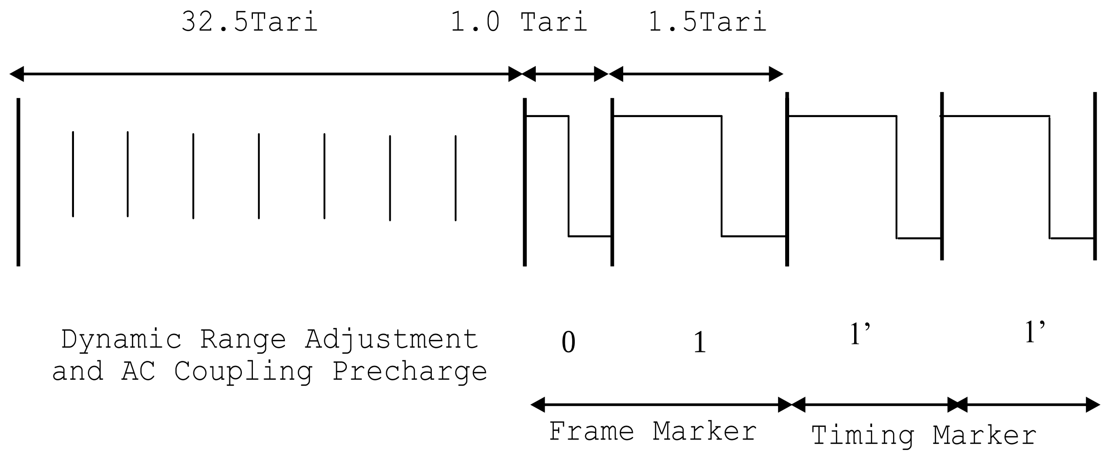


Figure 4.3: Option 2 AC PIE Activation Command preamble, where a reduced (60%) power carrier provides proper AC coupling charging. This method reduces reader on reader interference, and may be used by readers with precise variable control of reader transmit power.

Because it will take time to phase in readers with power level control adequate to the use of reduced carrier power as a training method, the optional use of either training method is recommended for standardization.

Since the AC coupling training in this option consists on a pure carrier waveform transmitted at a reduced (60%) power, it can be seen that the reader on tag interference is reduced by the simple fact of this power reduction. Additionally, the spectral pollution that the regular preamble produces during the training time is avoided and reader on reader interference is also reduced. Quantitatively, the total duration of the preamble is 37.5 Tari and the interference is produced by the AC coupling training that lasts 32.5Tari, therefore, the interference reduction is statistically 86.6% when compared to the preamble in Figure 4.2.

4.2.2.1.3 AC Coupled PIE Normal Mode Asymptotic Preamble Options

The normal command preamble follows the same guidelines as those used to derive the Activation Command preamble.

Option 1: The structure of this option is shown in Figure 4.4. Notice that the preamble structure is the same to that of the activation command, but Tari is no longer fixed at 125µs.

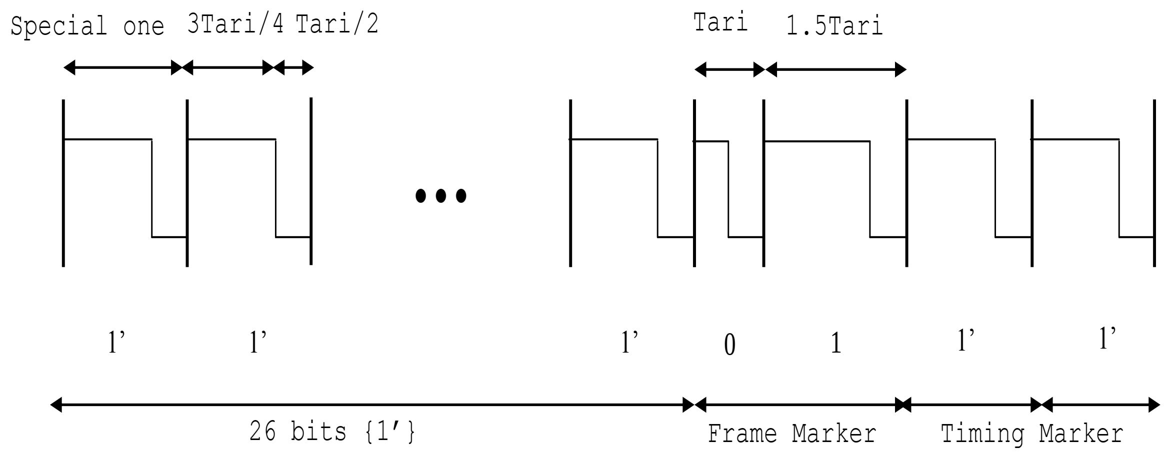


Figure 4.4: Option 1 normal command asymptotic preamble.

Option 2: for the preamble for normal command may contain a pure continuous wave carrier for AC coupling training transmitted at a reduced (60%) power. The optional preamble is shown in Figure 4.5. As explained above, this preamble reduces the time incidence of reader to reader interference during the training process by 86.6%.

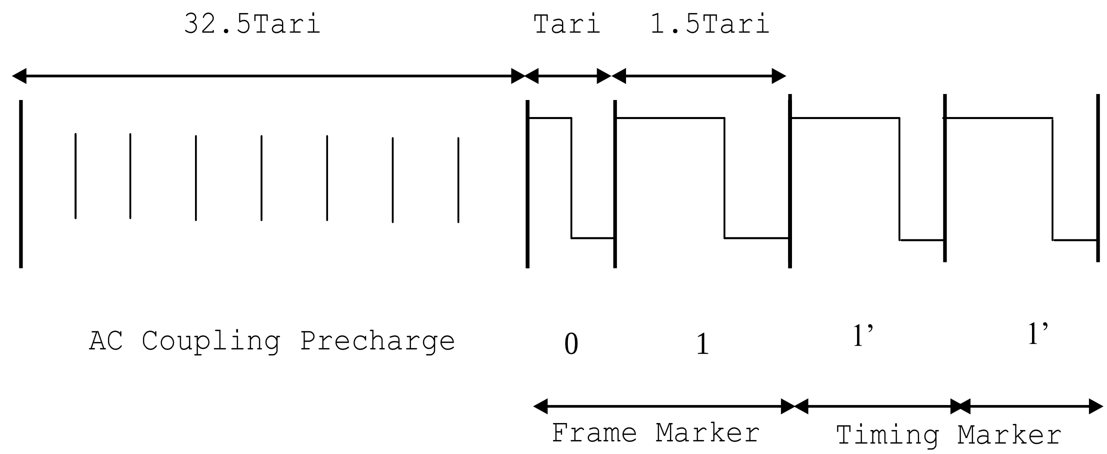


Figure 4.5: Option 2 normal command asymptotic preamble, which may be offered by readers with accurate variable transmit power in order to reduce reader on reader interference.

4.2.2.2 Overshoot Training

Overshoot training refers to the fact that the input training voltage is set lower or higher than the desired AC coupling voltage (in this case 60%), in that way, the training time is shortened. Since PIE data 0 symbol has an average of 50%, we can use a series of zeros to soft overshoot. Also, the same technique proposed for Manchester is proposed here, that is, transmitting zero-power (i.e. turning off the transmitter) for a period of time. That period of time (in units of T_{bit}) is governed by a simple RC charge or discharge given in Eq. 4.8 and Eq. 4.9 respectively.

Eq. 4.8: $t = \frac{-1}{2\pi N_c} \ln(1 - V_{desired})$

Eq. 4.9 $t = \frac{-1}{2\pi N_c} \ln(V_{desired})$

See more details in section 3.2.2.2.

4.2.2.2.1 Activation Command Overshoot Training

TBD.

4.2.2.2.2 Normal Command Overshoot Training

TBD.

4.2.3 AC Coupled PIE Command Set

4.2.3.1 Existing PIE Command Set

The current CD PIE command set is shown below. The "Global" commands are issued by readers to all tags that are listening at a given time. They are more dangerous to use in Semi-Passive (Class 3) and higher because the higher sensitivity of the tags and the use of power levelling creates much higher odds of a more distant reader accidentally commanding a tag and interrupting its communications with the desired reader.

Table 4.1: Current CD PIE **mandatory** command set. We include Activate even though its "command code" is effectively the signature of its unique preamble.

Command	Length (bits)[8]	Code	Comments
Activate	NA	NA	Effectively mandatory.
QueryRep (Global)	4	00	Counts down random counter in Ready state.
ACK	18	01	Causes tag to transmit XPC/EPC in Reply, and transition to Acknowledged.
Query[9]	4	1000	PASSIVE form of begin new query round. Selective as to flag state and session, sets up return link (tag transmitter)
QueryAdjust (Global)	9	1001	Respins random slot counter.
Select (Global)	44	1010	Resets flags.
NAK (Global)	8	11000000	Resets tag in higher states back to Arbitrate.
Req_RN	40	11000001	Causes tag to send new RN, can cause state change.
Read	57	11000010	Read single word.
Write	58	11000011	Write single word.
Kill	59	11000100	Permanently disable a tag, though recommissionable tags can be brought back to life.
Lock	60	11000101	Locks memory against writes, locks passwords against reads and writes. Read, Write, Kill, and Lock are already defined as well protected via CRC-16.

Note that Query is now defined as Mandatory and Query_BAT as optional.

[8] This includes command length plus the parameters length.

[9] We shall recommend that a passive Query NOT be mandatory. A required Query forces the tag to be able to operate with a dead battery, which has large and sometimes undesired process and design impact.

Table 4.2: Current CD PIE **optional** and unused command set.

Command	**Length (bits)**[10]	**Code**	**Comments**
Access	8	11000110	Provide password to specific tag via RN and move from Open to Secured.
Block Write	8	11000111	Write a block of data. CRC-16.
Block Erase	8	11001000	Erase a block of data. CRC-16.
Block Permalock	8	11001001	Lock a block of data against new writes. CRC-16.
Deactivate_BAT	8	11001010	Command battery tags in Ready state to go to Hibernate based on SL flag. Global, can be dangerous. CRC-16.
Query_BAT	8	11001100	Battery supported Query that sets up round based on SL and Session flag, provides return link setup and Q. Note that it has Reader ID, but that currently tag does not USE ReaderID. Note protection = CRC-5 (needs improving). Also, the CRC-5 is inadequate.
RFU	8	Codes 11001110 to 11011111	
Reserved for Custom Commands	16	1110 0000 0000 0000 to 1110 0000 1111 1111	
Reserved for Proprietary Commands	16	1110 0001 0000 0000 to 1110 0001 1111 1111	
Extended Commands	16	1110 0010 0000 0000 to 1110 1111 1111 1111	

[10] This includes command length plus the parameters length.

4.2.3.2 Proposed AC PIE Command Set

Problems with the expanding the existing AC Manchester command set to AC PIE include:

- Query is mandatory, implying that battery tags must be able to operate in a passive mode when batteries are dead, and that the primary reader round set up should be via Query instead of Query_BAT. Also, the standard passive Query does not specify return link parameters via data field. Instead, it assumes the use of special TRcal symbol, for which pulse width measurement is distorted by AC coupling.
- Adequate control of power leveling is not provided.
- Prevention of accidental reader access is not provided for. Such accidents become much more prevalent with sensitive tags and power leveling, since the desired reader may be at a low power state when a neighboring reader is at a high power state.
- Allowance for possible future expansion to higher level classes is not provided for. For example, the channelization does not allow for future narrowband channels that are highly likely in Semi-Active and active tags. Also, forward and reverse data rate minimums are not sufficient for these future narrowband plans.
- No command set provisions are made for regulatory roaming.

Basic recommendations for an AC PIE command set thus include:

- <u>Make power leveling capability mandatory for the sensitive AC</u> mode. Then provide command set and feature improvements that allow for convenient power leveling.
- Making Query_BAT a mandatory feature, since readers operating AC PIE are assuming battery power tags.
- Elimination of a plain Query in AC PIE even as an optional feature. A pure passive fall back for a battery supported tag in the event of battery failure is to use DC PIE, since that mode is inherently better at communicating power to the tag. Also, pulse width measurement for data rate commanding is simply not suitable for AC coupling.
- Make provision for <u>optional "locking" of tags to the reader</u> that wakes them up in order to prevent access by other readers. Accidental access of tags by more distant readers is also provided by use of programmable sensitivity in the tag and by time coordination between readers. This is especially critical when power leveling is being used.
- For reverse data rate increase divider M from maximum of 64 to maximum of 256 to allow lower reverse data rates with higher subcarriers.
- Make provisions for regulatory roaming via activation command.
- In general, it should be recognized that the Semi-Passive (Class 3) link in the case of excellent tag sensitivity is a <u>hostile link</u>. Thus there is an increased need for flexible link control (such as receiver sensitivity and data rate programming) and more recommended use of the safer CRC-16 as opposed to the CRC-5.

The optional locking of tags to the activating reader is implemented by the Activation command including a flag indicating if locking is to be observed by the tags and providing an 8 bit field identifying the reader. The global commands would then have the Reader ID appended when locking is in use.

The table below summarizes the recommended mandatory commands for PIE mode, and the following one summarizes the recommended optional commands. The following sections explain modifications to commands and recommended new commands. Commands that we have not recommended a change to and that are not used for fundamental air interface operations are not repeated here. The reader is referred to the current CD for definitions of those commands (such as block read and write commands).

Table 4.3: Proposed PIE **mandatory** command set. Commands necessary to power levelling operations are recommended as mandatory. Global commands have the option to be locked to the activating Reader.

Command	**Length (bits)**[11]	**Code**	**Comments**
Activate (Modified)	NA	NA	Extended to allow for wake up based on Class of tag and Session flag for power leveling, provide short reader number to tag for optional "locking" of tag to reader, provide regulatory region, and detailed tag receiver set up.
QueryRep (Global) (Modified)	4 or 12	00	Counts down random counter in Ready state.
ACK	18	01	Causes tag to transmit XPC/EPC in Reply, and transition to Acknowledged.
QueryAdjust (Global) (Modified)	26 or 34	1001	Re-spins random slot counter.
Select (Global) (Modified)	44 or 52	1010	Sets flag states.
NAK (Global) (Modified)	8 or 16	11000000	Resets tag in higher states back to Arbitrate.
Req_RN	40	11000001	Causes tag to send new RN, can cause state change.
Query_BAT_PIE (Global and Modified)	54	11010101	Battery supported Query that sets up round based on SL and Session flag, provides return link setup and Q. Note that it has short Reader ID as required field. Protection increased from CRC-5 to CRC-16.
Deactvate_BAT_PIE (Global and Modified))	30 or 38	11001010	Command battery tags in Ready state to go to Hibernate improved to be based on SL and/or Session flags. Global, can be dangerous.
Next **(New)**	24	11001011	Commands individual singulated tags back to Hibernate using RN.
WriteTimer **(New)**	36 or 52	11001101	Allows reader to program new timer values for proposed programmable timers associated with each Session flag. Flexible and accurate persistence is needed in power leveling operations.
ReadTimer **(New)**	43	11001110	Allows reader to read back current timer state. Read and Write timers are mandatory with power leveling capability mandatory.
Broadcast ID **(New)**	69	11001100	Provides 32 bit reader ID, antenna #, power, and channel. Modified to allow for finer channels and for inclusion of short ID.
Read	57	11000010	Read single word.
Write	58	11000011	Write single word.
Kill	59	11000100	Permanently disable a tag, though recommissionable tags can be brought back to life.
Lock	60	11000101	Locks memory against writes, locks passwords against reads and writes.

[11] This includes command length plus the parameters length.

Table 4.4: Proposed PIE **optional** and unused command set.

Command	**Length (bits)**[12]	**Code**	**Comments**
Access	8	11000110	Provide password to specific tag via RN and move from Open to Secured.
Block Write	8	11000111	Write a block of data.
Block Erase	8	11001000	Erase a block of data.
Block Permalock	8	11001001	Lock a block of data against new writes.
Rx_Cntrl_3_PIE **(New & Global or Individual)**	8	11001010	This command allows the reader to reprogram the data rate and sensitivity of awake tags. It is planned to have a flag for global or individual applicability.
Hib_Cntrl_3_PIE **(New & Global or Individual)**	8	11001011	This command allows the reader to reprogram the sensitivity and duty cycle of the hibernate mode receiver. It is planned to have a flag for global or individual applicability.
RFU	8	Codes 11001110 to 11011111	
Reserved for Custom Commands	16	1110 0000 0000 0000 to 1110 0000 1111 1111	Custom commands may be used in the field, but are restricted to use after tag singulation and reader determination that the tag supports the custom command.
Reserved for Proprietary Commands	16	1110 0001 0000 0000 to 1110 0001 1111 1111	Proprietary commands are vendor specific test commands, and are not to be used in the field.
Extended Commands	16	1110 0010 0000 0000 to 1110 1111 1111 1111	

[12] This includes command length plus the parameters length.

4.2.3.2.1 PIE Activation Command (Semi-Passive Class 3) (Modified)

The proposed Activation command provides all the information provided in the current draft and adds new information for Class of tag, detailed wake up based on either don't care or status of Session and Inventory flags (for improved power level control), the regulatory region of operation (allowing optimum tag set up, such as adjustment of front end filtering), reader identification and power (for optional control of backscatter power), and more data rate options. Additional data rate options are recommended in order to allow for fitting forward and reverse modulation into narrow channels that will likely be used in future Semi-Passive (Class 3 Plus) and Active (Class 4) tags. The general structure is shown in the figure below.

Preamble	Target (9 bits)	Length (7 bits)	Address (7 bits)	Mask (0 to 96 bits)	Rx Set Up (8 bits)	Reader Info (17 bits)	RFU (8 bits)

Figure 4.6: Proposed PIE Activation Command structure. (**Note:** Perhaps a tag optional CRC-16 should be appended. The reader would send it, but the tag has the option of doing bit by bit decoding and rejecting the activation on the first non-matching bit, or finishing the packet and running the CRC. The CRC does not help for the case when a bit error makes the tag receive a non-matching mask, since even without the CRC the tag still does not wake up. But, the CRC does help reject false wake ups when a bit error causes a mask match, or reject errors in set up.)

The Target subfield communicates the Class of tag to be woken up, and flags and their states that shall be used to authorize wake up. Note that Session and Inventory flag use are repeated as control parameters in the Query_BAT_PIE command used after wake up. The reader has the option to wake up based on one state of Inventory flag and use that state in a query round, or to use a Select command to change Inventory flag status, and then perform a query round based on this new Inventory flag status.

Table 4.5: Candidate Semi-Passive (Class 3) AC PIE Activate Target Field description.

	Class	SL Use	Match SL	Session	Inventory Flag Use	Match Inventory
# of bits	3	1	1	2	1	1
Description	000: all types 001:Semi-Passive (Class 3) 010:Semi-Passive (Class 3 Plus) 011: Active (Class 4) 100: RFU 101: RFU 110: RFU 111: RFU	0: Don't care about SL state 1: Do care about SL state	0: Activate if SL 0 and other conditions met 1: Activate if SL 1 and other conditions met	00:S0 01:S0 10:S2 11:S3	0: Don't care for Inventory state 1: Do care for Inventory state	0/A: Activate if Inventory 0/A and other conditions met 1/B: Activate if Inventory 1/B and other conditions met

The new Reader Info field provides information as to reader identity, whether the tag is to reply to only the activating reader or not after wake up, and the regulatory region of operation.

Table 4.6: Candidate PIE Activate Reader Info Field description.

	Reader ID	Reader Lock	Region Field
# of bits	8	1	8
Description	Reader ID code	0: Tag allows any reader to access 1: Tag only allows this reader to access	Specifies a region in which the tag operates. Precise interpretation TBD.

The Rx Set Up field informs the tag of the forward data rate to be used and the approximate tag sensitivity range for the tag to respond to. Note we have recommended extending the forward data rate control field from 3 bits to 4 bits in order to accommodate the likely future frequency plans using narrowband channels. The new recommendation of controllable tag sensitivity reflects the engineering realities that the tag square law receiver may be physically capable of sensitivities better than -60 dBm, but that there are situations where such good sensitivity is not desired. If the tag cannot meet the commanded sensitivity range (such as the common case of tag that has not been designed for best case sensitivity), then it will provide its best sensitivity.

Table 4.7: Candidate Rx Set Up Field description.

Rx Set Up	**Forward Data Rate**	**Tag Sensitivity**	**RFU**
# of bits	4	2	2
Description	0000: Tari 125 μs 0001: Tari 50 μs 0010: Tari 25 μs 0011: Tari 12.5 μs 0100: Tari 6.25 μs Others RFU	00: 0 to -20 dBm (nominal -10 dBm, like Passive (Class 1)) 01: -20 to -40 dBm (nominal -30 dBm, simple CMOS design) 10: -40 to -60 dBm (nominal -50 dBm, advanced CMOS design) 11: Better than -60 dBm (nominal -70 dBm, advanced CMOS design plus RF LNA)	Additional flexibility might be desired in the future, such as finer trims to sensitivity.

4.2.3.2.2 Query_BAT_PIE (Modified)

The methods by which data rates to and from the tag are controlled are fundamentally related to the coupling mode of the tag receiver, and thus to the sensitivity of the tag receiver. Note that in order to prevent the use of the Passive (Class 1) special timing symbols RTcal and TRcal that are not suitable for AC coupling, the forward (RT) and reverse (TR) data rates are commanded. The forward data rates are commanded in the PIE Activate command. The reverse data rates are commanded in Query_BAT_PIE command. The command structure is presented in the next table.

Table 4.8: Query_BAT_PIE Command structure.

	Command	RFU	BLF	M	TRext	Sel	Session	Target	Q	Reader ID	CRC-16
# of bits	8	4	4	4	1	2	2	1	4	8	16
description	11010101		0000: 64 KHz 0001: 80 KHz 0010: 128 KHz 0011: 160 KHz 0100: 256 KHz 0101: 320 KHz 0110: 640 KHz 0111: 1280 KHz (Note 1) 1000 to 1111: RFU	0000: M=1 0001: M=2 0010: M=4 0011: M=8 0100: M=16 0101: M=32 0110: M=64 0111: M=128 1000: M=256 1001 to 1111: RFU	0: No pilot tone 1: Use pilot tone	00: All 01: All 10: ~SL 11: SL	00: S0 01: S1 10: S2 11: S3	0:A 1:B	0-15	Always included	

Note 1: The 1280 KHz link frequency is optional. A tag that does not support 1280 KHz link frequency that receives a command to use 1280 KHz will ignore the Query_BAT_PIE command. Also, since T_{pri} is defined as 1/BLF, and T_2, the interrogator response time, is required to be between $3T_{pri}$ and $20T_{pri}$, for the optional BLF of 1280 KHz T_2 needs to be changed to be between $3T_{pri}$ and $40T_{pri}$.

4.2.3.2.3 Deactivate_BAT_PIE (Modified)

An important intended use of the deactivation commands is likely to be in power level controlled systems, where different power levels are used, and tags reply based on the state of a flag or memory value. It is desired that nearby tags that were successfully inventoried in a lower power state do not respond to a higher power command or activation. This requires that the Activate command be modified to be selective as to the state of the Select and Inventory Flags. The Deactivate_BAT_PIE to be described here allows for similar deactivation based on the state of either Select flag, a desired Inventory flag, or both.

The modified command Deactivate_BAT_PIE contains the fields of the command Deactivate in of the current draft, plus a session field, plus a Match Inventoried field, and Operation field. The modified command acts as a global command, since it does not use a handle. This improved command may thus be used in power leveling operations to put tags that were inventoried at a lower power level back to Hibernate as a group if they are woken up by a subsequent higher powered Activation command, or if they were inadvertently left awake if they missed a Next command to put them back to Hibernate. The command structure is presented in the following table.

Table 4.9: Deactivate_BAT_PIE command structure.

	CMD ID	**SL Use**	**Match SL**	**Session**	**Inventory Use**	**Match Inventoried**	**Reader ID**	**CRC**
# of bits	8	1	1	2	1	1	8	16
Description	1100 1010	0: Don't care for Match SL 1: Do care for Match SL	0: ~SL 1: SL	00:S0 01:S0 10:S2 11:S3	0: Don't care for Inventory 1: Do care for Inventory	0: ~Inventoried 1: Inventoried	Included only if Reader locking is in effect.	

The tag shall not reply to the Deactivate_BAT_PIE command.

4.2.3.2.4 Next (New and Mandatory)

We recommend the addition of this command, and repeat its definition as it is fundamental to air interface operation. The Next command puts a particular singulated tag back to Hibernate after the reader is done with it in the inventory process, and is ready to move on to singulation of the next tag by counting their random counters down to zero. Since it acts on a particular tag, the tag's random number handle is used to address it. The tag replies to the Next command with its RN16 handle to let the reader know that it received the command and is going to sleep.

Table 4.10: PIE Next Command structure.

	CMD ID	RN
# of bits	8	16
Description	1100 1011	RN16_handle

The tag reply to the Next command is presented in the following table.

Table 4.11: Reply to Next Command.

	RN16	Parity
# of bits	16	1
Description	RN16_handle	Odd parity

4.2.3.2.5 PIE Broadcast ID (New and Mandatory)

This command is proposed from the current draft (Manchester BAT section). The command is changed slightly because we are proposing to leave room for future Semi-Passive (Class 3 Plus) and Active (Class 4) extensions where narrowband channels are used (such as 25 KHz channel steps), thus requiring more bits. The use of 13 bits can perfectly specify the existing channels while allowing future channelization to cover any channel plan describable with 25 KHz steps and within a 200 MHz total range. That step and range should cover any feasible plan anywhere in the world in the band of 830 to 1030 MHz.

Table 4.12: Proposed Broadcast ID Command.

	CMD ID	Long Reader ID	Short Reader ID	Antenna	Power	Channel
# of bits	8	32	8	8	8	13
Description	1100 1100	MAC address	Same 8 bit field for local Reader ID used for Reader-Tag locking	Antenna number	2's complement -64 to +63.5 dBm in 0.5 dB step	Channel #

As is now described in the current draft, there is no tag response to a Broadcast ID command.

4.2.3.2.6 QueryRep (Modified)

The only change to this command is to include the optional short Reader ID if tag to reader locking is in effect.

Table 4.13: PIE QueryRep Command structure.

	CMD ID	**Session**	**Short Reader ID**
# of bits	2	2	8
Description	00	00: S0 01: S1 10: S2 11: S3	Included if locking is in effect.

The tag reply to the PIE QueryRep Command is presented in the following table.

Table 4.14: Proposed reply to PIE QueryRep Command.

	RN16
# of bits	16
Description	RN16_handle

4.2.3.2.7 QueryAdjust (Modified)

The only change to this command is to include the optional short Reader ID if tag to reader locking is in effect.

Table 4.15: PIE QueryAdjust Command structure.

	CMD ID	**Session**	**Q**	**Short Reader ID**	**CRC-16**
# of bits	4	2	4	8	16
Descrip-tion	1001	00: S0 01: S1 10: S2 11: S3	Q value from 0 to 15	Included if locking is in effect.	

The tag reply to the QueryAjust command is presented in the following table.

Table 4.16: Reply to PIE QueryAjust Command.

	RN16
# of bits	16
Description	RN16_handle

4.2.3.2.8 Select (Modified)

This command is only modified by the addition of the short Reader ID if tag to reader locking is in effect. The short Reader ID is inserted before the CRC so that the CRC may apply to it as well. There is no reply to the Select command.

Table 4.17: Proposed PIE Select Command structure.

	CMD ID	**Target**	**Action**	**Mem-Bank**	**Pointer**	**Length**	**Mask**	**Trun cate**	**Short Reader ID**	**CRC 16**
# of bits	4	3	3	2	EBV	8	Varia-ble	1	8	16
De-scrip-tion	1010	000: S0 001: S1 010: S2 011: S3 100: SL 101: RFU 110: RFU 111: RFU	See CD, Table 200	00: RFU 01: UII 10: TID 11: Us-er	Starting Mask address	Mask Length	Mask Value	0: En 1: Dis	Includ-ed if locking is in effect.	

4.2.3.2.9 NAK (Modified)

The NAK command sends a tag to arbitrate from any state except ready or killed, in which case the command does nothing. The only recommended change is to append the short Reader ID in the case of Locking being in effect. There is no tag reply.

Table 4.18: Proposed PIE NAK Command.

	Command	**Short Reader ID**
# of bits	8	8
Description	11000000	Included if locking is in effect.

4.2.3.2.10 WriteTimer (New and Required)

Three new commands are proposed in order to enable power leveling and to provide tag receiver control. The new power leveling commands are used to Write and Read programmable timers associated with each session (note that the tag shall maintain an individual timer per session). The programmable timers control the persistence of the inventoried and SL flags on a dynamically adjustable basis. The default timer value prior to first programming shall be 1.0 seconds (10 decimal). Notice that the persistence of the SL and the inventoried flags are equal, and therefore no target field (i.e. SL or Inventoried flag) is included in the commands.

This command may act on a global or individual basis. This allows groups of tags to be programmed when embarking on an application mission, and for readers to modify timers used in power leveling based on particular circumstances. The operation of the timer is to precisely control the persistence of the Semi-Passive (Class 3) and higher inventory flags. When the timer has timed out, it resets the Inventory flags from a state where the tag does not respond to Activate commands with Do Care on inventory flag control to a state where the tag will respond to this Activate. This controlled action of not waking up allows tags inventoried in a low power state to avoid accidentally waking back up to the same reader that just inventoried them in a lower power state. Tags with other opposite Inventory flag state have not been yet inventoried, and they do wake up. For further explanation see the power control section.

The following table shows the proposed implementation of the WriteTimer command.

Table 4.19: WriteTimer Command structure.

	Command	**Flag**	**Scope**	**Value**	**RN**	**CRC-16**
# of bits	8	3	1	8	16	16
Description	11001101	000:S0 001:S0 010:S2 011:S3 100:SL Others: RFU	0: Global 1: Individual	See dedicated table	RN16_handle (not sent if Scope is Global)	

The Scope field determines if the command shall be executed by all tags in the current inventory round and session or if only a specific tag shall execute the command. If the scope is set to global, the RN field shall be ignored by the tags.

Tags shall not reply to a WriteTimer command if the scope is global, but shall reply as below if the scope is individual.

Table 4.20: Proposed reply to WriteTimer Command (only if scope is individual).

	RN16	Parity
# of bits	16	1
Description	RN16_handle	Odd parity

In case that a particular tag receives the WriteTimer command in error, it shall ignore the command.

The following table is suggested as interpretation of the 8 bit values for timer operation. The overlap between timer ranges is suggested as a circuit design convenience, where the order of magnitude switching of timer controls are kept separated. Suggested accuracy requirement is 10% at 25 deg C and 20% from -40 to +85 deg C. Competent circuit design should typically reduce variations to less than half those tolerances, or to near zero if crystal timing is used.

Table 4.21: Value Field interpretation.

Code or Range (Decimal)	Interpretation	Comment
0	Does not time out	Flags remain as set until reset by a Select command.
1 to 100	100 mS to 10 sec in 100 mS steps	Most commonly used range.
101 to 200	1 to 100 sec in 1 sec steps	
201 to 255	10 sec to 550 sec in 10 sec steps	Max timer of 9 minutes and 10 seconds

4.2.3.2.11 ReadTimer (New and Required)

This command acts only on an individual basis. The purpose of this command is to allow a reader to see how a previous reader has set up the controlled persistence of a tag. Even if a tag has an Inventory flag state that has not timed out and allowed the tag to be activated when using Inventory flag to control wake up readiness, any reader can if necessary wake up any tag by setting Inventory flag control to a Don't Care state when the reader transmits an Activate command. This allows for future flexibility in the design and implementation of more advanced power leveling and interference control algorithms.

The following table presents the implementation of the ReadTimer command.

Table 4.22: ReadTimer Command structure.

	Command	**Flag**	**RN**	**CRC-16**
# of bits	8	3	16	16
Description	11001110	000:S0 001:S0 010:S2 011:S3 100:SL Others: RFU	RN16_handle	

A tag shall respond to the interrogator with the programmed maximum value of its persistence timer (the time to be measured at the beginning of timer activation) and the current remaining time before timer expiration. The following table presents the implementation of the tag reply to a ReadTimer command.

Table 4.23: Tag response to ReadTimer command.

	MaxValue	**CurrentValue**	**RN**	**CRC-16**
# of bits	8	8	16	16
Description	Initial value	Current value (at time of Read-Timer decode in tag)	RN16_handle	

4.2.3.2.12 Rx_Cntrl_3_PIE (New and Optional)

The reprogrammability of the tag to different forward data rate and sensitivity are desirable features in the interference limited environment of more sensitive Semi-Passive (Class 3) tags. This command may be individual, in which case a tag is addressed via RN16, or global, in which case the short Reader ID replaces the RN16. Two RFU bits are recommended. The table below is the recommended structure.

Table 4.24: Rx_Cntrl_3_PIE Command for reprogramming of tag normal receiver mode parameters.

	Command	**Scope**	**Forward Data Rate**	**Sensitivity**	**RFU**	**Reader ID or RN**	**CRC-16**
# of bits	8	1	4	2	2	0 or 8 or 16	16
Description	11001010	0: Global 1: Individual	0000: Tari 125 µs 0001: Tari 50 µs 0010: Tari 25 µs 0011: Tari 12.5 µs 0100: Tari 6.25 µs Others RFU	00: 0 to -20 dBm (nominal -10 dBm, like Passive (Class 1)) 01: -20 to -40 dBm (nominal -30 dBm, simple CMOS design) 10: -40 to -60 dBm (nominal -50 dBm, advanced CMOS design) 11: Better than -60 dBm (nominal -70 dBm, advanced CMOS design plus RF LNA)		RN_16 handle if scope is individual. Reader ID if scope is global and locking is in effect. Nothing if scope is global and locking is not in effect.	

If the scope of the Rx_Cntrl_3_Man command is global, then there is no tag reply. If the scope is individual, then the tag shall reply as below.

Table 4.25: Tag reply to Rx_Cntrl_3_MAN Command if Scope = Individual

	RN16	**Parity**
# of bits	16	1
Description	RN16_handle	Odd parity

4.2.3.2.13 Hib_Cntrl_3_PIE (New and Optional)

This new and optional command allows for increased battery life by providing duty-cycling of the hibernate receiver and programmable sensitivity. The programmable sensitivity also provides greater system adaptability with environmental variation such as variable noise floors.

Table 4.26: Hib_Cntrl_3_PIE command structure.

	Command	Scope	Sensitivity	Receiver OFF time	Receiver ON time	RFU	Reader ID or RN	CRC-16
# of bits	8	1	2	8	4	2	0 or 8 or 16	16
Description	11001011	0: Global 1: Individual	00: 0 to -20 dBm (nominal -10 dBm, like Passive (Class 1) 01: -20 to -40 dBm (nominal -30 dBm, simple CMOS design) 10: -40 to -60 dBm (nominal -50 dBm, advanced CMOS design) 11: Better than -60 dBm (nominal -70 dBm, advanced CMOS design plus RF LNA)	Number of units of time (each unit is 0.25s) receiver is off. Special Value 11111111 means infinite	Number of units of time (each unit is 0.25s) that the receiver stays ON		RN_16 handle if scope is individual. Reader ID if scope is global and locking is in effect. Nothing if scope is global and locking is not in effect.	

4.2.4 PIE Power Level Control

AC coupled PIE has nearly identical power level control requirements as Manchester. The two command sets are also effectively identical. Thus, the AC PIE power leveling algorithm is basically identical to the Manchester algorithm. Please see section 3.2.4 for details.

5 Semi-Active (Class 3 Plus) Mode

This section is incomplete but usefully far along.

The increased sensitivity of AC coupled Semi-Passive (Class 3) BATs (either PIE or Manchester) translates into increased range with an inverse square (with distance) fade on tag receive power. Since the backscattered power is proportional to tag receive power it is also inverse square with distance. The backscatter fades inverse square again going back, the reverse link as seen at the reader receiver becomes inverse 4^{th} with distance. Thus, the reverse link has to improve 2 dB for every 1 dB of forward link improvement to keep up. This turns out to be physically impossible even for excellent tag receiver design, and the communication system becomes thus reverse-link limited. In other words, the tag receiver is able to successfully decode bits from the reader at longer distances, but the backscattered information from the tag cannot be successfully decoded by the reader. In order to balance the forward and reverse links, power control can be used, so that the ranges of both links are reduced to be the same, with the positive advantage of less reader induced interference.

Another alternative, one that maintains longer range and that is conducive to non-hopping band plans that make much better use of spectrum, is to use an active transmitter that can be used when the tag is beyond the maximum range allowed by the backscatter reverse power. The suggested name for that evolved tag is Semi-Active (Class 3 Plus).

5.1 Semi-Active (Class 3 Plus) Philosophy

The heart of the design for Semi-Active (Class 3 Plus) is the use of a tag receiver that can achieve a sensitivity level of around -75 dBm (optimum square law plus an RF LNA), and an active transmitter capable of outputting around 0 dBm of power (which allows non-hopping operation under FCC rules). With these enhancements and power control, the system may have balanced forward and reverse links with over 100 dB of allowed link loss in each direction. For backwards compatibility to existing Passive (Class 1) readers, DC PIE (for backward compatibility) and a backscatter link reverse link capability would be maintained. For operation with newer Semi-Passive (Class 3) capable readers, AC Manchester forward air interface is envisioned using both backscatter and (when needed) active transmit.

5.2 Semi-Active (Class 3 Plus) Command Set Extension

A candidate Semi-Active (Class 3 Plus) command set is shown below.

Table 5.1: Semi-Active (Class 3 Plus) command set summary (only mandatory commands are shown).

Command	**Length (bits)**[13]	Code
QueryRep	4	00
ACK	18	01
QueryAdjust	9	1001
Select	44	1010
NAK	8	11000000
Req_RN	40	11000001
Read	57	11000010
Write	58	11000011
Kill	59	11000100
Lock	60	11000101
Query_BAT_XYZ[14]	43	11010101
Deactivate_BAT_XYZ	30	11001010
Next	24	11001011
Broadcast ID	69	11001100
WriteTimer	51	11001101
ReadTimer	42	11001110
SetTagActXmit	74	11001111

[13] This includes command length plus the parameters length.
[14] XYZ will be PIE or MAN depending on the air interface used.

5.2.1 New Commands and Features for Semi-Active (Class 3 Plus)

With the Semi-Passive command set designed to allow convenient extension to higher classes, only a limited amount command set change is needed to support Semi-Active. The primary changes are tag transmitter set up, which is implemented with a new field in the Activate command, and allowed to be modified in normal mode via a new command. These are described below.

5.2.1.1 Semi-Active Activation Command

The Activation Command structure is a direct extension of what is proposed for Semi-Passive. The target field already specified what class of tag to address, and included Semi-Active. The Length, Address, Mask, RxSetUp, and ReaderInfo fields are identical, and are described in the tables in Chapter 3. However, the tag must have its active transmitter set up for channel, power, data rate, and modulation mode. This information is communicated in the appended ActTxSetUp field. If it is commanded to backscatter (a choice under the base mode sub-field), then the backscatter parameters of link frequency (subcarrier) and data rate divider M are communicated in the Query_BAT command. There is a bit in the ActTxSetUp field that allows “automatic power leveling” where the tag selects its own transmit power.

Preamble	Target (9 bits)	Length (7 bits)	Address (7 bits)	Mask (0 to 96 bits)	Rx Set Up (8 bits)	Reader Info (17 bits)	RFU (8 bits)	ActTxSetUp (26 bits)	CRC (16 bits)

Figure 5.1: Proposed Semi-Active Activation Command structure.

The structure of the ActTxSetUp field is shown in the table below.

Table 5.2: Details of the ActTxSetUp field.

Base Mode	**New Channel**	**Auto Pwr Level**	**Low Pwr Tag Transmit Power (dBm)** (Base Mode = 01)	**Hi Pwr Tag Transmit Power (dBm)** (Base Mode = 10)	**Data Rate (kbps)**	**Mod Mode**
2	13	1	4	4	4	2
00: Backscat-ter 01: Low Pwr Active 10: High Power Active 11: TBD	Absolute Channel number in steps speci-fied during activation	0: No 1: Yes	0000: -45 0001: -40 0010: -35 0011: -30 0100: -25 0101: -20 0110: -15 0111: -10 1000: -5 1001: -3 1010: -2 1011: -1 1100: 0 1101: +1 1110: +2 1111: +3	0000: -45 0001: -40 0010: -35 0011: -30 0100: -25 0101: -20 0110: -15 0111: -10 1000: -5 1001: 0 1010: +5 1011: +10 1100: +15 1101: +20 1110: +25 1111: +30	0000: 4 0001: 6 0010: 8 0011:12 0100: 16 0101: 24 0110: 32 0111: 48 1000: 64 1001: 96 1010: 128 Others RFU	00: ASK 01: FSK 10: PSK 11: QPSK

5.2.1.2 SetActXmit

For tags with active transmit capability, it should be convenient to change tag transmit parameters such as whether to be backscatter or active, and if active, then parameters such as channels, transmit power, data rate, and modulation mode. This command also broadcasts the reader transmit power and a bit enabling or disabling tag transmitter power adjustment according to the current propagation conditions (auto power level). This command is used in common in Semi-Active (Class 3 Plus) and Active (Class 4) tags. The suggested structure of this command is given below.

Table 5.3: SetActXmit proposed command structure for Semi-Active (Class 3 Plus) and Active (Class 4) tags. Note that there is only one actual transmit power field, and that the base mode field determines how it is interpreted. Most tags would be low power tags with a max transmit power of +3 dBm, suitable for small lithium coin cell or flat batteries.

	Com mand	**Base Mode**	**New Channel**	**Auto Pwr Level**	**Low Pwr Tag Transmit Power (dBm)** (Base Mode = 01)	**Hi Pwr Tag Transmit Power (dBm)** (Base Mode = 10)	**Data Rate (kbps)**	**Mod Mode**	**Rdr Pwr**	**RN**	**CRC-16**
# of bits	8	2	13	1	4	4	4	2	8	16	16
Description	1100 1111	00: Backscatter 01: Low Pwr Active 10: High Power Active 11: TBD	Absolute Channel number in steps specified during activation	0: No 1: Yes	0000: -45 0001: -40 0010: -35 0011: -30 0100: -25 0101: -20 0110: -15 0111: -10 1000: -5 1001: -3 1010: -2 1011: -1 1100: 0 1101: +1 1110: +2 1111: +3	0000: -45 0001: -40 0010: -35 0011: -30 0100: -25 0101: -20 0110: -15 0111: -10 1000: -5 1001: 0 1010: +5 1011: +10 1100: +15 1101: +20 1110: +25 1111: +30	0000: 4 0001: 6 0010: 8 0011:12 0100: 16 0101: 24 0110: 32 0111: 48 1000: 64 1001: 96 1010: 128 Others RFU	00: ASK 01: FSK 10: PSK 11: QPSK	2's complement -64 to +63.5 dBm in 0.5 dB step	RN16_handle	

There are specific practical and regulatory reasons for the transmit power control ranges given. First, the tag transmit power ranges are broken up into "low" and "high" ranges because it is natural to provide a lower power range that can use small batteries (such as lithium coin cells) and operate under narrowband rules (FCC 15.249), as well as to cover the case of tags with larger batteries that can operate at high power. Of course, higher power tags would probably tend to be fully active. It may thus make more sense to break this command up into separate Semi-Passive (Class 3 Plus) and Active (Class 4) SetTagXmit commands, or to combine the tag transmitter control with receiver control in the Active (Class 4) case.

The tag shall reply to the SetActXmit as given below.

Table 5.4: Tag response to SetActXmit command.

	RN16	**CRC-16**
# of bits	16	16
Description	RN16_handle	

This section is incomplete. Lots of work needed, but it gets the idea across.

6 Active (Class 4) Mode

6.1 Active (Class 4) Philosophy

To get to still greater ranges, and most particularly higher reliability, we need the sensitivity and selectivity of active receivers in the tag. We refer to active transmit and receive in the tag as Active, Fully Active, or Class 4. This class is a natural extension to the lower classes with technical, regulatory, and business advantages. The technical advantage is the improved performance, the regulatory advantage is the large spectrum, higher power, and 100% duty cycle allowed at 900 MHz, and the business advantage is the capability to do it all under one infrastructure. The customer cannot help but appreciate being able to select tags from a huge range of performance, using high end tags only when needed, and being able to reuse installed infrastructure.

We're very early in the process of suggesting an Active feature and command set, but we are making an attempt to visualize it in order to put sufficient flexibility in the Semi-Passive command set that we are not locked out of this future advance. We want to avoid "ripping up and starting over" to the greatest degree possible.

For example, we foresee Active tags being able to "fall back" to Semi-Passive and Semi-Active operation, thus completely reusing those command sets. They would likely commonly operating with a low power square law mode hibernate receiver, only using their active receiver in a duty cycled mode for wake up under rare conditions of needing high sensitivity and selectivity. Thus the earlier receiver control commands can be reused. With a highly selective and frequency agile receiver in the tag, the existence of control channels is anticipated. Those control channels serve the purpose of bundling the information commonly needed by all active tags, decreasing the amount of overhead. With narrowband channels being the norm, we have requested that bedrock feature be incorporated now in commands such as BroadcastID, and that reader companies plan for them in new designs. With those features wisely designed in now, the system design may enjoy a graceful evolution to the power of Active with only a modest number of new commands and features, and without any major barriers that require rewriting earlier standards work.

6.2 Active (Class 4) Command Set Extension

Table 6.1: Active (Class 4) command set summary (only mandatory, note that the only new command from Semi-Active is the active receiver control command).

Command	**Length (bits)**[15]	Code
QueryRep	4	00
ACK	18	01
QueryAdjust	9	1001
Select	44	1010
NAK	8	11000000
Req_RN	40	11000001
Read	57	11000010
Write	58	11000011
Kill	59	11000100
Lock	60	11000101
Query_BAT_XYZ[16]	43	11010101
Deacti-vate_BAT_XYZ	30	11001010
Next	24	11001011
Broadcast ID	69	11001100
WriteTimer	51	11001101
ReadTimer	42	11001110
SetTagActXmit	74	11001111
SetTagActRx (New)	81	11010000

[15] This includes command length plus the parameters length.
[16] XYZ will be PIE or MAN depending on the air interface used.

6.2.1 New Commands and Features for Active (Class 4)

Since Active (Class 4) tags are expected to coexist with all types of tags, provisions in the activation command for all classes have been introduced allowing the selective activation of different classes of tags. For Active Class 4, the Semi-Active Class 3 Plus Activation code is supplemented by a new field to set up the active receiver, which we have tentatively titled ActRxSetUp. The general structure is shown in the figure below.

Preamble	Target (9 bits)	Length (7 bits)	Address (7 bits)	Mask (0 to 96 bits)	Rx Set Up (8 bits)	Reader Info (17 bits)	RFU (8 bits)	ActTxSetUp (26 bits)	ActRxSetUp (31 bits)	CRC (16 bits)

Figure 6.1: Proposed modification of Activation command structure, primarily adding active receiver set up to the Semi-Active activation, which was in turn a simple extension of the Semi-Passive activation.

Table 6.2 presents the description of the ActRxSetUp field. This field is used to control the duty cycle of the active receiver for battery life preserving purposes (if desired), and to inform the active receiver of the channel, data rate and modulation that the regular communications will use after activation.

Table 6.2: Details of the ActRxSetUp field.

Receiver OFF time	**Receiver ON time**	**New Channel**	**Data Rate (kbps)**	**Mod Mode**
8	4	13	4	2
Number of units of time (each unit is 0.25s) receiver is off. Special Value 11111111 means infinite	Number of units of time (each unit is 0.25s) that the receiver stays ON	Absolute Channel number in steps specified during activation	0000: 4 0001: 6 0010: 8 0011:12 0100: 16 0101: 24 0110: 32 0111: 48 1000: 64 1001: 96 1010: 128 Others RFU	00: ASK 01: FSK 10: PSK 11: QPSK

6.2.1.1 SetActRx

This command is introduced in order to give the system the flexibility for dynamically changing the active receiver behavior (i.e. duty-cycle, channel, data rate, and modulation). This functionality allows another system enhancing technique called load balancing, which is used to shift tags from heavily loaded channels or channels with high levels of interference to better channels. Regarding the channel target field, it serves to distinguish between a control and a regular channel. When the channel target is set to regular, the interpretation of the duty-cycling fields is to turn on and off the active receiver by a time specified in the fields "Receiver ON time", and "Receiver OFF time"; this duty-cycling of the active receiver is an option given to the system in order to obtain the sensitivity of an active receiver with a low power consumption via duty-cycling. When the channel target field is set to control channel, the interpretation of the duty-cycling fields is to tune to the control channel for the amount of time specified in the "Receiver ON time" field, and stay OFF only if the regular channel is not programmed. If the regular channel has been programmed, then the OFF time is interpreted as time available to allocated to the regular channel, and software should ensure that the regular channel is properly programmed between ON and OFF for this available time slot. Additionally, in order to make use of the low power square law receiver of the Semi-Passive and Semi-Active modes, the "Use Semi-Passive Rx" field is introduced. This receiver can be ON whenever the active receiver is OFF, in order that the tag always has some listen function. It can also be duty cycled itself. Notice that the tags can be commanded to always use the semi-passive receiver when this field is set to 1 and the "Receiver OFF time" field is set to infinity for a regular channel. The structure of this command is given in the following table.

Table 6.3: SetActRx command structure.

	Com-mand	**Channel Target**	**Receiver OFF time**	**Receiver ON time**	**Use Semi-Passive Receiver**	**New Channel**	**Data Rate (kbps)**	**Mod Mode**	**Rdr Pwr**	**RN**	**CRC-16**
# of bits	8	1	8	4	1	13	4	2	8	16	16
De-scri ptio n	1101000 0	0: Control Channel 1: Regular Channel	Number of units of time (each unit is 0.25s) receiver is off. Special Value 11111111 means infinite	Number of units of time (each unit is 0.25s) that the receiv-er stays ON	0:Semi-passive receiver OFF when Active receiver OFF 1: Semi-passive receiver ON when Active receive OFF	Absolute Channel number in steps spec-ified dur-ing activa-tion	0000: 4 0001: 6 0010: 8 0011:12 0100: 16 0101: 24 0110: 32 0111: 48 1000: 64 1001: 96 1010: 128 Others RFU	00: ASK 01: FSK 10: PSK 11: QPSK	2's com-plement -64 to +63.5 dBm in 0.5 dB step	RN16_han dle	

The tag shall reply to the SetActRx command as given below.

Table 6.4: Tag response to SetActRX command.

	RN16	**CRC-16**
# of bits	16	16
Description	RN16_handle	

7 Known Intellectual Property Applicable to ISO 18000 6c Standard

In this section specific examples of patents applications related to the ISO 18000 6c standard are presented and their applicability to the standard is briefly explained.

7.1 Summary

This section contains the summary of identified pending patents that the battery supported sections of ISO 18000-6C may infringe upon. There are likely to be others both pending and issued, but of which we are currently unaware.

7.1.1 Selective RF Device Activation (20070018794 Intelleflex)

This pending patent is deeply embedded into the current draft standard in terms of the use of the Hibernate state and activation code to exit the Hibernate state, where the activate code contains length and mask fields exactly as described in the draft standard.

The essential patent claims of this application have been set free-of-charge on condition of reciprocity for implementers of the ISO 18000 6c standard by the patent holder.

7.1.2 Smart Tag Activation (20060255131 Intelleflex)

The heart of this pending patent is the use of the activate code to “preset” the tag to particular states after it powers up in its normal mode or to use the activate code to power up particular subsets of the Class 3 tag population. Examples of modes would be for particular forward data rates, or to set filtering for particular regulatory environments (anticipated as typical operation).

The essential patent claims of this application have been set free-of-charge on condition of reciprocity for implementers of the ISO 18000 6c standard by the patent holder.

7.1.3 Battery Activation Circuit (200501211526 Intelleflex)

The heart of this pending patent is the method of an AC coupling training preamble, followed by an “interrupt” (longer symbol detected by a timer that serves as a delimiter), followed by an activation code.

The essential patent claims of this application have been set free-of-charge on condition of reciprocity for implementers of the ISO 18000 6c standard by the patent holder.

7.1.4 Ramped Interrogation Power Levels (20070018793 Intelleflex)

This application has to do with the method to implement power leveling. As discussed earlier in this document, interference reduction is key to attain good system performance, and power leveling is one tool to use the minimum amount of power needed for reliable operation.

The essential patent claims of this application have not been set free-of-charge on condition of reciprocity for implementers of the ISO 18000 6c standard by the patent holder.

7.1.5 Method and Apparatus to Configure an RFID System to be Adaptable to a Plurality of Environmental Conditions (20050099269)

This patent application presents the ideas that enable an RFID tag to adapt to different regulatory regions. Possible adaptations include among others, backscatter modulation, duration, bit rate, bandwidth, subcarrier frequency, symbol assignment, etc. Possible environmental conditions include among others, levels of interference, reader/tag density, geographic location, etc.

The essential patent claims of this application have not been set free-of-charge under any conditions for implementers of the ISO 18000 6c standard by the patent holder.

7.1.6 RFID Tags Adjusting to Different Regulatory Environments, and RFID Readers to so Adjust Them and Methods (20050099270 Impinj)

This patent application presents the ideas that enable an RFID tag to adapt to different regulatory regions. Among other things, it deals with the configuration signal, sent to tags, that is indicative of a particular geographic region to which tag need to adapt to meet regulatory requirements.

The essential patent claims of this application have not been set free-of-charge under any conditions for implementers of the ISO 18000 6c standard by the patent holder.