White Paper

A comparison of RFID frequencies and protocols

Introduction

Background to this paper

In Aug 2004, ISO 18000-3 Mode 2 the new RFID global standard at 13.56 MHz was formally published by the International Standards Organization, ISO/IEC, after five years of intensive international efforts by JTC1/SC31 committee member experts from 28 countries.

This new standard defines the new very high speed RFID communication protocol based on Phase Jitter Modulation (PJM). In June 2005 high volume production ISO 18000-3 Mode 2 microchips for the new PJM StackTag ® and the new PJM ItemTag ® tags and the new family of Mode 2 PJM RFID readers started to be delivered in commercial quantity to the first global customers.

It is therefore now timely to provide a White Paper to correctly inform users of RFID of the significant functional and operational improvements offered by this new HF RFID technology and how this technology differentiates itself from alternative LF and UHF systems.

This paper will first cover some basics and then explain in more detail the key specifics of the Mode 2 functionality at HF and give illustrative examples. These examples will compare the new technology with earlier good but now significantly less capable technologies. Earlier technologies served their purpose and will have a continuing role in the market but such legacy RFID systems can never compete with the new and greatly enhanced functionality and raw performance provided by ISO 18000-3 Mode 2 (PJM.)

RFID Basics – Applications

The first point to appreciate is that not all of today's diverse RFID technologies are the same. There are as many types, shades and variations of RFID as there are types of car in the motor vehicle industry. The respective attributes, advantages and disadvantages of RFID technologies are often not properly understood and self appointed experts and consultants often speak with little knowledge and practical insight. In many cases these commentators lack even a basic understanding of the underlying physics governing the operation of RFID systems. This paper seeks to correct some of the often well meaning but never the less ill informed views being put forth in the RFID marketplace.

Bar code versus RFID technology

Bar code is a perfectly good automatic identification technology, which after some 20 odd years of evolution is now quite mature and well established. Bar code should always be used in preference to RFID if it does the job required, as it is invariably a cheaper solution. RFID is a relatively new and quite different automatic identification technology that provides much greater functionality than bar code but it also costs a great deal more. Bar Code labels, for example, are basically free as they can be printed on an existing paper label or package. RFID tags, however, generally comprise a semiconductor microchip attached to an antenna (thus forming an inlay) which when appropriately packaged to suit the application inevitably has a higher cost. This typical cost today for a converted and ready to deploy RFID tag is in the region of 20 – 35 US cents (in volume) and this cost must be justified. This cost is for an elementary self-adhesive paper RFID label, and more complex/rugged packaging requirements can add significantly to the final cost of the RFID tag.

It therefore makes little commercial sense to apply RFID functionality to any application unless there is a solid business case and ROI to justify the cost of the increased functionality.

RFID Basics - Frequencies

It is assumed that readers of this paper are aware or have at least a working knowledge of the ISO/IEC 18000 series of RFID standards that provide and define the air interface and communication protocols for RFID technologies operating at different frequencies. This paper is interested in four global ISO standards that apply to passive RFID tags (tags which operate without a battery). These RFID standards are ISO 18000-2 which covers Low Frequency (LF) around 130 kHz; ISO 18000-3 which covers High Frequency (HF) at 13.56 MHz; ISO 18000-4 which covers 2.45 GHz; and ISO 18000-6 which covers various Ultra High Frequencies (UHF) from 860 - 960 MHz.

It is important for global users of RFID to note that the operating frequencies of ISO 18000-2 (LF) 125-135 kHz and ISO 18000-3 (HF) 13.56 MHz are already accepted worldwide as agreed ISM bands and radio frequency spectrum. This means these common frequencies are approved worldwide for use in industrial, scientific and medical applications. There are also ISM bands approved for UHF but these are only at 902 - 928 MHz and at 2.45 GHz (Microwave Ovens) where the heating effect of the frequency is used in cooking and in industrial plastic sealers.

RF communication theory shows the frequency band of choice for achieving the optimal performance from passive UHF backscatter tags is the 800 to 900 MHz frequency range. However this bandwidth conflicts with GSM mobile and DECT Cordless telephone systems in many countries. This portion of the UHF radio spectrum is not uniformly available for RFID usage on a worldwide basis and radio regulations vary greatly between geographic regions. This variation in regulations in respect to available channel bandwidth, number of channels, and power levels materially affects the attainable practical performance of UHF systems.

It is also assumed that the reader of this paper is aware of the limitations of UHF frequencies in respect of their ability to read through mixed and especially wet or liquid products where the energy in UHF frequencies is absorbed and dissipated as heat. Such ubiquitous “RF difficult” materials typically have a high dielectric constant and loss tangent/dissipation factor that cause severe signal attenuation effects when in proximity to the tag antenna, and a deleterious loss of signal strength as the UHF energy propagates through intervening material to energize the tag located behind it. This kind of self-shielding and “RF shadowing” from surrounding materials is inevitable in real world deployments of UHF RFID tagged objects.

On the other hand far-field propagating UHF waves do have an offsetting advantage in that, while subject to path losses and attenuation through such troublesome materials UHF has a better free space reading range performance of several meters (up to 10 m) compared to LF and HF systems which, by the inherent nature of the magnetic/inductive near-field, operate at ranges of less than 1.5 m. (Note however, that it is often better to use a low cost battery tag if all you want is additional range as a battery will provide additional range without the limitations of passive UHF). Further information on this topic is freely available at www.magtech.com.au under ‘downloads’ in a presentation entitled Traps for New Players.

The ISO 18000-3 HF standard provides a choice of a Mode 1 and a Mode 2 solution. The ISO 18000-6 UHF standard provides, at present, a choice of a Type A and a Type B protocol. Of topical interest is that EPC (the EPCGlobal organisation’s initiative to replace barcode with an electronic product code on every article in the consumer supply chain) has recently been accepted as a proposed candidate for inclusion in ISO 18000-6 as a new Type C. The ISO standardisation process for Type C is expected to be completed in 2006, concurrently with a revision and update to ISO 18000-6 Type A and Type B protocols. Work is ongoing in UHF standardization. Of particular interest will be developments in the European market where ETSI and not USA rules apply and UHF is more limited.

Main Paper

Functionality

Magellan and its licensees provide a family of PJM readers and two distinctly different types of RFID tag. One of these tags is known as PJM ItemTag ® the other as PJM StackTag ®. ItemTag is designed primarily, as are most other RFID tags today, to read separated single tags. These single tags generally use tuned inductive loop antennas, as resonant antennas provide the best powering and communication range when the individual tags are reasonably well separated from each other. StackTag as the name implies is designed, uniquely, to read multiple tags that touch in intimate physical contact or are in a contiguous stack of some form. Stackable technology is actually essential in all real-world RFID applications unless it can be ensured that no two tags will touch and deleteriously interfere with each other's operation.

There is a fundamental law of physics that says two independent tuned resonators when sufficiently close to each other will exhibit parasitic mutual coupling phenomena that manifests itself as a shift in resonant frequency and bandwidth/Quality factor. This effect is frequency dependent and affects all RFID tags that use frequency selective antennas. All magnetic field/inductively coupled RFID tags have inherent mutual inductance when they are in close physical proximity to each other. The resultant strong mutual coupling between adjacent tag antennas causes serious de-tuning that destroys/severely compromises the tag's powering distance and hence reliable communication and readability.

Among the more important of the new functionalities provided by Magellan's HF RFID systems and in particular StackTag are the following:

- **Phase Jitter Modulation.**

  Both ItemTag and StackTag tags use a completely new and spectrally efficient method of forward link/reader to tag communication called Phase Jitter Modulation. This new system is specified in ISO/IEC 18000-3 Mode 2 and provides for very fast data rates that are as much as 100 – 400 times faster than other RFID data rates. Indeed, because it uses PJM technology, the data rate of PJM Mode 2 at 13.56 MHz HF is in fact demonstrably many times faster than the achievable data rates of UHF technologies in real applications. (See Annex C)

  Data and commands are transmitted to the tags by the use of low level (a few degrees) phase modulation of the RF powering field. The low level modulation causes the generation of sidebands out to +/– 450 kHz from the powering field carrier. The amplitude level of these modulation sidebands is, however, well within the regulatory defined mask levels at all sideband frequencies. These mask flanks (which are specified to extend out to +/– 900 kHz) are defined by the radio spectrum regulator specifically to accommodate these transmitted sidebands, and it was the regulator's intention that reader commands and data be transmitted to tags by this method.

  The use of Phase Jitter Modulation permits the Magellan HF system to have a wide communication bandwidth in excess of 900 kHz while still meeting the strict requirements of the regulatory imposed spectrum mask. The fast data rates characteristic of PJM are impossible to achieve with the conventional Amplitude Modulation (AM) methods used by earlier generation RFID technologies.

- **High data rate – PJM.**

  The speed at which PJM communicates is so fast that a reader can communicate with many hundreds of tags practically simultaneously. This also means that PJM tags can access much more memory in the same time than other RFID tags. Importantly, because of its high speed data rate the PJM based protocol can also use a full and very robust 16 bit error checking CRC for commands, and a 32 bit error checking CRC for replies which is the widely accepted data standard for ensuring strong data integrity and security. A key parameter for attaining high speed data transfer and fast anti collision arbitration performance is the reader to tag, or "forward link" signalling rate, and this important link parameter has been optimised through the use of PJM.

- **Excellent Anti Collision function.**

  Earlier or legacy RFID systems are severely limited by the fact that the tag and the reader can only communicate on a single RF frequency or channel. StackTag and ItemTag are quite different in that each tag has the capability to randomly reply on any one or more of 8 different reply frequencies. This parallel data flow means, particularly when large numbers of multiple tags are simultaneously within the operating range of a reader, that they will be correctly identified and their several identifying messages individually and correctly received. Earlier RFID systems cannot do this as they have to use a time multiplexed slotted protocol to achieve multiple tag read over a single half-duplex communication channel. Using traditional sequential slot protocols for anti collision means these systems are both slow and limited in the number of tags they can read in the same time.

  Other RFID protocols are also subject to tag throughput saturation and choking effects. Notably, from a practical deployment point of view, and as mentioned earlier, large numbers of tags also cannot be read when their antennas overlap, as tuned antennas typically interfere with each other due to their parasitic mutual coupling. This interference is often to the extent that neither or none of the touching tags can be read. Refer variously to http://www.itpapers.com/search.aspx?kw=ETH+Zurich+RFID

- **Un-tuned antenna.**

  StackTags are made intentionally with un-tuned antennas. This is to ensure that the antenna of tags which touch or overlap do not interfere and either, or many tags can be read at the same time even when touching or stacked in multiples of 50-100 tags e.g. in gaming chip/gaming table and pharmaceutical/retail item applications. The ISO 18000-3 Mode 2 protocol and air interface is fully supportive of such un-tuned/non-resonant antenna operation. This is in contrast to RFID systems that rely on the presence of tag antenna resonance as an integral part of the mechanism they use to generate their return link reply signals to communicate stored tag data back to the reader.

- **High and low power mode.**

  StackTags operate in two power states, a normal power state and a low power state where the tags draw only the lowest possible quiescent standby current. Tags move deliberately between the normal and low power states so that at any time the majority of the tags are in the low power state. This dual mode further mitigates/eliminates the normal problems associated with parasitic mutual coupling between the antennas of closely stacked tags and also provides the benefits of time division multiplexed operation with the added major advantage of multiple reply channel frequency division, together with frequency hopping between the available channels. Magellan calls this unique feature Frequency & Time Division Multiple Access (FTDMA).

- **Memory Capacity**

  Because of its exceptionally high data rate PJM chips have a very significant speed/time advantage over slower tags. This speed advantage translates directly into not only improved communication and improved anti collision throughput but also into much larger on chip memory. PJM has, for example, the raw speed to provide 8 kbit of user memory where other earlier technologies are limited to a modest 256 bit or 512 bit because they simply cannot communicate with or use more memory in the time made available by their slow anti collision systems and relatively slow data transfer rates.

Advantages of Magellan's PJM technology operating at 13.56 MHz

- The communication channel bandwidth available at the 13.56 MHz ISM band is limited. This is a significant constraint to being able to meet simultaneously the tight spectral mask and also achieve good HF anti collision arbitration, reader to tag data rate, and hence read throughput performance. However, by Phase Jitter Modulation of the powering carrier, this limitation is completely overcome and permits both of Magellan's ISO 18000 Part 3 Mode 2 tags to have a forward link signalling/command data rate of **424** kbits per second. This is very much faster than other technologies and can be used without restriction anywhere in the world. (See Annex B.)

- This very high command signalling data rate provides not only the high performance anti collision functionality of reading many hundreds of tags at the same time, but also reading these tags when they are stacked hundreds deep or 50 tags high in multiple stacks in fractions of a second per stack, and of reading many hundreds of tags in only one or two seconds. Tags can also be rapidly written to, and the time taken is defined by the length of the messages to be communicated to and from tags. For short blocks of data such as a 96 bit number, writing and verification is extremely fast.

- Tags can reply on any one of eight discrete and independent channels so where one channel is blocked, for whatever reason, there are seven other available channels a tag can use to reply. All tag replies are at 106 kbits a second but, as these are simultaneously distributed over eight different parallel or frequency hopped reply channels, then the effective notional tag reply rate if all channels are in use is an extremely fast 848 kbits per second. Such a fast data rate enables tags to be identified at speeds up to 1200 tags per second.

- The ISO 18000-3 Mode 2 HF protocol conforms to international spectrum regulatory requirements including the ERC 70-03 Recommendations 2005 Annex 9 "Inductive Applications". Figure 3 of this annex shows the permitted spectrum mask for 13.56 MHz RFID systems. The 14 kHz wide centre frequency band is only useful for and used for powering the tags. The narrow 14 kHz bandwidth is of no interest beyond merely powering the tag except in so far as it constrains the stability of the crystal oscillator used for generating the 13.56 MHz reader signal.

- Magnetic field coupled HF tags operating at 13.56 MHz are significantly less expensive than LF tags operating at 125 kHz because they use less expensive etched or printed antenna, whereas LF tags generally use much more expensive air wound copper coils. HF tags can also be price competitive with UHF Gen 2 tags, while outperforming them in certain tough and operationally demanding supply chain item-level applications.

- The inductively coupled HF magnetic fields deployed in PJM systems for powering and communications are not deleteriously influenced by liquids and lossy dielectric materials that are problematic to the propagation/transmission of UHF energy and which can seriously detune UHF tags when these kinds of materials are in close proximity. This contributes immensely to the read robustness of HF RFID systems. The underlying physics and electromagnetics governing the behaviour of RFID systems are strongly in favour of HF. This is particularly so when “RF unfriendly” materials intervene in the energy coupling pathway between the reader and the tag.

Typical Problems of LF tags operating at 125 kHz

- The bandwidth available at this frequency is very limited which results in very slow data rates. In the case of the new International Standard ISO 18000 Part 2 covering LF RFID systems the command signalling rate, meaning the communication speed between reader and tag, is only a modest 5.2 kbit per second. (See Annex A for direct contrast with PJM)

- This very slow data rate does not and cannot provide a fast anti collision protocol or fast data transfer and the technology is inherently not suited to reading multiple tags at once.

- Tags can only reply on one channel and this makes the entire system vulnerable to collapse if interference and strong environmental electrical noise is experienced.

- The requirement for air wound copper coil antennas of a large number of turns makes the inlays for LF tags much more expensive to build than are the inlays for HF tags that use printed or etched antennas. The attachment of the microchip circuit to the wire terminals of the air wound copper coil is both difficult and slow (ultrasonic welding) and this adds markedly to the overall cost of LF tags. By comparison, HF inlays are manufactured with very high speed Flip-Chip die attach assembly lines that bond the IC directly to the planar etched copper or aluminium or conductive ink printed antenna coil.

- For a given die size, silicon microchips cost essentially the same and that cost is independent of the operating frequency or the protocol. Superior RFID protocols like ISO 18000-3 Mode 2 do not inherently cost more than the legacy technologies.

Typical Problems and limitations of UHF tags

There are two ISO 18000-6 protocols, Parts A, and B operating at various frequencies in the UHF range. The proposed new ISO/IEC 18000-6 part C will embrace the EPC UHF Gen 2 Specification. In different countries different frequencies within the UHF band will need to be adopted due to different national regulations.

UHF technologies do have a longer reading range advantage over LF and HF systems but they also have many disadvantages that limit their functionality in real world applications.

- 900 MHz intrudes on the GSM mobile telephone and DECT Cordless telephone system bands in certain countries other than the USA. This is not desirable, as equipment licenses need to be obtained, and the existing entrenched users of this portion of the radio spectrum will oppose these. Furthermore, it has been shown that in respect of interference RFID equipment does not harmoniously coexist with cellular telephone systems, and wide guard bands are necessary which severely confine the amount of available spectrum remaining to accommodate UHF RFID systems.

- 900 MHz is also a frequency where the energy carried by the radio frequency radiation is attenuated by liquid. This attenuation not only causes a heating effect but more importantly the RF energy absorbed by liquids can seriously reduce range. This is one of many reasons why this frequency is experiencing difficulties in various trials word wide for item identification.

- UHF systems are also still trying to solve the multiple reader or "dense reader environment" typically found in distribution centres and at "Dock Doors" applications (identifying pallets and cases/boxes of goods and not items). The problem UHF systems have is that the operating range of multiple UHF readers means they will often interfere with each other to an unacceptable degree. The solution proposed, at present, is that all UHF readers share the available spectrum in turn. Such systems may work in a controlled or laboratory environment but are impractical in real life applications where entire networks would congest and slow down unacceptably.

- Unlike 2.45 GHz, which is a UHF frequency that can be quite unsafe for human exposure, 900 MHz is a safer UHF frequency except where focussing Yagi or horn type UHF antennas are used to produce a focussed beam. Focussed beams can be unsafe because in concentrating the radiated energy to achieve range they can exceed OH&S exposure levels. It is already well known that it is not desirable to expose the human eye to any UHF radiation for any appreciable length of time. The US FDA has also reported recently on the heating of insulin when exposed to prolonged UHF radiation at 900MHz.

- UHF is subject to severe environmental multipath propagation effects where reader signals can be reflected by environmental objects, particularly metal and high conductivity materials. An RF unfriendly multipath scenario often exists causing the simultaneous reception at any point in space of multiple signals of differing relative path length and hence phase. This results in a complex 3 D pattern of destructive interference between the waves and creates a highly non-uniform field strength with deep nulls or holes in the RF field at a periodic distance related to the signal wavelength. Such null aberrations cause the power available to energise the passive tag to drop below its activation threshold. Any tag so positioned will not be visible to a reader and communication can never occur. Conversely, constructive wave interference can also occur which causes a beneficial increase in RF field strength at certain spatial locations.

- Propagating UHF fields in typical commercial and industrial environments tend to be very non-uniform and "lumpy" in strength, whereas HF magnetic near fields tend to be very homogenous, localized, and predictable in their 3D spatial distribution around the reader antenna structure. Provided the HF tag is in adequate communication range to the reader, robust and reliable data capture is ensured. This anomalous propagation of UHF fields means they are difficult to contain in localised read zones, something that HF does inherently very well. UHF systems are therefore often plagued by "RF hot spots" where distant tags are read inadvertently far from where intended or desired. This creates "Ghost Tag" problems in warehouses and retail.

- UHF RFID tags, by their nature have relatively broad band antennas. If these antennas are brought closer together than about ¼ wave length, then they will interact with each other and drain each others' energy. If UHF antennas are aligned in a row then they will create an antenna array. If UHF tags are closer than about 1/8th wavelength then they will create what is known as a super gain array. This type of interaction will also cause nulls in the powering field and result in some tags not being seen at all. An array of evenly spaced tags (as in a box of pharmaceutical vials or bottles) can create an almost impossible read situation for UHF.

- Surprisingly, while UHF is faster than HF systems using ISO 18000-3 Mode 1, UHF is actually slower than HF systems using ISO 18000-3 Mode 2. This speed differential is even more marked in the European ETSI regulatory jurisdiction that has bandwidth and channel limitations more stringent than are found in the USA. (Refer Annex C).

Use of the slotted protocol - A fundamental problem for certain LF, HF and UHF tags (but not PJM Mode 2)

A major, if not mandatory, requirement for all advanced RFID tag systems is to be able to rapidly and simultaneously read large populations of multiple tags at the same time. While reading a single tag may be acceptable for limited applications such as air line baggage, which is carefully separated on a conveyor belt, or for bus tickets which are presented one at a time, for the majority of real world applications the singulation of tags is not a practicable solution. Real world applications require reading and writing to multiple tagged items where articles will touch, sometimes overlap and are often closely stacked.

Naturally where an existing RFID product has performed well in one application there is a compelling wish by the manufacturer to try and use that RFID product into other applications. The laws of physics do not, however, permit a product with functionality suited to one particular application to be used satisfactorily in applications that require substantially improved functionality.

Many RFID tags (but not PJM) use an approach to anti collision arbitration based on simple time division and a slotted system in which competing tag replies try to find a time window in the single reply communication channel frequency available to them. Conversely PJM uses the powerful added dimension of multiple parallel reply frequencies and time division (FTDMA) together with a very high data rate to achieve a very high degree of tag throughput performance in the system's anti collision operation.

Typical applications that require this higher order of PJM enabled functionality are:

- Pharmaceutical applications
- Item management
- Gaming applications.
- Document management
- Postal and courier applications,
- Blood management
- Fresh food
- Fresh fish and frozen meat
- Jewellery
- Forensics

The common salient point relating to all of these hitherto "tough" applications is the mandatory requirement to reliably read multiple tags in very close physical proximity combined with fast and accurate reading and writing to large populations of tagged objects. These key operational features formed the basis for the original design goals of the ISO/IEC 18000-3 Mode 2 standard.

It is demonstrably the case that the legacy slotted protocols based on a single command and reply communication channel, a slow data rate and simple time division, can never hope to provide a functionally competitive solution to that provided by PJM. In the case of StackTag, the competitive product offerings simply cannot read stacked tags in either the time or with the stack height provided routinely by PJM based RFID systems.

Summary

The performance of Magellan's technology operating at 13.56 MHz compared to other RFID technology at other frequencies is vastly superior as shown in the following examples:

<u>HF (PJM) compared with LF</u>

- In a typical example the total identification time to identify 500 tags for a 125 kHz technology (based on the published ISO18000 Part 2) is 30 seconds compared to 0.340s for Magellan's 13.56 MHz technology.

- Similarly, the total time to identify and read 100 bit of data from each of 500 tags takes 330 seconds for a 125 kHz technology compared to 0.879 s for Magellan's 13.56 MHz technology.

- When identifying and reading data from large numbers of tags the Magellan 13.56 MHz protocol is **375 times faster** than the 125 kHz protocol.

HF (PJM) compared with other HF systems

A similar comparison using a typical ISO 15693/18000-3 Mode 1 HF system based on 500 tags shows it takes 19.2 seconds to read 100 bit of data and a total identification and data read time of 24.3 seconds from the 500 tags, compared to 0.879 seconds when using Magellan's 18000-3 Mode 2 technology, which is **28 times faster**.

HF (PJM) compared with a UHF system

Simply moving to a higher frequency does not mean a higher reader to tag communication rate. ISO 18000-6 parts A and B at 900MHz have a much slower data rate than ISO 18000-3 Mode 2 (PJM). The command data rate of ISO 18000-6 is 40 kbit/s on a single channel whereas ISO 18000-3 Mode 2 (PJM) is **424** kbit/s. Similarly ISO 18000-6 has a reply data rate also of 40 kbit/s whereas ISO 18000-3 Mode 2 (PJM) has a reply data rate of 106 kbits/s. This faster reply can also be on each of eight reply channels giving an effective reply data rate as high as **848** kbits/s.

The proposal for ISO 18000-6C, which is still in development, could conceivably, in Europe, operate with a nominal 60 kbit/s command data rate using Phase Reversal Modulation and a reply data rate of 80 kbit/s in dense reader mode on a 320 kHz sub carrier under proposals being discussed with radio regulators. None of this is yet final.

The cost of the silicon used in RFID tags is protocol and frequency neutral. In selecting an optimum RFID technology for any given application, particularly the demanding ones, it makes sense to choose a tag having a protocol and IC architecture/reader platform designed from the outset for high performance. The elements of inlay/tag construction, substrate, antenna, die attach, and assembly and label conversion are similarly cost neutral in respect of protocol and frequency.

For a concise summary of the advantages of PJM over LF refer to Annex A.

For a concise summary of the advantages of PJM over HF refer to Annex B.

For a concise summary of the advantages of PJM over UHF refer to Annex C.

Conclusions

RFID systems that deploy inductive/magnetic near-field coupling for their powering and communication mechanisms exhibit demonstrably superior read reliability and robustness compared with their UHF counterparts. This relates to the physics of how electromagnetic fields behave and interact with matter and common everyday materials. Depending on the choice of HF air interface protocol, an even greater data capture robustness and read integrity can be gained, together with very high speed reading and rapid anti collision throughput, combined with the unique ability to read large populations of stacked and physically overlapping tags.

RFID systems based on ISO 18000-3 Mode 2 are, in terms of all round utility and functionality, far superior to LF , UHF and other HF RFID systems.

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Comparative Table showing the functional advantages of HF (PJM) over LF

Parameter	Typical LF reference tag	Magellan HF StackTag
Frequency	125 kHz	13.56 MHz
Bit rate - Command	5.2 kbit/s	424 kbit/s
Bit rate - Reply	2 or 4 kbit a second during anti collision	106 kbit/s
Number of reply channels	One	Eight
Memory capacity	256 bit -2048 bit	8128 bit
CRC error checking	8 bit sometimes used	16 bit command 32 bit in reply
Anti Collision functionality	Not reliable (no CRC in replies during the anti collision procedure)	Fast and reliable
International standard	Yes, recent ISO 18000-2	Yes, ISO 18000-3 Mode 2
Tag antenna type	Air wound copper coil Many hundreds of turns	Slim foil, few turns Cu, Al or printed ink inductive loop coil
Suitability for use in gaming tokens and playing cards	Limited use in gaming tokens not possible in playing cards	Yes – Both
Suitability for use in closely stacked applications - documents etc	No does not work in these applications	Yes, stackable to greater than 100 tags deep
Silicon cost	Low	Low
Tag antenna cost	High due to many turns	Low
Antenna and chip attachment cost (manufacturability)	High, especially if moulded package is also used	Low
Theoretical maximum read rate in one second	Approx 20 – 25	Approx 1,200
Ability to read many hundreds of tags in one second	No. 100 tags in 5 – 7 seconds	Yes. 800 tags in under one second in real world applications

Annex B to RFID White Paper

Comparative Table showing the functional advantages of HF (PJM) over other HF

Parameter	HF (PJM) ISO 18000-3 Mode 2	Other HF ISO 18000-3 Mode 1
Frequency	13.56 MHz	13.56 MHz
Bit rate – Command	424 kbit/s	26.48 kbit/s
Bit rate – Reply	106 kbit/s	26.69 kbit/s
Number of reply channels	Eight	One
Memory capacity	8128 bit with essentially no protocol limit	Generally under 2 kbit. occasionally higher
CRC error checking	16 bit command 32 bit in reply	16 bit
Anti Collision functionality	Fast and reliable	Limited and slow
International standard	Yes ISO18000-3 Mode 2	Yes ISO 18000-3 Mode 1
Tag antenna type	Slim foil coil inductive loop	Slim foil coil inductive loop
Suitability for use in gaming tokens and playing cards	Yes - Both	No
Suitability for use in closely stacked and overlapping applications, documents etc	Yes	No does not work in these applications
Silicon cost	Low	Low
Tag antenna cost	Low	Low
Antenna and chip attachment inlay cost (manufacturability)	Low	Low
Theoretical maximum read rate in one second	Approx 1,200	Approx 40
Ability to read many hundreds of tags in one second	Yes. 800 tags in under one second in real world applications	No – anti collision function insufficient
Stackability. Tags touching still reliably read	Yes	No

Comparative Table showing the functional advantages of HF (PJM) over UHF

Parameter	**HF (PJM) ISO 18000-3 Mode 2 (Stack Tag)**	**UHF Proposed as ISO 18000- 6 type C**
Frequency	13.56 MHz	860-960 MHz
Bit rate - Command	424 kbit/s	26.7 to 128 kbit/s
Bit rate – Reply	106 kbit/s	40 to 640 kbit/s
Number of reply channels	Eight	One
Read and write range	0 – 1.5 m	0 – 10 m
Reader density	Not an issue	This is a major issue as readers interfere with each other unless spectrum is shared. No agreed solution has yet been found. Readers are also sensitive to side band noise and can lock themselves out if the local spectrum is noisy
Reader safety and OH&S issues	Safe	Can be unsafe where focussing Yagi or horn antennas are used.
Tag Stackability	Yes even when touching exactly	Not stackable unless well separated
Unintended reading of distant tags. (False positive reads).	No	False positive reads are a major issue as distant tags will often be read in error due to "Spill Over" from UHF antennas.
Ability to read tags which touch exactly	Yes – many hundreds	No – very poor
Ability to read many hundreds of tags in <u>one</u> second	Yes 800 tags in under one second in real world applications	Yes, if separated, but actual number very dependant on the regulatory jurisdiction
Ability to read dynamic and changing population of tags	Yes	Limited as all tags need to stay in the field of the reader during the anti collision procedure

Comparative Table showing the functional advantages of HF (PJM) over UHF (continued)

Parameter	HF (PJM) ISO 18000-3 Mode 2 (Stack Tag)	UHF Proposed as ISO 18000- 6 type C
Ability to read evenly spaced multiple tags	Yes	Major limitation when tags create a super gain array such as in evenly spaced tags on vials or pill bottles
Ability to read mixed cartons (frozen, wet and dry)	Unaffected	Affected by liquid content and dielectrics.
Anti collision function	Simple – FTDMA Frequency and Time Division Multiple Access	Very Complex – Slotted Terminating Adaptive Collection
Memory capacity	High – 8128 bit with no protocol limit	Low – 256 bit extensible
CRC error checking	Good. 16 bit command 32 bit in reply	Poor. 5 to 16 bit command 16 bit in reply - inadequate
Anti Collision functionality	Fast and reliable	Slow and with a tendency to choke
International ISO standard	Yes. Already Published	No under consideration
Tag antenna type	Slim foil, H-field loop coil	Slim foil, E-field dipole
Silicon cost	Low	Low
Tag antenna cost	Low	Low
Antenna and chip attachment cost (manufacturability)	Low	Low
Functionality in USA and Europe	Yes - no difference	Major difference. In Europe where the notional speed of UHF systems is severely restricted by bandwidth and other limitations.
Manufacturability	Standard processes	Standard processes
Inlay/Tag Cost	Similar	Similar