Before the
Federal Communications Commission
Washington D.C. 20554

In the Matter of	)	
	)	
Modification of Parts 2 and 15 of	)	
the Commission's Rules for	)	ET Docket No. 03-201
unlicensed devices and equipment	)	FCC 07-117
approval	)	

RF Controls, LLC reply to comments
NPRM Adopted June 19, 2007

RF Controls, LLC ("RFC") respectfully submits these comments in reply to comments previously submitted in response to the further Notice of Proposed Rulemaking in the above-captioned proceeding seeking comment on the imposition of a spectrum etiquette for unlicensed transmitters authorized under 47 CFR Parts 15.247 and 15.249 of the rules.

We believe that the Commission should maintain its current regulatory framework for unlicensed operation in the 902 – 928 MHz band but introduce a number of modifications to further improve access to the available spectrum. The existing framework has effectively encouraged the proliferation of diverse technologies under Part 15 of the FCC rules while at the same time provided the necessary protection for primary users of the band. This is not to say that the framework has remained fixed or inflexible, nor that it should remain unchanging. Small adjustments in the rules from time to time have permitted greater use of the band for unlicensed devices. The imposition of a spectrum etiquette on the band as proposed by some commentators, would stifle further development and the deployment of new technologies and would not achieve the intended goal of facilitating improved access to the band.

It is our submission that a spectrum etiquette would not improve access to the 902 – 928 MHz band but would instead benefit one or two current users of the spectrum at the expense of other existing or future users. We note that a number of respondents have expressed a similar opinion. In reply to comments submitted, we wish to address a number of issues.

We note that there appear to be two opposing points of view.

One view, expressed by companies providing broadband internet services, is that any form of spectrum etiquette would seriously damage their ability to deliver broadband service to their customers, particularly in rural areas. This view opposes any changes to the rules.

The second point of view expressed by companies supplying or using "traditional" Part 15 devices such as cordless phones, wireless audio and low power SCADA and meter reading systems is that unlicensed equipment using digital modulation (DM) dominate the spectrum to the detriment of all other users. In general, the opinion is that there should be some sort of spectrum etiquette imposed on DM equipment and/or systems, but that spread spectrum systems (FHSS and DSSS) by their nature already exhibit spectrum etiquette, in that an individual device only occupies a small amount of spectrum for short period of time, typically less than 5% of the time, i.e. 95% quiet time.

It is our view that Digital Modulation is the "odd man out" that affects all other unlicensed equipment and systems in the 915 MHz band.

RFC is aware of new 'advanced antenna technology' that is applicable to RFID and other unlicensed wireless technologies operating in the 915 MHz, 2.45GHz and 5.8 GHz bands. We are of the opinion that this new technology would contribute to more efficient reuse of the unlicensed spectrum by allowing transmit signals to be directed to where they are needed and at the same time reducing emissions in directions where they are not required. RFC is keen to ensure that unlicensed use continues to grow and offers the widest range of opportunity for both existing and new products and systems.

We wish to address a number of issues which have been raised in comments to the Commission.

1. Antenna Gain vs Conducted RF Power output

Under the present rules (Part 15.247 (b)(1), (b)(2), (b)(3) and (b)(4), Conducted RF power is limited to 1 Watt or less, which is based on the use of antennas having a gain not exceeding 6dBi. This equates to a radiated output power of 4 Watts EIRP (effective isotropic radiated power). It is usual to calculate antenna gain as the sum of 10log(number of elements) + the gain of an individual element. This applies where an antenna array is designed to maximise gain at some distance. However, there are applications such as RFID where it may be desirable to direct or focus the antenna beam to establish a read zone at a point close to the reader antenna (i.e. within a few tens of feet). Advanced antennas designed for these applications may exhibit an effective gain at a distance which is somewhat less than the theoretical gain assumed by the standard equation.

Part 15.247 does not define an EIRP but simply specifies a conducted output power and assumes a maximum antenna gain of 6dBi and requires that the conducted output power be reduced by 1dB for each dB increase in antenna gain. This simple approach works for conventional systems but does not necessarily work in the case of advanced RFID antenna systems where beam shaping is used to illuminate tags in a read zone. It is quite possible for the signal to be far less at some distance away than it would be for a conventional antenna emitting 4 Watts EIRP. Furthermore, many passive RFID systems in the 902 – 928 MHz band are operated indoors where the building itself can provide between 20 and 30dB of additional path attenuation, as measured by ETSI TG/34 at a Metro Group facility on 2nd May 2006.

We request the Commission to consider modifying the rules contained in Part 15.247 to permit an alternate Effective Radiated Power measurement to be used for compliance testing. The spirit of the current rules requires that the Effective Radiated Power be limited to 4 Watts EIRP. Because EIRP is not currently used as a measurement, there is no measurement distance specified. We are of the opinion that if the rules specified an alternative test method that measured EIRP then there would be greater scope for improving spectrum re-use. We recommend that ERP measurements be permitted at a distance of several 10s of wavelengths or more since this the distance where other users of the spectrum are likely to operate and where the real potential for degradation in co-channel (or co-frequency) use is of most concern.

We further request the Commission to modify the rules for the 902 – 928 MHz band to allow high gain antennas to be used on systems deployed primarily indoors <u>without</u> the need to reduce conducted power by 1dB for every dB of antenna gain. Instead, we request the Commission to apply the rules already established for point to point systems in the 2400 – 2483.5 MHz band as specified in Part 15.247 (c)(1)(i). These sections require that the conducted output power be reduced by <u>1 dB for every 3 dB</u> of antenna gain over 6 dBi.

2. Listen Before Talk (LBT)

GE MDS, Freewave and Data Radio raised the issue of the 'hidden transmitter syndrome'. This was also raised as an issue when LBT was proposed as a solution in Europe for RFID under EN 302 208. Hidden transmitter syndrome is the result of two transmitter/receivers or base stations operating in the same service area but hidden from each other. If they transmit at the same time all stations on the same frequency in the service area would receive clashing transmissions. LBT would not resolve this problem because neither transmitter would know that the other was transmitting because they are hidden from each other. Another form of channel sharing could mitigate this problem.

A further problem with LBT is how to handle the multiplicity of modulation schemes and bandwidths associated with Part 15 devices. LBT may be usefully deployed in systems using the same or similar channel spacing and modulation schemes. However, LBT is inherently flawed where a multitude of different modulation schemes, channel spacing and bandwidths are used, such as in the 902 – 928 MHz band. It is extremely difficult and costly to design and produce an LBT receiver which would satisfactorily recognise all possible transmissions present in the unlicensed band. This cost and complexity of a comprehensive LBT receiver would defeat the intent of the unlicensed rules to facilitate low cost and wide spread use of low power devices. A further problem with implementing an LBT etiquette affects devices or equipment that need to operate in real time. Examples are cordless audio devices which need to react immediately or stream audio and other devices which are event driven such as RFID readers and industrial control equipment. In the event that these devices are prevented from transmitting immediately on a real time event trigger, the event could be lost and in the case of RFID tags would not be read. As mentioned in the comments from Global Information Systems LLC, if RFID tags are required to be read as they pass through a reader zone, they may only be present in the zone for a second or two at the most. If the reader cannot respond immediately to the tag arrival event (or more precisely the arrival of a tagged item at a location where the tag it is to be read by a portal reader sub-system, for example), then the tagged item would leave the zone before it could be read. This particular problem was highlighted in documents presented to ETSI TG/34 by the ISO 18000 RFID standards working group. We attach a copy as Annex A.

3. Occupied Bandwidth

It has been pointed out by a number of commentators that unlike spread spectrum systems, which have inherent etiquette, Digital Modulation systems have no inherent etiquette and are therefore able to completely block a channel or frequency for long periods of time, if not indefinitely. Direct Sequence Spread Spectrum (DSSS) systems fall into the digital modulation category but are subtly different to non-DSSS systems in that they are able to recognise and demodulate their corresponding station in the presence of another DSSS signal of similar signal strength, whereas a DM system needs the corresponding station's signal to be several times stronger than any other signals. A Frequency Hopping Spread Spectrum (FHSS) system only occupies a relatively narrow channel for a period of time not exceeding 0.4 Seconds before it moves to another channel and does not return for at least 20 seconds. It is our view that there needs to be a limit on <u>time vs occupied bandwidth vs output power</u>.

We therefore ask the Commission to consider whether a formula can be evolved which is based on the three parameters, time, occupied bandwidth and output power. Time/power/bandwidth is already inherent in the FHSS limits specified in 15.247 (b)(2). A system employing 50 or more hopping channels is

permitted to transmit at 1 Watt, whereas a system employing less than 50 channels has its output power limited to 0.25 Watts. In their comments, Shure Corporation suggest that if new requirements are absolutely necessary, then consider limiting either bandwidth and/or antenna beamwidth. We support this comment.

Summary

RF Controls is of the opinion that a spectrum etiquette regime is not required to ensure future viability of the 902 – 928 MHz band. But, RF Controls believes the Commission could introduce a number of measures which would greatly improve the utility and spectrum efficiency of the band. These measures are:

(i) Introduce an alternative measurement method for radiated power using a measurement distance of several tens of wavelengths.

(ii) Permit the use of gain antennas for indoor systems, requiring only that the conducted output power be reduced below 1 Watt by 1dB for each 3dB of antenna gain.

(iii) Introduce rules based on an algorithm which takes into account the three measures of: time, occupied bandwidth and output power. This is already inherent in the rules for FHSS.

(iv) NOT to introduce listen before talk (LBT) or other similar spectrum etiquette measures, as proposed by Cellnet and others.

We thank the commission for affording us the opportunity to comment on the proposed rule making.

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ANNEX A

ISO 18000 Standards WG Commentary to ETSI TG/34

WHITE PAPER ON THE DENSE READER PROBLEM IN EUROPE

Prepared by: ISO-IEC JTC1/SC31/WG4/SG3 Ad Hoc committee on Dense Reader Problem.

Members: Chris Turner (Ad Hoc convenor), Chris Diorio (Impinj), Steve Lazar (TI-RFID), Josef Preishuber-Pflugel (CISC), Rene Martinez (Intermec), Mike Guillory (Philips) & Steve Halliday (SG3 convenor).

29 January 2006.

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overview

Passive RFID Systems are those in which the tags have no built-in power source but instead rely on the incident energy from a reader to energise them. A typical RFID tag is about the size of an ISO card (credit card size) though there are other form factors. Tags may be embedded in paper labels or objects in order to allow identification of the object to which they are attached. Passive RFID systems are available in different forms and operate on frequency bands ranging from LF (<132kHz), to HF (13.56 MHz) to UHF (nominally 900 MHz) to 2.45GHz. The International Organisation for Standardisation (ISO) has a family of standards ISO-IEC 18000 specifically targeting RFID for supply chain applications. ISO-IEC 18000 has a number of parts each addressing the use of RFID for item management at different frequency bands. UHF RFID (860 – 960 MHz band) is the preferred choice for supply chain management applications.

The use of RFID is governed by the local radio regulations in each country. In Europe and a number of countries in Asia, the amount of radio spectrum available for RFID at UHF is limited and is shared with other users of the spectrum. In Europe those users are Short Range Devices operating licence free under the EU R&TTE directive.

Thanks to the hard work of many involved in the regulatory and standards committees, the CEPT together with ETSI put into place a regulatory framework for RFID systems operating in the 865 – 868 MHz band. However the regulations and accompanying ETSI standard were based on laboratory work and provided a “best assumption” at that time. It was not possible at that time to foresee all of the issues and challenges which have become evident now as a result of the deployment of systems and many field trials.

Passive UHF RFID systems are expected to be widely deployed over the next few years, in supply chain management and will be installed in warehouses, distribution centres and stores. In many of these deployments tens or even hundreds of readers will be in operation within close proximity to each other. This has been coined "The dense reader environment".

This so called dense reader environment presents a number of unique problems or challenges. Since the formulation of the framework, field experience has shown that the earlier assumptions on LBT and channel sharing would severely limit the number of readers that can be deployed in a radio neighbourhood. Some changes in the way that RFID systems are configured and operated would greatly improve both efficiency of spectrum usage and RFID system operation. This paper addresses those issues.

Regulatory and standards background

The use of radio based applications of which RFID is one, is governed by the national radio regulators. National regulations are based on recommendations from the CEPT (Conference of European Posts and Telecommunications) and are adopted in part or full or with conditions by each CEPT member country according to their own local circumstances. The Recommendations for Short Range Devices (SRDs) are embodied in CEPT Rec 70-03E. Annex 11 deals specifically with RFID.

ETSI, the European Telecommunications Standards Institute has published a standard EN 302 208 which provides the basis for operation under ERC Recommendation 70-03E Annex 11. EN 302 208 and Annex 11 provide a band from 865 – 868 MHz divided into 15 channels of 200kHz.

The lower 3 channels are limited to a radiated power of 100mW, the upper 2 channels 500mW and the 10 channels in between 2 watts erp. This band is not exclusive to RFID but is shared with other non-specific Short Range Devices (SRD). In the USA and Canada RFID is accommodated in the 902 – 928 MHz band where wider bandwidths and frequency hopping spread spectrum are used.

The Problem

RFID, unlike other communications systems, does not provide propagation reciprocity between base station and mobile station. In other words for RFID, the relative transmission range of the base station (reader) is much greater than that of the mobile station (tag). This creates the potential for base stations to interfere with each other over a range of several kilometres,

whereas the backscatter signals radiated from tags propagate over distances of a few tens of metres.

EN 302 208 requires the use of Listen Before Talk (LBT) to prevent a base station from transmitting if the channel is already occupied by another transmission. The LBT threshold is set to -96dBm which has the effect of severely limiting the number of readers able to operate simultaneously in a particular radio neighbourhood if all available channels are used. "Listen Before Talk" is presently effective in preventing interference to non-specific Short Range Devices (SRD) but has the effect of crippling other RFID readers in the radio neighbourhood. There have been a number of suggestions on methods to synchronise reader transmissions in order to allow more readers to transmit at once using a single LBT receiver. However using a single LBT receiver still has the drawback that reading of items cannot be truly event driven because by their nature the arrival of items to be read is random. If the LBT receiver cannot find a free channel because of channel occupancy from RFID systems at another site or from other non-specific SRD transmissions, then all readers will need to wait until a channel becomes free. It can also occur that there is a race to seize the next available free channel and this particular LBT receiver loses and has to wait for another period of time. The number of reader systems that can be accommodated can be calculated using the Erlang B equation. Because Listen Before Talk is based on "Trunking" principles as used in Telephony the number of reader systems that can be accommodated on a given number of channels, can be calculated using the Erlang B equation.

In calculating multi-channel system capacity, the overall "grade of service" of a switching system refers to the anticipated ratio of calls "lost" at the first attempt to the total number of attempts to establish a connection through the system during a specified period of time, usually the "busy hour". The probability that a call offered to a group will find all available channels already occupied depends on a number of factors, the most important of which are:

- The distribution in time and duration of the offered traffic
- The number of traffic sources
- The availability of channels
- The conditions under which calls are lost.

The CCITT equation for determining the probability of blocked calls is known as Erlang B and may be found in the CCITT Blue Book. See Appendix 2 of this white paper.

In a Distribution Centre (DC) there is a need to operate tens or even hundreds of readers in close proximity to each other. In order to not upset or interfere with the movement of goods, each reader needs to be able to respond to a trigger, either manual or automatic, on demand and asynchronous of other readers. In a multi-vendor environment such as a shopping centre, where the receiving docks belonging to different organisations are in close proximity, synchronisation of readers is impractical.

In addition to the problems above there is also the issue of handheld readers as they are constantly moving, do not have a fixed location and cannot easily be synchronised. Furthermore their transmissions are truly random and event driven.

The challenge

The challenge is to provide a means whereby RFID systems are able to operate freely under the following conditions:

- Provide a method for multiple readers to operate in the same radio neighbourhood without undue interaction or mutual interference.
- Allow readers belonging to different organisations to operate independently of each other.
- Allow readers to be truly event driven without the need to wait or be synchronised with other readers.
- Ensure that tag replies can be heard when a reader is operating in an adjacent portal.
- Minimise the chance of not reading tags while at the same time keeping individual reader transmit time to a minimum
- Take account of other non-RFID devices sharing the same channel/s

Some basics

Passive RFID tags are powered by the incident energy from a reader. A signal strength of several volts per metre is required at the tag antenna. Tags inherently have a very broadband response therefore, increasing the attenuation between a reader and 'tags not required to be read' is necessary, no matter what frequency is used.

A heterodyne tone (beat note) is produced when two readers operate simultaneously in close proximity to a tag; the tag rectifier acting as a mixer. This heterodyne signal can interfere with the ability of the tag to reliably decode reader commands. *See the paragraph below on Tag Interference Rejection.* Where two (or more readers) transmit on the same channel (co-channel operation), the difference in signal levels between a wanted transmission and an unwanted transmission, at the tag is referred to as the *protection ratio*.

Many readers can transmit on the same nominal frequency, provided that

- The reader receivers listen for tag backscatter signals at a frequency far enough removed from the reader transmissions so as to not suffer desense of the receivers.
- The heterodyne/s produced by the reader carriers should be lower in frequency than the highpass cutoff frequency of the tag demodulator and at a level at least 13dB lower than the reader transmitter modulation level.

A tag can reject an in-band beat note at a level of -13 dB ("band" here means the Bandwidth of the tag demodulator filtering, which is roughly 4kHz to 400kHz) . The further out of band, the better the beat-note rejection. If the beat note is 1MHz out, then a -6dB beat note is tolerable. What this means is that 2 readers on either side of a dock door should transmit at least 600kHz apart. Readers on other dock doors (13 - 20 dB away) can transmit on the same channel.

Good design practice (based on test results) dictates that the wanted reader signal should typically be at least 13dB stronger than interfering signals. For example two reader transmissions separated by 200kHz will produce a heterodyne of 200kHz at the tag rectifier. It is therefore important that

- The separation between the transmit frequency of two readers should be greater than the cutoff frequency of the tag filter circuit; and

- The separation between the transmit frequency of two readers should be less than the highpass frequency of the tag filter circuit.

See the paragraph below on reader spectrum occupancy.

Tag Interference Rejection.

In a typical operating environment RFID tags are exposed not only to their intended RFID reader, but also to a wide variety of radio frequency sources. These include mobile phones, radio data systems, electrical systems and also other RFID readers. All these sources have the potential to interfere with the ability of a tag to communicate with the reader. The nature of a tag makes it a broadband receiver; it is therefore susceptible to interference from all these sources. Good tag design will incorporate circuitry which reduces or eliminates interference. This circuitry will in effect reduce the tag demodulator sensitivity to low frequency modulation (high pass filtering)

and will also limit the demodulator upper frequency response (low pass filtering) so that the demodulator only responds to reader transmissions to the tag.

The greatest potential source of interference is from a nearby reader. For example, system X operating in a dock doorway and another system Y operating in an adjacent dock door. A tag in system X will receive signals from both its own reader X and also from adjacent [unwanted] reader Y.

The degree of harmful interference will depend on three main factors;

- The difference in signal strength (protection ratio) between the signals received by the tag from readers X and Y,
- The frequency separation between readers X and Y; and
- The ability of the tag to reject interference.

Additionally, the occupied bandwidth of the unwanted reader Y (for example modulated v unmodulated) will have an effect.

Figures 1, 2 and 3 show the results of Matlab™ simulations of the effect on tag demodulation and data recovery in the presence of two reader transmissions differing in level by 10dB.

Figure 1 shows the relative level of two signals at the tag antenna input; figures 2 and 3 show the raw Tag envelope detector output and the recovered pulse chain output after processing for the two conditions of zero frequency difference and 500kHz frequency difference.

Figure 4 is based on measurement data from Impinj Monza™ EPC Gen II (ISO 18000-6C) tags.

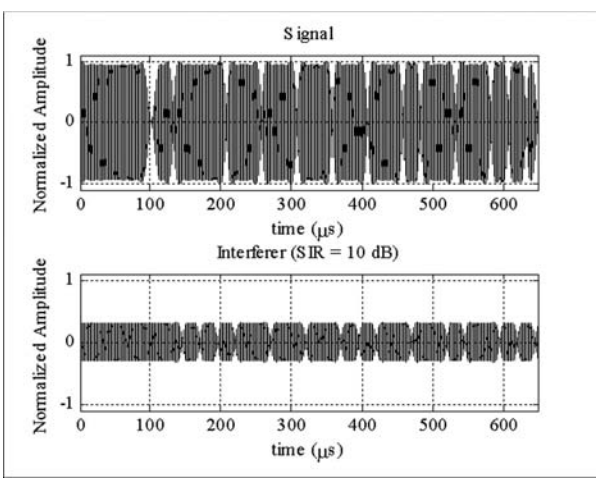


Figure 1 shows the relative signal levels of two modulated transmissions from two readers as received at a tag demodulator.

Figure 1. Top trace - Wanted Signal, lower trace - Interferer

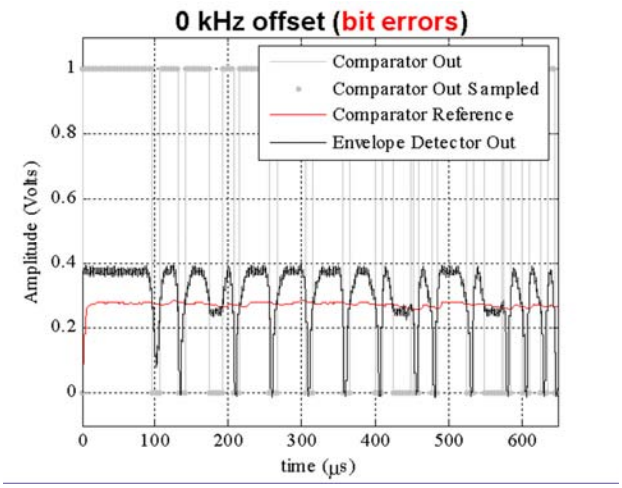


Figure 2 shows the recovered data output when the wanted signal and the interfering signal are on the same frequency where the interferer is 10dB below the wanted signal. It is expected that where the difference in signal strength is in excess of 13dB there will be negligible bit errors. It should be noted that if the reader signals are exactly zero beat (ie. fed from the same reference signal or of identical frequency and phase) there is no beat note.

FIGURE 2. RECOVERED DATA AT TAG COMPARATOR OUTPUT – NO OFFSET

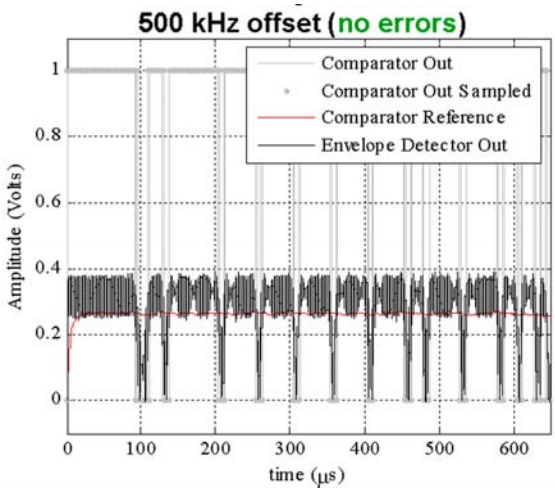


Figure 3 shows the recovered data output when the wanted signal and the interfering signal are separated by 500kHz and the interferer is 10dB below the wanted signal.

Figure 3. Recovered data at tag comparator output – 500kHz difference

Impinj, a designer and manufacturer of UHF RFID hardware, conducted a number of tests on an 18000-6C RFID tag to determine the effect of two reader signals on the ability of the tag to successfully decode and execute commands from readers in adjacent dock doors.

Figure 4 shows the results of these tests in graphical form and also defines a tag measurement method, which Impinj refers to as *Receptivity,* for a frequency separation between the wanted signal and the interfering signal of 1 MHz.

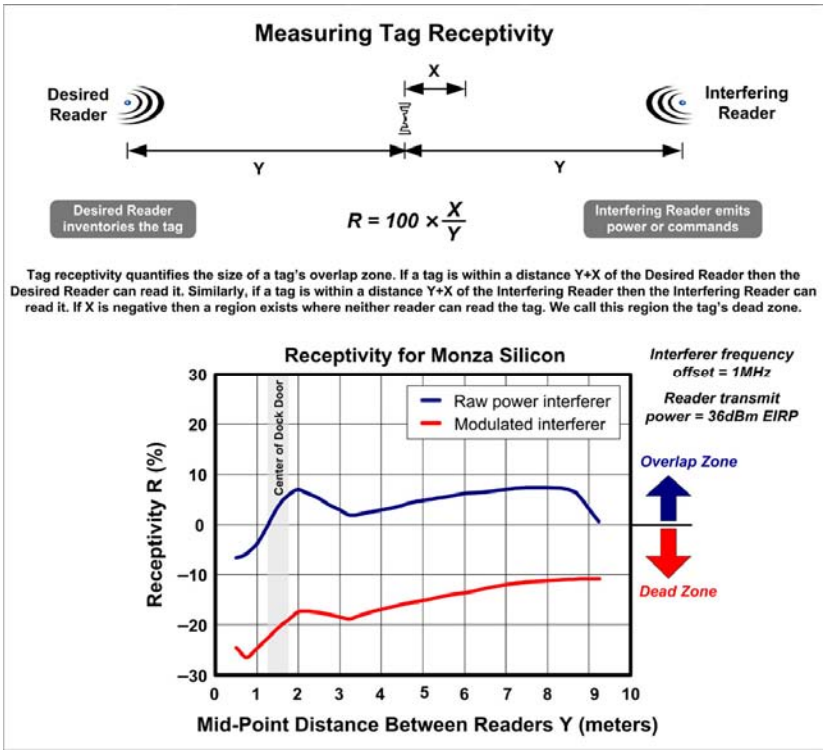
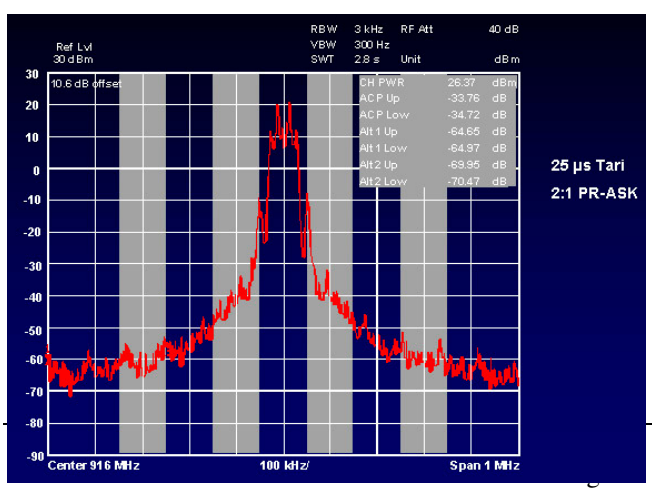


Figure 4. Tag receptivity as measured by Impinj on an ISO18000-6C tag

From the graph it can be seen that a tag can be closer to the interfering reader than the wanted reader if the interferer is unmodulated (ie. transmitting a CW carrier only). If the interfering reader is modulating (ie. sending commands) then the tag needs to be 20% closer to the wanted reader and there is a dead zone where the tag cannot be read at all. The purpose of this test is to demonstrate the ability of a tag to work properly even in the presence of an interfering signal.

Appendix 3 shows the results of tests conducted by Rene Martinez and A Witherspoon of Intermec Technologies Inc. Those tests indicate that a frequency separation of 1 MHz or more between co-located readers (i.e. readers in adjacent portals) is required to ensure maximum interference rejection by a typical tag.

READER SPECTRUM OCCUPANCY



Radio transmitters occupy a finite spectrum. This spectrum occupancy is a function of the transmitter noise (phase and amplitude) and the modulation. Modulation bandwidth is a function of the waveform, modulation depth and the modulating frequency (bit rate in terms of a data signal). Transmitter spectrum occupancy may be expressed in terms of their Power Spectral Density (PSD).

Figure 5 shows the measured PSD plot of a reader transmitter using Phase Reversal (PR-ASK) modulation of a 2:1 PIE signal having a Tari of 25µs according to ISO 18000-6. Note that at 500kHz removed from the carrier, the total noise is at a level of almost -90dB with respect to the carrier. This signal meets the spectral mask specified for "dense reader mode" in ISO 18000-6.

Figure 5. Reader Transmitter PSD plot, PR-ASK, Tari = 25µs.

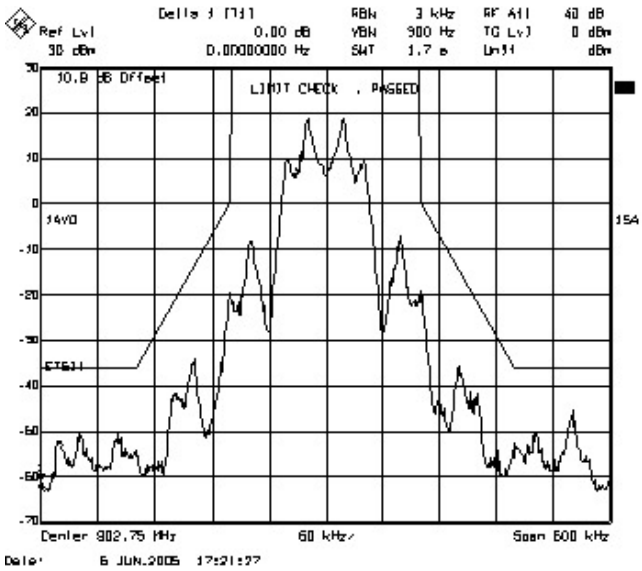


Figure 6 shows the measured PSD plot of a reader transmitter using PR-ASK modulation of a 1.5:1 PIE signal having a Tari of 16.67µs. The emitted noise easily meets the occupied bandwidth mask specified in ETSI EN 302 208.

Figure 6. Reader transmitter PSD plot, PR-ASK, Tari = 16.67µs

From these plots it can be seen that the noise level in the adjacent channels is at a level of only -40dBm which would have the effect of blocking a tag backscatter to a reader in an adjacent portal if the path loss was less than 30dB. However if the adjacent portal operated on a channel 600kHz removed then only 10dB isolation would be required.

THE SOLUTION

There is no single solution, however there are a number of methods that can be applied to the problem which go a long way to making possible the use of large numbers of RFID readers in a close reader neighbourhood while at the same time satisfying the users' needs.

REDUCE THE NUMBER OF HIGH POWER CHANNELS AND PERMIT CO-CHANNEL TRANSMISSIONS

The most important principle is to operate RFID systems as "two-frequency" systems so that the higher power readers transmit on a first channel and the tags reply on a second channel. This is the principle embodied in the international standard ISO/IEC 18000-6:2004 FDAM Annex I.

In the present scheme (EN 302 208) where there are 15 channels of which 10 are currently for high power use, this is difficult to achieve. However if the emitted power requirements in Annex 11 were modified such that only 4 high power channels were allowed and the rest were limited to 100mW or less, then it would encourage the use of two-frequency operation. This scheme relies on permitting multiple readers to transmit on a common frequency (frequencies) so that more than one reader can operate at any one time. This implies that either some form of synchronisation is required or that the Listen Before Talk threshold be modified.

For example using the channel numbers from CEPT Rec 70 03E, Annex 11 Edition October 2004 as listed in Annex 1 of this white paper:

Readers transmit on channels 4, 7, 10 and 13.

Tags backscatter their replies at 300kHz removed on the boundaries between channels 1and 2, 5 and 6, 8 and 9, 11 and 12 and 14 and 15.

Note: the reason for backscatter on channel boundaries is to avoid the centre of the intermediate channels so as to provide some protection to and from other [non-rfid] SRD devices.

Figure 7 shows spectrum proposal. Readers are transmitting on Channels 4 and 7. Reader on Channel 4 is modulating and talking to a tag population, reader on channel 7 has already commanded tags and is in the CW mode while tags reply. It will be seen that there is a clear separation between reader transmissions and tag replies.

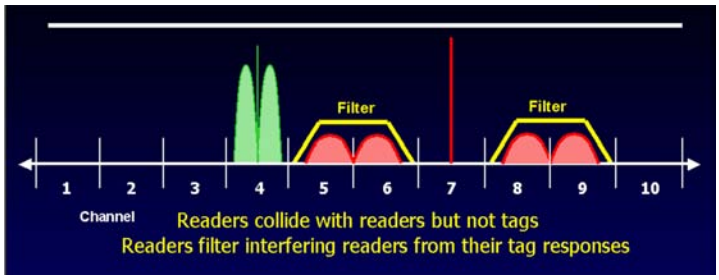


Figure 7. Proposed spectrum plan for Europe.

This satisfies the accepted spectrum management principle of keeping devices of similar power levels together and maintaining separation between devices having widely disparate power levels. This means that communication between reader and tags is "2 frequency full duplex".

This can be achieved by operating the tag reply at a baseband data rate high enough to remove the backscatter signal from in-channel to an adjacent channel – example: 320 kb/s will place the sideband at 320kHz removed from the reader transmission. Alternatively it can be achieved by using the dense reader mode (sub-carrier mode) in ISO 18000-6C.

Because readers now listen for tag replies outside their channel, there is no need to have a clear channel before transmitting, as long as the desired transmission (protection ratio) is at least 13 – 20 dB stronger at a wanted tag than another co-channel reader.

It was shown earlier in tag receptivity (and in annex 3) that multiple readers can transmit on the same channel provided that the signal strength differential (protection ratio) between wanted and unwanted signals at the tag is greater than 13 – 20 dB. In the case of dock doors, this can be achieved by operating readers in adjacent portals at a frequency separation of at least >600kHz, but it is even better if reader frequencies can be separated by 1.2MHz. In this suggested solution, two pairs frequencies (channels 4 & 10 or 7 & 13) would be used for reader transmitters in a multiple dock door environment such as a distribution centre. The channels in a pair would be alternated at every second dock door. (Door 1 = ch 4, Door 2 = ch 10, Door 3 = ch 4, etc...). The channel pairs could then be alternated with each other in order to provide a listen time before transmit at least every 4 seconds or less. (Door 1 = ch 7, Door 2 = ch 13, Door 3 = ch 7, etc...). It was pointed out by one contributor to this white paper that it is possible by improving tag filtering to use channels 4 & 7, or 7 & 10, or 10 & 13 in adjacent dock doors. Martinez (appendix 3) however shows that this is not ideal with current generation silicon.

SYNCHRONISED LISTEN BEFORE TALK

A central LBT receiver/controller is used to send synchronisation commands to individual readers. This ensures that all readers know which channel to use and allows readers to transmit simultaneously on common channels by steering readers to those channels.

One method would use the central LBT receiver to define a maximum time window for a particular channel. All readers would then be able to transmit on demand within the window. The window would begin for a particular channel when a first reader transmits in that channel. Under EN 302 208, the maximum window size would be 4 seconds.

Example: On the trigger of a read event, Reader A is allocated channel 4 by the central LBT receiver and begins reading its tags; it has a maximum of 4 seconds on channel 4. Reader B has a trigger event at T + 1 second and begins reading; it has only 3 seconds available to complete its read before switching to another available channel. Reader C has a trigger event at T + 3 seconds; it therefore has only 1 second in which to read on channel 4. At the end of the 4 second window, the LBT searches for another free channel and allocates this to the readers, and so on.

The drawbacks with this methodology are that

- It prevents true event driven reading if all available channels are in use by transmissions (non-specific SRDs, handheld readers etc.) not under the RFID LBT receiver control.
- It does not allow for situations in closely packed Industrial environments where adjacent reader systems are established and operated by different companies and where synchronisation is not possible or desirable.

There are several proposals under consideration within ETSI Task Group TG/34 so these will not be discussed in detail in this white paper.

SMART LISTEN BEFORE TALK

"Smart" RFID readers listen for other RFID readers on their channels and if they recognise other RFID readers then they transmit but if the transmission is not an RFID reader but another SRD, then the reader holds off until it finds a clear channel. Smart LBT may be clever enough to tell if the co-channel reader is in an adjacent dock door portal or further away – if it is in the adjacent portal then the reader should look for another frequency so as to avoid jamming the adjacent portal reader.

RFID readers with smart LBT may solve the problem of how to synchronise readers and may also improve event driven operation by improving channel availability. It achieves this by removing effective channel occupancy by other readers. However, it does not fully resolve the problem of channel non-availability due to other non-RFID SRD If all channels are busy then it is quite possible that tags will pass the reader before the reader is allowed to transmit.

The use of Smart LBT could be an interim solution and go part way to resolving some of the problems identified in the 'PROBLEM' section above, until such time that the LBT parameters can be revised. More practical work is required to determine the feasibility and practicability of such a scheme.

GIVE RFID READERS A PRIORITY WEIGHTING ADVANTAGE

RFID compared with most SRD systems have different channel availability requirements. RFID readers must be able to transmit and read tags present, immediately on an event trigger. If they cannot, then tags may arrive and leave the reader field before they can be read and are therefore lost forever. However, most SRDs are able to wait or hold for a short period of time without suffering any penalty.

In those regulatory jurisdictions where there are no wideband systems in use, or where there are only SRDs, it may be possible to raise the Listen Before Talk (LBT) threshold on only the 4 high

power channels, while retaining the present LBT threshold on the 11 low power channels. This would have the effect of giving RFID readers a priority weighting (on 4 channels) in order to overcome the potential for lost reads due to a reader not being able to transmit immediately on an event trigger. (i.e. when the tagged item enters the reader field).

Even though this may at first seem like a penalty on non-specific SRDs, in fact it helps them. If the expected number of installed RFID readers comes to pass, then high power readers will for all practical purposes dominate all 10 high power channels, giving SRDs almost no look in. The suggested solution provides 6 additional lower power channels for non-specific SRDs which will transmit at power levels of <100mW. (The majority of SRDs work at radiated power levels of less than 25mW).

RECOMMENDATIONS

1. As soon as possible, introduce a form of smart Listen Before Talk to permit multiple readers to transmit simultaneously on the same channel where there is a means to synchronise them or a mechanism to distinguish between other RFID readers and SRD devices.
2. In the medium term, investigate the practicality of modifying the radiated power output requirement such that the 2 Watts ERP operation be limited to Channels 4, 7, 10 and 13 and the power output on channels 5, 6, 8, 9, 11 and 12 be reduced to 100 mW.
3. In the longer term, determine whether it is possible to provide RFID readers with a priority weighting advantage on channels 4, 7, 10 and 13. (to allow RFID to jump the LBT queue on these 4 channels for true event driven operation.)
4. Retain all the other attributes contained within EN 302 208 and Rec 70-03E Annex 11.

The Effect of the above

- Large numbers of readers may be deployed in the same RF neighbourhood.
- Readers will be able to operate asynchronously of each other and be truly event driven.
- Readers will not desense each others' receivers except when they are very close to each other, such as in adjacent dock doors.
- Tag backscatter transmissions will be 'in the clear' on low power LBT channels and therefore there will be no danger of blocking from distant high power users of the channel.
- Low power [SRD] co-users of the band will be provided with an additional 6 channels where they will be protected from High Power reader transmissions.

Acknowledgements

THANKS TO CHRIS DIORIO OF IMPINJ FOR PROVIDING DIAGRAMS AND TEST RESULTS AND R MARTINEZ AND A WITHERSPOON OF INTERMEC FOR THEIR TEST REPORT.

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ANNEX 1

Channel numbers – 865 – 868 MHz Band
From CEPT Rec 70 03E Annex 11, October 2004

Channel	Centre Freq	Current Pwr	Proposed Pwr
1	865.1	100mW	100mW
2	865.3	100mW	100mW
3	865.5	100mW	100mW
4	865.7	2W	2W
5	865.9	2W	100mW
6	866.1	2W	100mW
7	866.3	2W	2W
8	866.5	2W	100mW
9	866.7	2W	100mW
10	866.9	2W	2W
11	687.1	2W	100mW
12	867.3	2W	100mW
13	867.5	2W	2W
14	867.7	500mW	500mW
15	867.9	500mW	500mW

ANNEX 2
TRAFFIC CONCEPTS

DEFINITIONS

Traffic Quantity – is the aggregate occupancy time of a traffic path or group of paths expressed in hours (or call-hours). Note: it does of itself not refer to any particular period of time. The dimension of the unit of traffic quantity is ***t***.

Traffic Intensity – sometimes referred to as **Traffic Density** is the traffic quantity in a traffic path or group of paths per unit of time and is expressed in erlangs (**E**) or traffic units (**TU**). 1E = 1 call-hour per hour.

One erlang of traffic intensity in one traffic path, means continuous occupancy of that path, irrespective of the duration of that occupancy.

Grade of Service – is the probability, that during a specified period of peak traffic, a call offered to a group of trunks or circuits will fail to find a free circuit at first attempt.

QUEUING THEORY

Think of a bank with a number of tellers. It is a system providing a service of random duration to customers requiring service at random times. The actual service (banking) is performed in what is known as a *Service Channel* (teller position). The duration of the service is from the actual time that the customer arrives at the teller position to the actual time that he leaves. This duration is known as *Service Time*. (In telephony, the time that the facility is busy, is referred to as the *Holding Time.*) This could vary from a few seconds to hours. In a multi-channel system where there are a number of positions, an arriving customer will demand service from an available teller. If all positions are busy, an arriving customer can:

- Choose to wait until a position becomes free (*Queue*)
- Go away and try again later (*Retry*)
- Give up and not return. (*Lost*)

Queuing theory investigates stochastic (random) service systems and helps to solve such problems as; how many service channels are needed to satisfy customer demand while providing an adequate service at the busiest time. A perfect system would be one in which all customers are served immediately on their arrival at the bank. This is clearly not always possible or economically viable. So, what is practical, is to ensure that there are enough service positions to provide for the number of customers demanding service at a given time.

In the case of a telephone network it is necessary to provide the number of trunks as there are telephone conversations at a given time. However this number is random. If n subscribers are connected to a network, the number of paths connecting two at a time is $n(n - 1)/2$, so that the

actual number of conversations will vary between zero and $n(n - 1)/2$. As we said earlier it would be impossible to provide for the upper limit, thus the probability of connecting all calls cannot be made 100%. If the facility is busy arriving calls will need to be blocked (i.e. rejected or delayed). Calls are said to be *lost* if rejected or *held* if delayed. A caller who is delayed may either wait until there is an available server or keep re-trying until a server comes free.

The quality of service is given by the fraction of all calls offered (demanding service) to calls blocked at the busiest time.

The number of calls offered to a traffic handling system per unit time is a random variable; and so is the time for which each subscriber uses the system. Let the mean frequency of offered calls (call rate) be v, and let the mean holding time be h. Subscriber demand, referred to as *load* L is proportional to these two quantities and is given as:

$$L = vh$$

The basic problems to solve are:

- For a given *load* how many lines c are required to handle the traffic if the blocking probability is not to exceed a certain value? In other words, what load can be handled by c lines, if the blocking probability is not to exceed a certain value?
- Given the load offered to a given number of lines what is the probability that a call will be delayed by more than a given time t?

There are two basic systems:

- The loss system, where a customer is blocked and never returns for whatever reason
- The delay system, where a customer is blocked but is prepared to wait until the service becomes available.

The number of customers, Q in a queue is sometimes limited to a certain maximum number. This results in a combined loss and delay system; for $Q = 0$, it turns into a loss system and for $Q = \infty$ into a pure delay system. There are endless varieties of these basic types depending on the distribution of customer arrival and the distribution of service time.

The Poisson Distribution

During a given time interval, some customers will demand service and others will not. It is impossible to find out which customer will call next. Because calls are assumed independent, it means that a call made by one subscriber in no way affects the probability of a call by any other subscriber. It is also assumed that the probability of a customer demanding service during a small time interval $(t, t +)t)$ is constant for all t. This means that this probability is the same at all times if the length of interval $)t$ is kept constant. Because this probability is proportional to $)t$ we can write:

$$P(1 \text{ call during })t) = v)t, \qquad v = \text{const.}$$

where it is assumed that $)t$ is so short that either no call will occur or only just one call will occur in it but that two or more calls will only occur with negligible probability.

It has been found that the number of calls initiated during a given time interval has Poisson distribution. The same is true for trunked radio systems. The number k of arrivals in a fixed time interval is random and its probability distribution is Poisson.

It has also been shown by observation in both telephone systems and trunked mobile radio systems that where the initiated calls have a Poisson distribution, the service time (holding time) i.e. the time that a channel is in use by a single subscriber, has an exponential distribution.

TRUNKED NETWORKS

The system of Listen Before Talk (LBT) used in EN 302 208, is the same as the system used in telephone switching networks. A common pool of servers or trunks (Radio channels) is shared among a much larger pool of subscribers or callers (RFID Readers). The subscribers (readers) only access the servers (channels) as required (when reading tags). Trunking permits a highly efficient use of available channels because not all subscribers need to call (readers read) at the same time. However it is important that a subscriber can access a server when required. Grade of Service is a measure of this availability.

The Grade of Service in the telephone world is a measure of the probability that a [offered] call will be blocked [due to the non-availability of a channel] and thus lost. It refers to the anticipated ratio of calls “lost” at the first attempt to the total number of attempts to establish a connection during a specific period of time.

In the RFID world, a blocked [therefore lost] call is one when there is no free channel for use by a reader, when a read event is triggered. The Grade of Service is the ratio of unsuccessful trigger events to the total number of trigger events.

In the telephony world a blocked call can be re-tried many times, either by queuing the caller or by repeated re-tries by the caller. However, in the RFID world, if a read event is blocked, the items/s to be read may pass by the reader before the reader has a chance to read them. Any automatic queuing therefore must be of very limited duration. For the purpose of this paper it will be assumed that queuing is not practical.

The theory used to anticipate the Grade of Service was developed by the Danish scientist Erlang, after whom it is named.

Loss Probability, is the ratio of customers unable to obtain service (obtain a channel) to the total of arrivals seeking service.

The Erlang-B equation is given as:

$$P = (y^n / n!) / \left(\sum_0^n y^n / n! \right)$$

where;

P = probability of loss or blocking
n = number of trunks (channels)
y = traffic offered (in erlangs)

(Note: an Erlang is unit of traffic density expressed as quantity of traffic in unit time. One Erlang is equal to 100% occupancy of a channel and is expressed as 1 call-hour per hour where a call-hour is the aggregate occupancy time of a traffic path or group of paths.)

The probability of blocking is equal to the probability that a call will find all servers already in use.

Calls can be lost in this arrangement so actual traffic load that can be handled will be less than that offered by a factor (1 – P).

The theory above has several underlying assumptions.

1. Calls are assumed to arrive at random and users whose calls have been blocked cannot immediately retry.
2. Call service time, i.e. channel occupancy is exponentially distributed
3. The number of traffic sources is essentially infinite i.e. they are all drawn from the same exponential population.
4. The offered load is known

In the case of 10 channels the following table illustrates the traffic intensity for different Grades of Service.

Grade of Service	Traffic Intensity

1 in 1000	3.09
1 in 500	3.43
1 in 200	3.96
1 in 100	4.46
1 in 50	5.08
1 in 20	6.22

From the above, it can be seen that for a 1% probability that a channel will be busy when required (calls lost), a 10 channel system can tolerate a loading of 4.46 Erlang. (system is busy for 44.6%) of the time.

Appendix 3

Reader-on-tag Interference

Attachment to ISO-IEC JTC1/SC31/WG4/SG3 Dense Reader Ad Hoc White Paper

Authors: R. Martinez & A. Witherspoon, Intermec Technologies Inc.

Date: 12 January 2006.

INTRODUCTION

RF systems placed in close proximity can interfere with each other and degrade transaction throughput. In passive RFID systems, identification rate is a transaction throughput figure of merit, and ideally where two (or more) systems placed in close proximity with each other will not interfere and degrade the identification rate of either system.

RF interference between systems occurs when a source of undesired RF transmissions corrupts the ability of an RF receiver to decode information. In interference analysis, a “source-on-victim” terminology describes the effect of interference from an undesired transmission source on a victim receiver. In RFID systems, both tags and readers have receivers and both are sources of transmissions. Figure 1 shows four potential interference mechanisms.

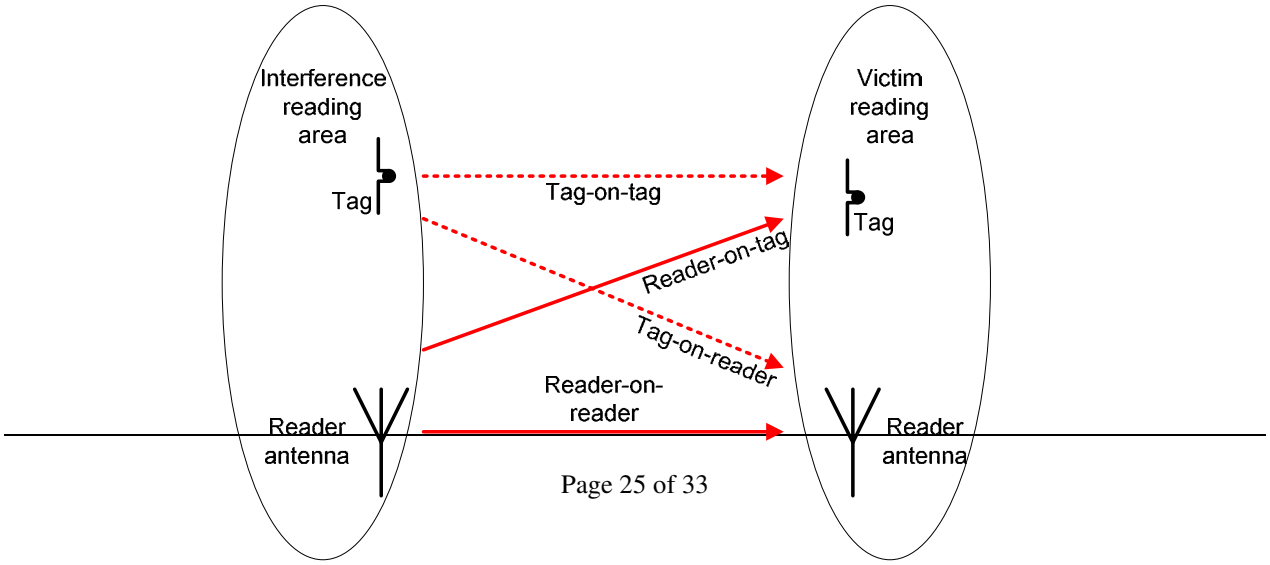


Figure 1 Four interference mechanisms for RFID system-on-system interference

Transmissions from readers are extremely large compared to tags, so the dominant mechanisms to consider are reader-on-tag and reader-on-reader interference as shown by solid lines. Reader-on-reader interference can occur over tens or even hundreds of meters, but ensuring that readers have 'clean' emissions, can greatly mitigate interference. Currently, reader-on-reader interference limits the proximity of RFID systems to each other, however reader-on-tag interference is an often overlooked factor. Reader-on-tag interference is therefore the focus of this document.

MEASUREMENTS OF TAG INPUT SIGNAL

Reader-on-tag interference occurs in an RFID system when the [unwanted] transmissions from a nearby reader interfere with a tag's ability to decode a desired signal, as shown in Figure 2. Most RF devices have frequency selective filters which select the desired transmission and reject unwanted signals. Passive UHF RFID tags are by their nature wide-band devices and therefore have no inherent "frequency" selectivity. Instead, the tag "sees" the largest amplitude signal as the desired signal, and and uses amplitude selectivity to reject a smaller, interfering signal. Tags can successfully decode the desired signal if, and only if, the desired signal is large relative to the interfering signal.

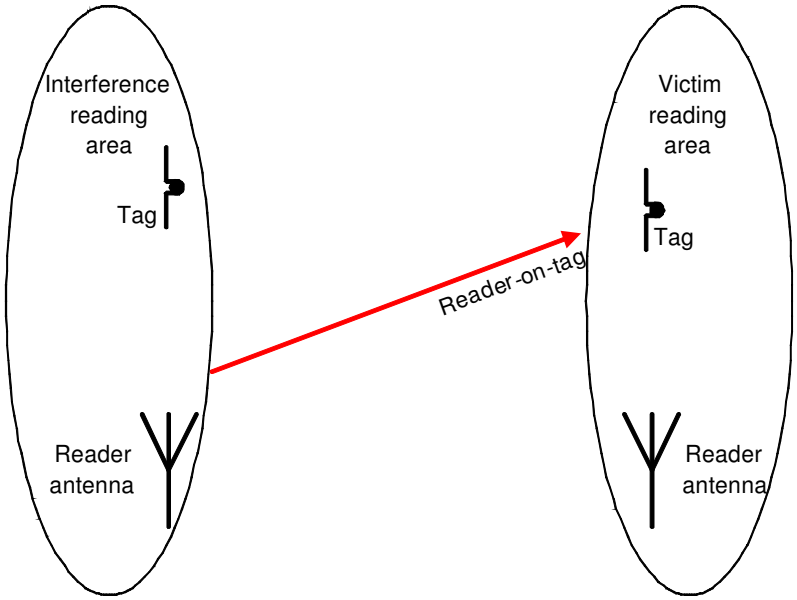


Figure 2 Reader-on-tag interference mechanism

Depending on the radio regulations and the RFID system configuration, two or more readers in close proximity to each other may operate on different frequencies creating a beat note (heterodyne) at a frequency equal to the difference between the RF frequencies of two reader transmissions. If this beat note is outside the passband response of a tag, the tag is able to reject the beat note and select the desired signal. The ability of the tag to select the desired signal is a function of its design and a function of the reader signals the tag needs to decode. This mechanism is discussed below. The amplitude and beat frequency selectivity mechanisms become more intuitive by looking at the receiver input of a tag when both interfering and desired readers are transmitting. Figure 3 is a measurement of the input signal into a tag when only a desired reader is transmitting. The upper half of Figure 3 is a frequency domain plot of the input signal and shows no other transmissions to either side of the desired carrier frequency of

866.1MHz. The lower half of Figure 3 is a time domain plot of the RF envelope that a tag receives. Because there is no interference, the maximum and minimum values of the time domain signal are constant over the duration of several bits, and note the signals are well behaved with monotonically increasing and decreasing transitions between the nominal minimum and maximum values

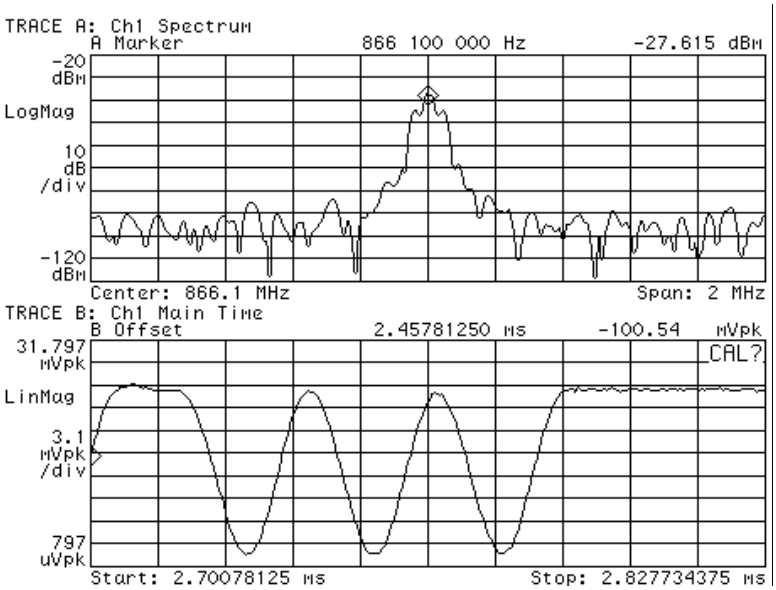


Figure 3 Frequency and time domain of tag input signal without interference

Figure 4 shows the same plots after introducing a second reader transmission at 866.9MHz as can be seen in the frequency domain plot. The desired signal operates at 866.1MHz, so an 800kHz beat frequency is generated. As seen in the time domain plot, the beat frequency creates a rapidly varying sinusoidal interfering ripple over the desired reader signal. A simple low pass filter can eliminate the ripple provided the ripple occurs fast enough and the beat frequency is high enough.

Figure 4 Tag input signal with interference at 800kHz offset

As the difference in carrier frequencies decreases and the beat frequency decreases, the rate of the ripple decreases and may begin to impact the tag's ability to decode data. The frequency of the interfering reader was reduced to 866.5MHz in Figure 5, and the rate of the ripple decreases to 400kHz. At some point, the ripple cannot be filtered and will impact the tag's ability to decode the wanted signal modulation

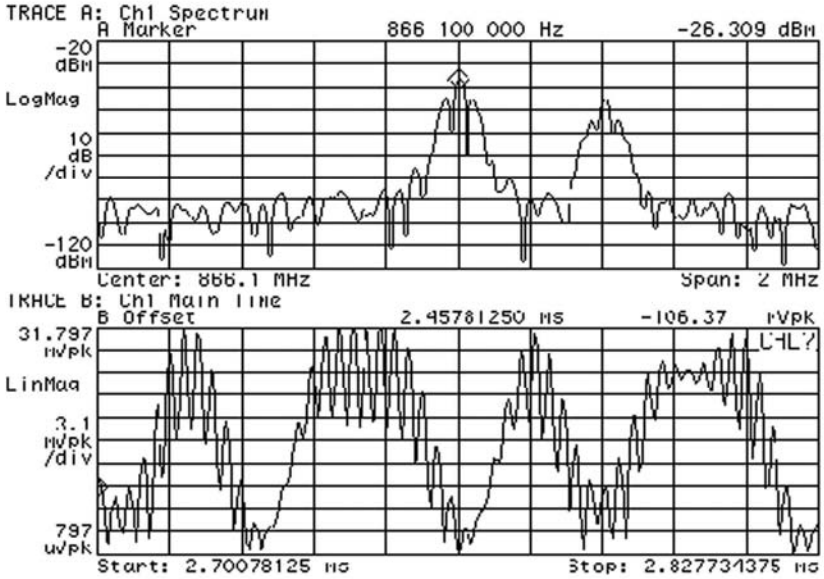
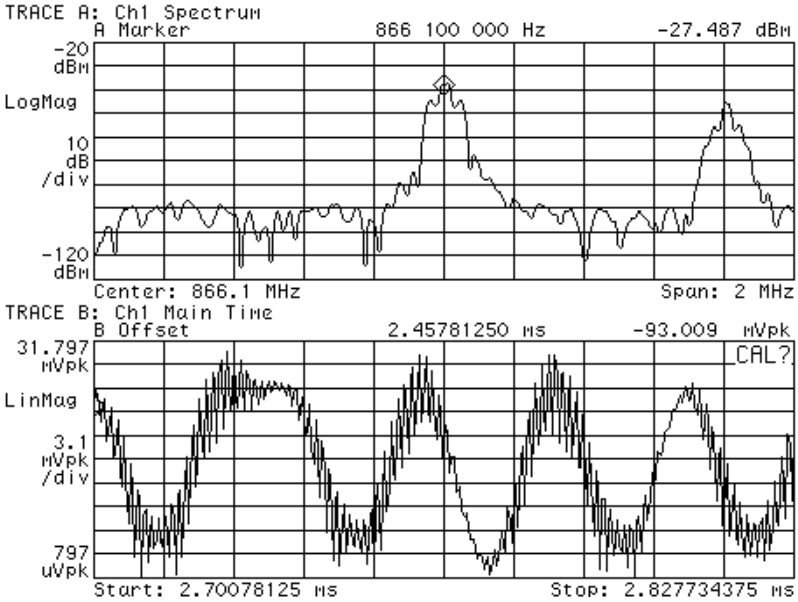


Figure 5 Tag input signal with interference at 400kHz offset

If the wanted and unwanted transmissions have identical frequency and phase, there will be no beat frequency. However, because most readers operate independently of each other there will in practice always be a difference in frequency between their transmissions and a slow beat



frequency will exist. For example, the draft standard ISO-IEC 18000-6C standard permits up to ±10ppm of frequency error for "dense" readers over a limited temperature range, which could

correspond to a slow beat frequency as high as 18kHz. Figure 6 is the measurement of the input signal into a tag with co-channel operation of desired and interfering readers. In the time domain, note the minimum and maximum values vary greatly from bit to bit, which is caused by a slow beat signal. Decoding this signal becomes difficult, especially when the interfering reader also modulates – with no large beat frequency, the interfering and desired signals become very similar and corrupt the desired signal even more.

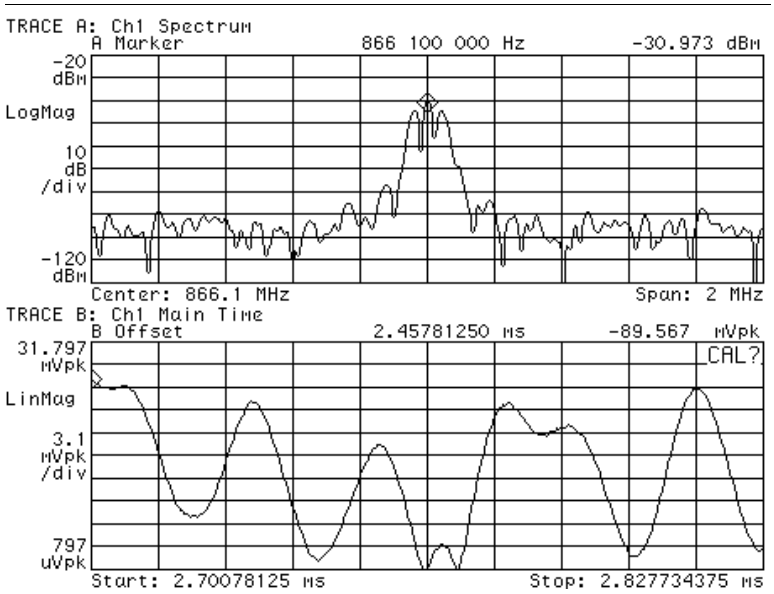


Figure 6 Tag input signal with co-channel interference

Regardless of the complexity, all passive UHF RFID tags detect and demodulate an average of the RF envelope to decode information from the reader. Figure 7 is a simplified view of tags demodulation circuit.

The envelope detector and averaging circuit is equivalently formed by the diode and a parallel resistor-capacitor combination. If the beat frequency is significantly faster than the time constant of the demodulator, the demodulator assists by rejecting the interfering ripple. As the beat frequency decreases, the demodulator's filter is less effective in rejecting interference. (Note: a high pass filter after the demodulated output voltage could remove very slow beat frequencies, but not if the beat frequency is close to the frequency of the information signal from the desired reader.)

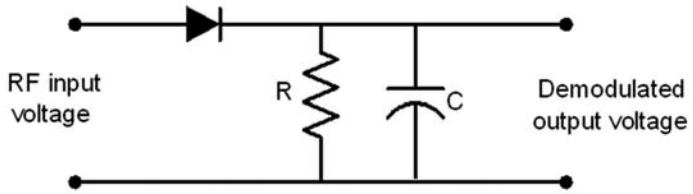


Figure 7 Simplified view of tag demodulation

Reader on Tag Interference Results

In order to quantify the reader-on-tag interference rejection capability of a tag, a consistent measurement method is required. Figure 8 is a diagram of a conducted test used to isolate and measure reader-on-tag interference. In a conducted environment without antennas, a desired reader on the left of the diagram communicates via attenuators, circulators, and cables with a tag IC on the right. Two circulators isolate the communication links between the tag and the desired reader into the upper reader-to-tag link and lower tag-to-reader link. The interfering reader is introduced into the reader-to-tag link via an adjustable attenuator. A real time analyzer monitors the lower tag-to-reader link to corroborate with the decoder on the desired reader that the tag is operating. An adjustable attenuator in the reader-to-tag link can effectively change the range between the tag and the desired reader for different interference measurements.

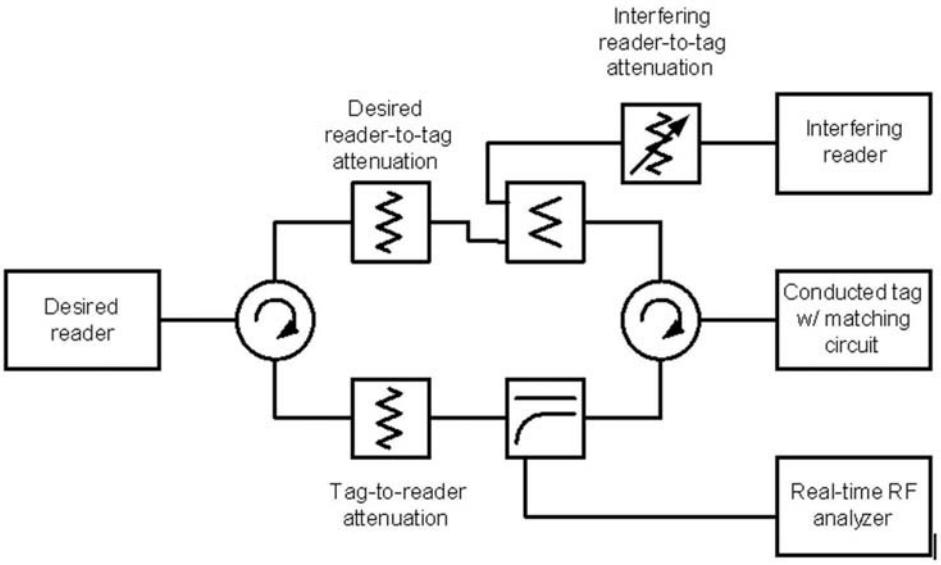


Figure 8 Reader-on-tag interference test set

The analysis of interference can take several forms, and for RF interference, a common analysis is the capacity for interference rejection, such as an “image rejection ratio”. In this analysis, a channel interference rejection ratio (CIRR) is defined to express the tag’s capacity to reject interference, and in the future, CIRR can be extended a reader’s capacity to reject interference.

The channel interference rejection ratio (CIRR) measures a receiver’s ability to reject interference, and for tags, CIRR will depend on the offset frequency between the desired and interfering signals. For a given offset, CIRR is the maximum acceptable ratio of interference-to-desired power for successful reception. Better rejection and selectivity appears as higher CIRR values, and on a dB scale, CIRR > 0dB signifies successful reception even if the interferer is stronger than the desired signal. Worse rejection and selectivity appears as lower CIRR values, and CIRR < 0dB signifies successful reception only if the desired signal is stronger than the interfering signal.

The tag's measured rejection capacity, or CIRR, as a function of 200kHz channel offset frequencies is in Figure 9. Data sets for the CIRR measurements were gathered from the same Gen2 chip manufacturer, for different Gen2 chips, for different tag ranges from 50% to 100% of maximum range, and for different interfering reader emissions of CW and modulated. For low offsets of three channels or less (≤600kHz frequency separation), the ability of a tag to reject interference is greatly limited compared to high offsets of five channels or more (≥1MHz). Specifically, the interference for low channel offsets must be reduced by over a factor of ten in power (10dB) compared to the high offsets.

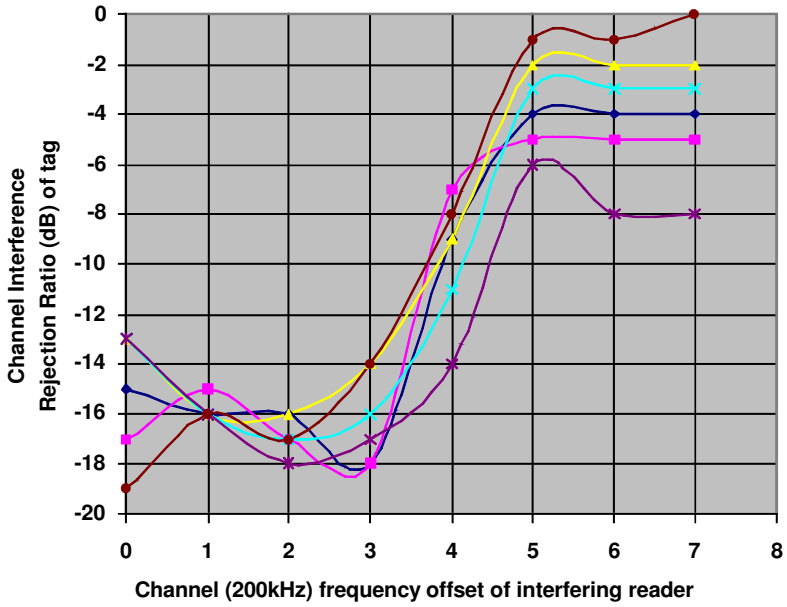


Figure 9 Tag channel interference rejection ratio as a function of channel offset frequency

Translating the rejection ratio results into separation distance in real environments can take several forms. The most basic form is to consider an unobstructed "RF-friendly" environment with free space propagation. Figure 10 is a graph of the minimum reader-to-tag distance for reader to prevent interference into a tag. The graph assumes the tag is 3 meters away from a desired reader and assumes the orientations from the tag to the desired and interfering reader antennas are the same - for example, the tag is in the bore-sight of both the desired and interfering reader antennas

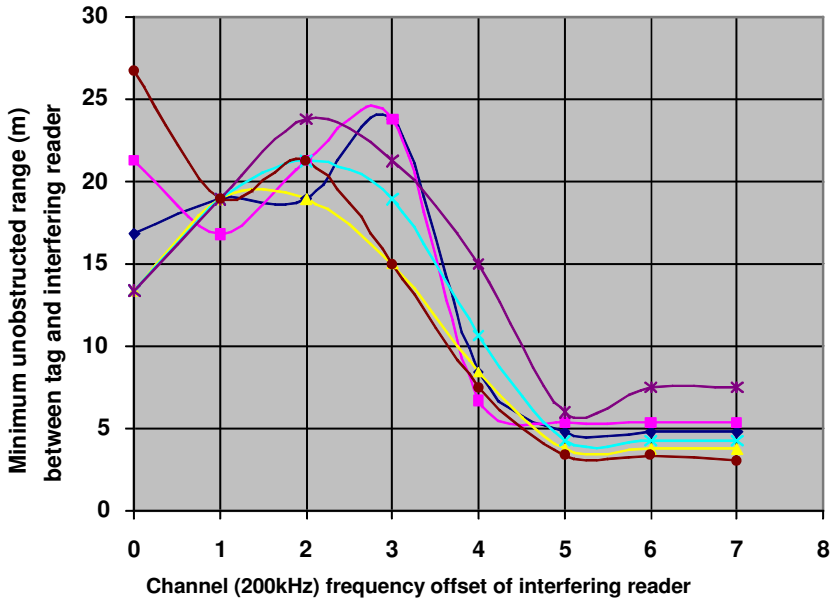


Figure 10 Minimum ranges between interfering reader and tag versus channel offset

CONCLUSIONS

The collected data for the same ISO-IEC18000-6C tag Integrated Circuit model indicate that the carrier frequencies of the desired and interfering reader should differ by more than 800kHz to significantly reduce reader-on-tag interference. Tags need significantly more (13-20dB) desired signal power if the difference in the reader carrier frequencies is less than 800kHz, and tags need nominally (~6dB) more desired signal power if the difference is more than 800kHz. Transitioning from high and to low frequency offsets requires the interference be reduced by over 10dB, which corresponds to tripling the distance between the interfering reader and the tag in a free-space environment.

Different or future models of the ICs may have different rejection ratios or may have an interference offset transition frequency that differs from 800kHz. However, the tag must receive the modulation from the reader, so rejecting frequencies that are similar to the modulation frequency is very difficult. Therefore the frequency difference between readers in close proximity should be outside of the passband response of the tag. Tag IC designers should continue to work on improving the interference rejection resilience of their designs so as to reject all types of interference.