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Technical Report

Electromagnetic compatibility and Radio spectrum Matters (ERM); Technical characteristics of RFID in the UHF Band; System Reference Document for Radio Frequency Identification (RFID) equipment; Part 1: RFID equipment operating in the range from 865 MHz to 868 MHz

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

The present document includes necessary information to support the co-operation under the MoU between ETSI and the Electronic Communications Committee (ECC) of the European Conference of Postal and Telecommunications Administrations (CEPT).

The present document is part 1 of a multipart deliverable covering Technical characteristics of RFID in the UHF Band; System Reference Document for Radio Frequency Identification (RFID) equipment, as identified below:

Part 1: "RFID equipment operating in the range from 865 MHz to 868 MHz";

Part 2: "(UHF) RFID - Additional spectrum requirement".

Introduction

The current requirements for RFID at UHF are governed by several inter-related documents. The two most relevant European documents are the ERC Recommendation 70-03 and the ETSI Standard EN 302 208 [2]. In addition the EC has recently approved its Decision on RFID at UHF. The recommendations in annex 11 of ERC/REC 70-03 [1] form the basis for the national interface regulations. Currently RFID devices transmitting at levels up to 2 W e.r.p. (33 dBm) are constrained to use 10 channels, each of 200 kHz in the range 865,6 MHz to 867,6 MHz. Before each transmission the RFID interrogator must perform a listen before talk (LBT) cycle for a period of 5 ms. It may only transmit if no signals are received at levels greater than 0,25 pW (-96 dBm). The maximum period of continuous transmission is 4 s, after which, if the system stays on the same channel, transmission must cease for a period of not less than 100ms. If the interrogator changes channel it may immediately transmit (subject to the LBT_{rfid} requirements). If the LBT_{rfid} check detects a busy channel, the interrogator can search other channels, until a free one is found. Alternatively the interrogator can wait on a channel until it becomes free.

This worked well in low reader density environments. In real-world deployments the reader density is not random, but frequently is in a series of clusters. A distribution centre or manufacturing facility, for example, may have many readers in close proximity. The spacing to the next cluster in another facility is random but is always greater than the distance between readers within the cluster. In such higher density environments the existing 10 channels soon become saturated. The ability for readers to switch frequencies to gain channel access means that in dense reader applications, all of the channels are occupied for much of the time. For example in order to provide acceptable access to channels at a distribution centre during busy loading periods, only 20 dock doors (i.e. interrogators) can be operated simultaneously. This is clearly a significant operational limitation.

In dense reader environments an SRD will have difficulties in getting access to a channel, as it will have to compete with other RFID interrogators. This is further complicated by the fact that unless the SRD is physically close to the interrogator it will not be detected by the interrogator's LBT_{rfid}.

The problem of channel capacity is overcome by interrogators simultaneously sharing the same channel. Under the existing regulations this is only possible by means of synchronization. This technique requires that the mandatory LBT_{rfid} operation is synchronized in time between a group of interrogators. It has proved successful in tests and there are several methods of synchronization that permit this type of operation. It has further been shown in large scale tests on synchronization that only 4 channels are absolutely necessary, provided these are evenly spaced across the 10 designated channels. The release of the remaining channels from high power use also brings benefits to SRDs since co-existence with the low level response from the tags is more readily achievable.

While synchronization overcomes the problem of channel capacity, it still lacks operational certainty. An outside interfering signal can quickly bring a busy distribution centre to a halt. This is a real concern to end users, and for many makes the technology unacceptable. Consequently end users have been pressing for the removal of LBT_{rfid} from the four high power channels as a potential solution.

The present document analyses the impact of removal of LBT_{rfid} from the four high power channels and its effect on both RFID and other generic SRDs in the band. It also proposes a new channel plan for enhanced spectrum efficiency for RFID as well as generic SRDs operating in the range of 865 MHz to 868 MHz.

1 Scope

The present document applies to RFID systems operating in the UHF frequency band from 865 MHz to 868 MHz.

It defines RFID systems that are used in item management, logistics and in a wide range of applications such as:

- automatic article identification;
- asset tracking;
- airline baggage handling;
- security and alarm systems;
- waste management;
- proximity sensors, anti-theft systems;
- location systems;
- data transfer to handheld devices;
- automotive and general manufacturing automation;
- wireless control systems;
- animal identification; and
- transport and logistics.

Most of these applications require reading ranges of at least 2 meter that cannot be provided by alternative technologies and at other frequencies.

Logistics and item management together with other major applications must frequently operate in dense installation situations. This is not feasible with the present channel allocation plan as identified in ERC/REC 70-03 [1], annex 11 and in EN 302 208 [2].

The present document describes a new channel plan within the designated frequency range that will lead to a more efficient spectrum usage. It will enable end users to operate RFID interrogators at high densities with greater data throughput, improved reading performance and reliable availability of channels.

The present document does not contain proposals for additional spectrum. This will be defined in TR 102 649-2 [16] .

The proposals in the present document will reduce the number of channels necessary for powering RFID interrogators at power levels up to 2 W e.r.p. This improvement in spectrum efficiency will also benefit generic SRDs using Listen Before Talk with Adaptive Frequency Agility.

2 References

For the purposes of this Technical Report (TR), the following references apply:

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

[1] CEPT/ERC/REC 70-03: "Relating to the use of Short Range Devices (SRD)"; 31 Oct 06.

[2] ETSI EN 302 208 (V1.1.2) (all parts): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Radio Frequency Identification Equipment operating in the band 865 MHz to 868 MHz with power levels up to 2 W".

[3] ETSI TR 101 445 (V1.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM);Short-Range Devices (SRD) intended for operation in the 862 MHz to 870 MHz band; System Reference Document for Radio Frequency Identification (RFID) equipment".

[4] ETSI ERM TG34 meeting 12, documents 12-06, 12-07, 12-11r1: "Report of trial, part 1 and part 2" and "RFID use in Europe".

[5] ETSI/B57(06) 55r1: "RFID a strategic topic for ETSI in 2007".

[6] Directive 1999/5/EC of the European Parliament and of the Council of 9 March 1999 on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity (R&TTE Directive); Official Journal of the European Union, L 91/10 ff, 07 April 1999.

[7] CEPT ECC(06) 097Rev2-annex 17-Report 2nd Mandate for SRDs Strategy.doc: "Final report from CEPT in response to the Second EC Mandate to CEPT to develop a strategy to improve the effectiveness and flexibility of spectrum availability for Short Range Devices (SRDs)" .

[8] ETSI ERM TG34 meeting 14, document 14-18: "Letter from IATA".

[9] ISO/IEC 18000-6 (1st edition; 15 August 2004): "Information technology - Radio frequency identification for item management - Part 6: Parameters for air interface communications at 860 MHz to 960 MHz".

[10] ISO/IEC 18000-6 (2004) AMD1 (E) (19 June 2006): "Information Technology - Radio frequency identification for item management - Part 6: Parameters for air interface communications at 860 MHz to 960 MHz, AMENDMENT 1: Extension with Type C and update of Types A and B".

[11] CEPT ECC Report 37: "Compatibility of planned SRD applications with currently existing radiocommunication applications in the frequency band 863-870 MHz".

[12] EPC™ Radio-Frequency Identity Protocols, Class-1 Generation 2 UHF RFID (Version 1.0.9, 31 January 2005): "Protocol for Communications at 860 MHz to 960 MHz".

NOTE: Available at http://www.epcglobalinc.org/standards/.

[13] Commission Decision of 23 November 2006 on harmonisation of the radio spectrum for radio frequency identification (RFID)devices operating in the ultra high frequency (UHF) band, (2006/804/EG). Official Journal of the European Union, L 329/64.

[14] ETSI EN 300 220 (V2.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25 MHz to 1 000 MHz frequency range with power levels ranging up to 500 mW; Part 1: Technical characteristics and test methods".

[15] ETSI TR 102 436: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) intended for operation in the band 865 MHz to 868 MHz. Guidelines for the installation and commissioning of Radio Frequency Identification (RFID) equipment at UHF".

[16] ETSI TR 102 649-2: "Electromagnetic compatibility and Radio spectrum Matters (ERM), Technical characteristics for RFID in the UHF Band Part 2: (UHF) RFID - Additional spectrum requirement".

[17] ITU-R Report 567-4: "Propagation data and prediction methods for the terrestrial land mobile service using the frequency range 30 MHz to 3 GHz".

[18] ETSI ERM TG34 meeting 12 document 15_04r1: "Report by ETSI ERM_TG34 on ETSI Tests at a Distribution Centre".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

adaptive frequency agility: technique that allows an interrogator to change its frequency of operation automatically from one channel to another

channel: small frequency sub-band within the operating frequency band into which a *Radio Signal* fits

NOTE: Commonly, a *frequency band* is divided into contiguous channels.

dense-interrogator mode: RFID operating mode in which multiple, nearby interrogators can transmit simultaneously in a channel without incurring noticeable performance degradation

listen before talk: action taken by an interrogator to detect an unoccupied sub-band prior to transmitting

NOTE: Also known as "listen before transmit.

transponder: device that responds to an interrogation signal

3.2 Symbols

For the purposes of the present document, the following symbols apply:

E	Electrical field strength
f	frequency
P	Power
R	distance
t	time
λ	Wavelength

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AFA	Adaptive Frequency Agility
C/I	Carrier to interference ratio specified for the victim receiver in dBm
CEPT	European Conference of Postal and Telecommunications Administrations
DFS	Dynamic Frequency Selection
DSSS	Direct Sequence Spread Spectrum
e.r.p.	effective radiated power
ECC	Electronic Communications Committee
EN	European Norm
EPCglobal	Electronic Product-Code/Global
ERC	European Radiocommunication Committee
FHSS	Frequency Hopping Spread Spectrum
I/N	Interference to Noise ratio
IATA	International Air Transport Association
ISO	International Standardization Organization
ITU	International Telecommunication Union
LBT_{rfid}	Listen Before Talk implemented by interrogator
LBT_{srd}	Listen Before Talk implemented by an SRD
LPRA	Low Power Radio Association
MCL	Minimum Coupling Loss
MUS	Maximum Usable Sensitivity
M_{WALL}	Attenuation of WALL
PL	Path Loss
P_{RAD}	RADiated Power

P_{RX}	Victim received power in dBm
R&TTE	Radio & Telecommunications Terminal Equipment
REC	RECommendation
rf	radio frequency
RFID	Radio Frequency IDentification
R_{INT}	INTerference Radius or distance
RM	Radio Matters
Rx	Receiver
SRD	Short Range Device
SRDoc	System Reference Document
TG	Task Group
TR	Technical Report
Tx	Transmitter
UHF	Ultra High Frequency

4 Executive summary

RFID technology is used increasingly across a wide range of applications. There are many systems available operating at a number of different frequencies. The choice of frequency is a function of the specific application. For satisfactory operation in logistics, item management and many other applications, reading ranges in excess of two meters using passive tags are necessary. This is not feasible using either inductive or microwave RFID technology. However operation at UHF provides this reading performance.

The present document considers the SRDoc TR 101 445 [3] and proposes a revised channel plan within the frequency range from 865 MHz to 868 MHz as contained in ERC/REC 70-03 [1], annex 11 and in accordance with the EC Decision on the harmonization of RFID devices at UHF. The revised plan provides improved spectrum usage within the identified band for both RFID systems and generic SRDs where generic SRDs use Listen Before Talk (LBT_{srd}) with Adaptive Frequency Agility (AFA).

This proposal provides the following operational and spectrum usage benefits:

- The number of high power RFID channels is reduced from 10 to 4, providing significant improvements in spectrum efficiency, as required by the RTTE Directive [6]. It will release 2.2 MHz of UHF spectrum from use at high power by interrogators, giving improved availability of spectrum for generic SRDs using LBT_{srd} and AFA. This spectrum access method enables SRDs to select spectrum dynamically while it is unused by interrogators and tags.

- Generic SRDs using LBT_{srd} and AFA are in effect provided with an additional eleven usable channels (see figure B.3). For SRDs without LBT_{srd} and AFA a suitable protection distance must be observed. In the four high power RFID channels, this may vary from 918 m (indoor) to 3,6 km (rural outdoor). In the remaining 2,2 MHz, where tags at -20 dBm e.r.p. occupy the spectrum, this may vary from 24 m (indoor) to 58 m (rural outdoor) (see table D.3).

- It is understood that generic SRDs may also use the four channels dedicated to higher power transmissions by interrogators.

- Tag backscatter reply signals may be placed in the low power channels and are therefore afforded protection from higher power interrogator transmissions. This technique reduces interference to tag transmissions and greatly improves tag reading throughput.

- Because interrogator transmissions may take place simultaneously on the same channel, many more interrogators may use fewer channels and therefore reduce spectrum occupancy.

- The ability of RFID with LBT_{rfid} to protect SRDs is very limited due to the wide difference in their respective power levels. In order to operate in the band, generic SRDs must rely on their own LBT_{srd} and AFA. Therefore there is no benefit in retaining LBT_{rfid} for RFID (see clause D.6).

- Without the requirement to "listen before talk", it is possible for RFID interrogators to be truly event driven and so provide greatly improved reliability in both fast moving and bulk reading applications, such as palettes on forklift trucks and goods on high speed conveyor belts. This also allows operation of RFID in other event driven and time critical applications such as airline baggage control [8].

The availability of the dense interrogator mode has significantly changed the way in which RFID at UHF operates.

There is an agreement between ETSI_ERM TG34 and ETSI ERM_TG28 that RFID, without LBT_{rfid}, may co-exist with generic SRDs using LBT_{srd} and AFA, or SRDs without LBT_{srd} operating at a suitable protection distance. In the four high power RFID channels, this may vary from 918 m (indoor) to 3,6 km (rural outdoor). In the remaining 2,2 MHz, where tags at -20 dBm e.r.p. occupy the spectrum, this may vary from 24 m (indoor) to 58 m (rural outdoor) (see table D.3). Therefore, the case for RFID with LBT_{rfid} is less compelling.

An additional factor is that major projects for logistics and baggage handling applications have operational requirements that conflict with the LBT_{rfid} requirement [8].

ERM TG34 has recently conducted a number of studies and a large scale practical test to verify operation of the proposed channel plan in a dense interrogator environment.

ETSI ERM_TG34 and ETSI ERM_TG28 have jointly undertaken a feasibility study to determine whether RFID and SRDs can co-exist in the band 865 MHz to 868 MHz if LBT_{rfid} is removed from RFID in the four high power channels (see annex D). The conclusions from this study are favourable, provided generic SRDs use LBT_{srd} with AFA or alternatively observe appropriate protection distances.

The market forecast for the next five years shows a very high demand for RFID systems in Europe for which the current frequency designations in annex 11 of ERC/REC 70-03 [1] and EN 302 208 [2] are unable to cope. More technical details are given in references [4] and in annex B.

Practical tests have been carried out to verify that SRDs can co-exist with RFID in the band 865 MHz to 868 MHz. The tests were performed using a home automation system that incorporated LBT_{srd} and AFA as specified in EN 300 220 [14]. The results showed that at separations between an RFID interrogator and the home automation system in excess of 5 m coexistence was readily achievable.

The tests also demonstrated that those SRDs with very wide band receivers as defined in EN 300 220 [14] operating outside the band 865 MHz to 868 MHz may be subject to blocking from RFID.

4.1 Status of the System Reference Document

Following a joint meeting of TG34/TG28 on November 15th to 17th, a draft of the SRDoc was circulated for comments. After incorporation of comments, a revised version of the draft SRDoc was circulated and approved by TG28/TG34.

Version 1.1.1_2.0.2 has been approved by ERM_RM at its 35th meeting.

ERM RM has forwarded the SRDoc to ECC.

The present document has been submitted in March 2007 to ERM #31 for approval and publication.

4.2 Market information

The market forecasts indicate a very high growth rate for RFID. A market forecast is given in the "*Final report from CEPT in response to the second mandate to CEPT to develop a strategy to improve the effectiveness and flexibility of spectrum availability for SRDs"*, Chapter 6 entitled: *"Short Range Device Industry: Market and Technology Trends"*, [7].

The market information at annex A of the present document will be updated upon availability of a more detailed market research presently underway and financed by the EU Commission

4.3 Technical issues

Annex B displays the present UHF SRD band plan in accordance with annex 11 of the ERC/REC 70-03 [1] and the proposed RFID channel plan.

5 Current regulation

The present document for RFID provides fifteen channels, three of 100 mW e.r.p., ten of up to 2 W and two of up to 500 mW. Furthermore, the current plan also provides for a system of Listen Before Talk (LBT_{rfid}) so that only one device in a radio neighbourhood is able to occupy a channel at a time. In the case of high density RFID systems where interrogators transmit at 2 W e.r.p., it is only possible for a maximum of 10 interrogators to operate simultaneously. If more than 10 interrogators wish to transmit at the same time, it is necessary for them to share time on the same channels. This means that at busy sites all ten of the high power channels may be occupied for extended periods of time.

The current ECC recommendation for RFID as given in annex 11 of ERC/REC 70-03 [1] for the frequency band from 865 MHz to 868 MHz is shown in table 1.

Table 1: Current RFID recommendation annex 11 of CEPT/REC 70-03 [1]

Frequency band	Power	Duty cycle	Channel spacing	Notes
b1 865 MHz to 868 MHz	100 mW e.r.p.	LBT	200 kHz	Listen before talk (LBT_{rfid}) shall be used, preferably with the option of frequency agility.
b2 865,6 MHz to 867,6 MHz	2 W e.r.p.	LBT	200 kHz	Listen before talk (LBT_{rfid}) shall be used, preferably with the option of frequency agility.
b3 865,6 MHz to 868 MHz	500 mW e.r.p.	LBT	200 kHz	Listen before talk (LBT_{rfid}) shall be used, preferably with the option of frequency agility.

The availability of the dense interrogator mode has made it possible for interrogators to share the same channels. However, in order to comply with the current LBT_{rfid} requirement, interrogators must be synchronized. This technique is possible where all the interrogators in a specified geographic area are under the control of a single user (master-slave concept). Where interrogators are under the control of different users, synchronization between separate systems is more complex.

Operators of large real-time systems have expressed concerns over the restrictions imposed by LBT_{rfid}. They require certainty that interrogators will always transmit when they are required to read passing tags [8].

If the LBT_{rfid} requirement is removed from the four high power channels, then it will be possible for interrogators to operate asynchronously. This will eliminate the need for synchronization and satisfy the needs of end users.

The current regulatory parameters for SRDs as given in annex 1 including its notes 1 to 8 of ERC/REC 70-03 [1] for the frequency band from 863 MHz to 870 MHz are shown in table 1.A.

Table 1.A: Current generic SRDs recommendation annex 1 of CEPT/REC 70-03 [1]

Frequency band	Power	Duty cycle	Channel spacing	Notes
863 MHz to 870 MHz (notes 3, 4 and 6)	≤ 25 mW e.r.p.	≤ 0.1 % or LBT (notes 1and 5)	≤ 100 kHz for 47 or more channels (note 2)	FHSS modulation.
	≤ 25 mW e.r.p (note 6) Power density: -4,5 dBm/100 kHz (note 8)	≤ 0.1 % or LBT_{srd} (notes 1, 5 and 6)	No spacing	DSSS and other wideband modulation other than FHSS.
	≤ 25 mW e.r.p.	≤ 0.1 % or LBT_{srd} (notes 1 and 5)	≤ 100 kHz, for 1 or more channels (notes 2 and 7)	Narrow/wide-band modulation.

NOTE 1: For single frequency devices the duty cycle limit applies, unless LBT is used. For FHSS, DSSS or AFA devices, the duty cycle applies to the total transmission unless LBT_{srd} is used.
NOTE 2: The preferred channel spacing is 100 kHz allowing for a subdivision into 50 kHz or 25 kHz.
NOTE 3: Sub-bands for alarms are excluded (see ERC/REC 70-03 [1], annex 7).
NOTE 4: Audio and voice applications are excluded.
NOTE 5: Duty cycle may be increased to 1 % if the band is limited to 865 MHz to 868 MHz.
NOTE 6: For other wide-band modulation than FHSS and DSSS with a bandwidth of 200 kHz to 3 MHz, duty cycle can be increased to 1 % if the band is limited to 865 MHz to 868 MHz and power to ≤ 10 mW e.r.p.
NOTE 7: For other narrow-band modulation with a bandwidth of 50 kHz to 200 kHz, the band is limited to 865,5 MHz to 867,5 MHz.
NOTE 8: The power density can be increased to +6,2 dBm/100 kHz and +0,8 dBm/100 kHz, if the band of operation is limited to 865 MHz to 868 MHz and 865 MHz to 870 MHz respectively.

6 Proposed regulation

The amended standard proposed in the present document requires the frequency separation of interrogator transmissions from tag backscatter replies. This allows multiple co-located RFID interrogator transmissions to share a small number of channels simultaneously, leaving the remaining channels for the very low power backscatter replies from the tags and for use by other SRDs. Tests conducted by ETSI ERM TG34 have shown that large numbers of interrogators are able to operate simultaneously on only four transmit channels. These tests were supported by ETSI members from ISO/IEC JTC1/SC31/WG4, EPCglobal together with manufacturers from the LPRA organization. These tests have demonstrated that the concept of four high power channels allows many more interrogators to operate simultaneously than is possible under the present channel plan [4].

The proposed plan designates four of the fifteen available channels in annex 11 for high power transmissions up to 2 W e.r.p. without LBT_{rfid} and designates the eleven remaining channels to low power transmissions to a maximum power of 25 mW e.r.p. and to tag backscatter transmissions. At any time an interrogator will transmit on one of the four high power (2 W e.r.p.) channels and will listen for the low power tag replies in the adjacent low power channels.

Table 2: Proposed recommendation for annex 11 of ERC/REC 70-03 [1]

Frequency bands	Power	Duty cycle	Channel bandwidth	Notes
Interrogators: 865,2 MHz - 868,0 MHz 4 interrogator channels centered at the frequencies f_{c} = 865,7 MHz; 866,3 MHz; 866,9 MHz and 867,5 MHz,	≤ 2 W e.r.p. on a single interrogator channel for each individual interrogator.	max TX on-time on a channel of 4 sec for each interrogator. min TX off-time on a channel of 100 msec for each interrogator.	f_c ± 100 kHz for interrogator.	LBT_{rfid} not mandatory.
Tags: Centred at frequencies between 865,4 MHz to 867,8 MHz	< -20 dBm e.r.p. per tag		f_c ±500 kHz for tag response.	
NOTE: fc is the carrier frequency of the interrogator.				

See figure B.4 for the spectrum masks of the interrogator and tag.

It is proposed that existing installations will be subject to a grandfather clause. However it is anticipated that existing users will wish to migrate to the new channel plan as soon as conveniently possible since this will enable them to operate without LBT_{rfid}.

In addition an acceptable period should be provided in which manufacturers must place equipment to the old design on the market.

Proposed recommendation for annex 1 of CEPT/REC 70-03.

No change is required to table 1.A in clause 5.

Note 5 should be reworded as follows:

"NOTE 5: In order to avoid harmful interference from RFID applications in the band 865 MHz to 868 MHz, generic SRDs should use LBT_{srd} with AFA. Alternatively duty cycle operation is possible, subject to the use of a suitable protection distance. In the four high power RFID channels, this may vary from 918 m (indoor) to 3,6 km (rural outdoor). In the remaining 2,2 MHz, where tags at -20 dBm e.r.p. occupy the spectrum, this may vary from 24 m (indoor) to 58 m (rural outdoor)."

For generic SRDs in that band the duty cycle may be increased to 1 %.

For information it should be noted that ETSI will amend its RFID Code of Practice [14] following the revision of EN 302 208 [2]

7 Main conclusions

If EN 302 208 [2] is amended as proposed, it will be in accordance with the EC Decision on the harmonization of RFID devices at UHF [2]. It will provide significant improvements in the reading capacity, reading performance and reading reliability of RFID systems. This is essential to meet the needs of anticipated dense interrogator installations over the next 3 to 5 years.

The market forecasts indicate a very high growth rate for all RFIDs. Some indications are in the order of "*… tens of billions in 2006, hundreds of billions in 2009, and perhaps trillions later…" [*5*]*. A market forecast is also given in the "*Final report from CEPT in response to the Second Mandate to CEPT to develop a strategy to improve the effectiveness and flexibility of spectrum availability for Short Range Devices (SRDs)"*, Chapter 6. entitled *"Short Range Device Industry: Market and Technology Trends"*, [7]. The forecast for UHF RFID is contained in annex A.

A more up-to-date and comprehensive market study on the projected growth of RFID is underway and will be available for TR 102 649-2 [16]. It is expected that this study will point to the need for additional spectrum for RFID within the next 5 to 10 years. Annex A of the present document will be accordingly updated when new data are available.

Implementation of the proposed channel plan using four high powered channels without LBT_{rfid} will add significantly to spectrum efficiency, as required by the R&TTE Directive [6]. It will release 2,2 MHz of UHF spectrum from high power use by RFID interrogators, thereby providing improved availability of spectrum for generic SRDs to share the same band. Harmful interference from RFID can be avoided by SRDs using dynamic spectrum access methods such as LBT_{srd} with AFA.

Generic SRDs without LBT_{srd} and AFA may use alternative spectrum access methods such as duty cycle provided they observe a suitable protection distance. In the four high power RFID channels, this may vary from 918 m (indoor) to 3,6 km (rural outdoor). In the remaining 2,2 MHz, where tags at -20 dBm e.r.p. occupy the spectrum, this may vary from 24 m (indoor) to 58 m (rural outdoor) (see table D.3).

8 Requested ECC, ETSI and EC actions

ETSI requests ECC to consider the present document, which includes the necessary information to support the co-operation under the MoU between ETSI and the Electronic Communications Committee (ECC) of the European Conference of Post and Telecommunications Administrations (CEPT).

It is proposed that ECC considers modifications to the proposed regulation in annex 11 of the ERC/REC 70-03 [1].

ETSI requests that the ECC finalizes the changes in ERC/REC 70-03 [1] annex 11 and annex 1, note 5 by mid 2007. In addition ECC should be aware of the need to have a timely implementation at national level.

There have been significant technical developments since ECC Report 37 [10] was generated and its conclusions are at variance with the findings in the present document. This is due to a number of reasons. For example modern generic SRDs have significantly higher input sensitivities than were assumed at the time of the original study. Also the densities of RFID equipment are considerably greater than were originally assumed. In addition low cost high performance chipsets with LBT_{srd} and AFA are now readily available for SRDs. It is recommended that ECC should take into account the results of the ETSI joint TG28/TG34 feasibility study as given in annex D. Consideration should be given to revision of ECC Report 37 [10] to take into account the findings of the feasibility study. The EC is requested to amend their EC Decision on the harmonization of RFID devices at UHF [12] so as to restrict the use of high power transmissions to channels 4, 7, 10 and 13 only.

ETSI ERM TG34 intends to create a revision of EN 302 208 [2] in line with the proposed changes.

It is noted that the European Commission Decision on harmonization of the radio spectrum for radio frequency identification (RFID) devices operating in the UHF band [12] states *(quoted from whereas 3)*:

> "The radio communications services, as defined in the International Telecommunications Union Radio Regulations, have priority over such RFID devices and are not required to ensure the protection of RFID devices against interference and RFID systems shall not cause interference to these radio communications services. Since no protection against interference can therefore be guaranteed to users of RFID devices, it is the responsibility of manufacturers of RFID devices to protect such devices against harmful interference from radio communications services as well as from other short range devices operating in accordance with the applicable Community or national regulations. Pursuant to *Directive 1999/5/EC [6] of the European Parliament and of the Council of 9 March 1999 on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity (the R&TTE Directive*) manufacturers should ensure, that RFID devices effectively use the radio frequency spectrum so as to avoid harmful interference to other short-range devices."

And also (whereas 5):

> "The bands proposed by CEPT for harmonization are covered for use by RFID by harmonized standard EN 302 208 [2] adopted pursuant to Directive 1999/5 of the European Parliament and of the Council of 9 March 1999 on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity (R&TTE Directive). This standard describes a listen-before-talk technique meant to provide appropriate mitigation levels to avoid harmful interference to other users in the band. The use of this standard or other relevant harmonized standards gives the presumption of conformity with the essential requirements of the R&TTE Directive."

The present document demonstrates that RFID with LBT_{rfid} under the present channel plan provides only very limited protection to SRDs.

An improved method, without the use of LBT_{rfid} by RFID, proposed in the present document is based on a combination of:

a) Reducing the number of high power channels on which RFID operates, thus reducing the probabilistic risk of interference to SRDs.

b) Reliance by SRDs on the use of LBT_{srd} with AFA as described in EN 300 220 [14] to protect themselves from RFID systems. Generic SRDs without LBT_{srd} and AFA may use alternative spectrum access methods such as duty cycle provided they observe a suitable protection distance (see clause 7).

The European Commission should be made aware of the above and consider the legal implications for the RFID EC Decision.

Annex A:
Detailed market information

A.1 Range of applications and market size

The following is an excerpt from the final report from CEPT in response to the second mandate to CEPT to develop a strategy to improve the effectiveness and flexibility of spectrum availability for SRDs, chapter 6 "Short Range Device Industry: Market and Technology Trends" [7].

This market information will be updated upon availability of a more detailed market research presently ongoing in EPC global and financed by the EU Commission.

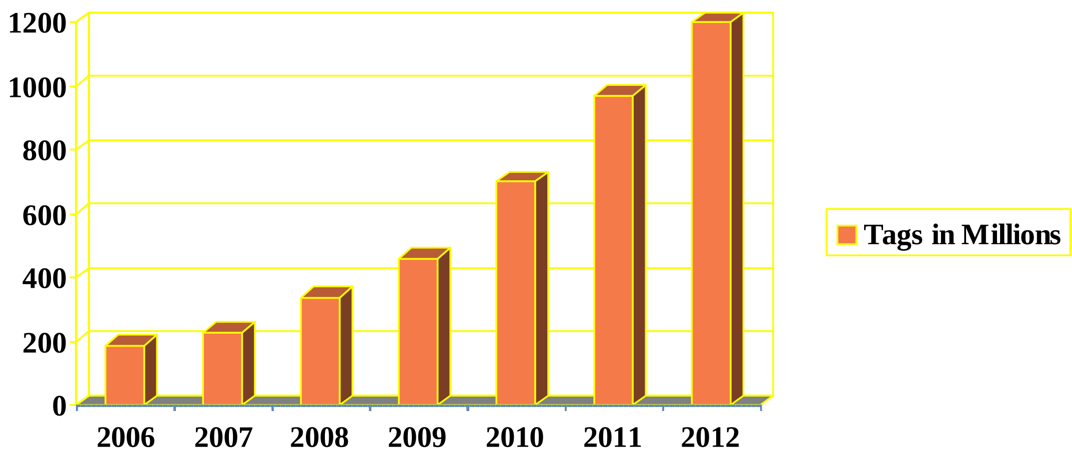


Figure A.1: Projected growth of UHF RFID tags between 2006 and 2012

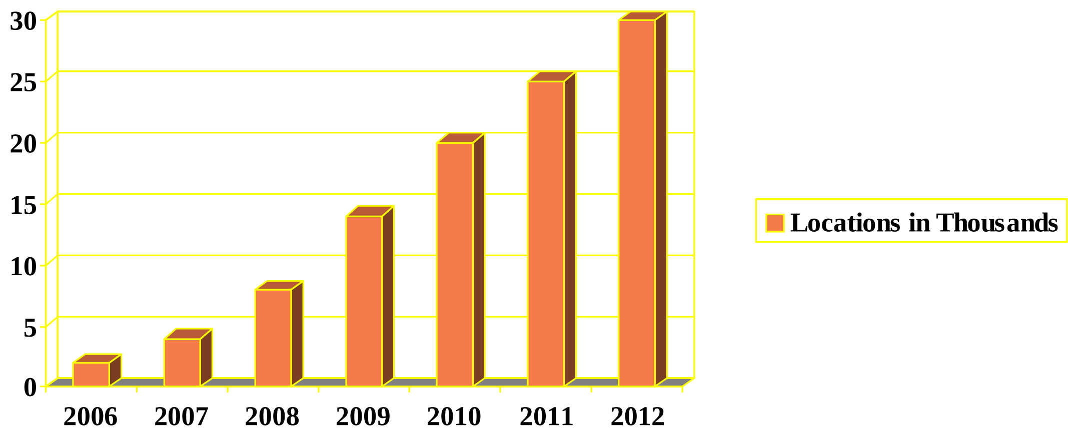


Figure A.2: Projected growth of sites to be installed with UHF RFID tag/interrogator systems between 2006 and 2012

Annex B: Technical information

B.1 Detailed technical description

The present band plan for SRDs and RFID from 865 MHz to 868 MHz is given in figure B.1 (from TR 101 445 [3]).

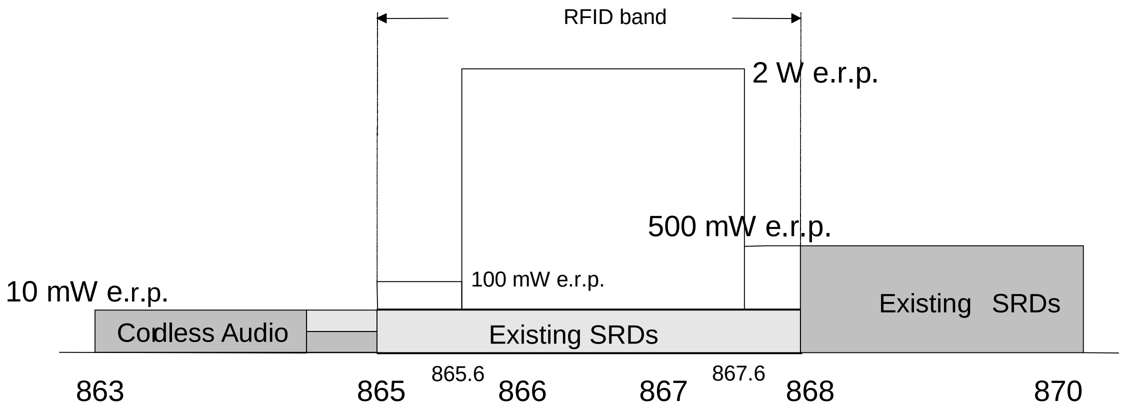


Figure B1: Present UHF SRD band plan

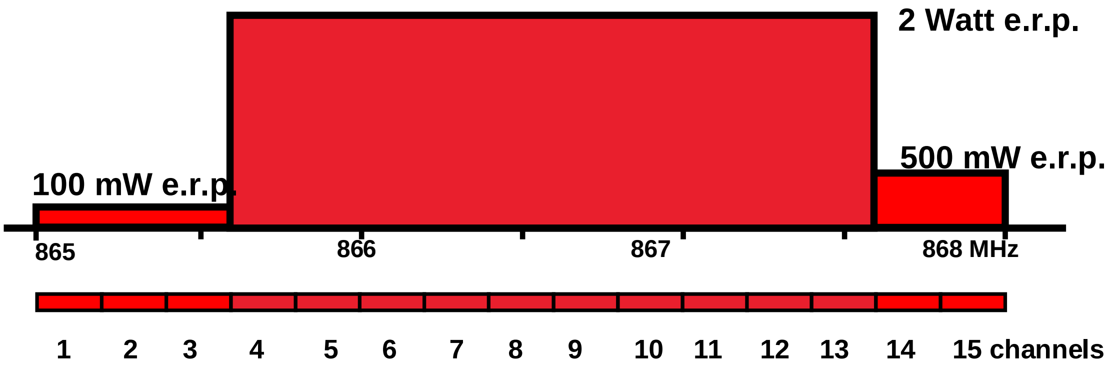
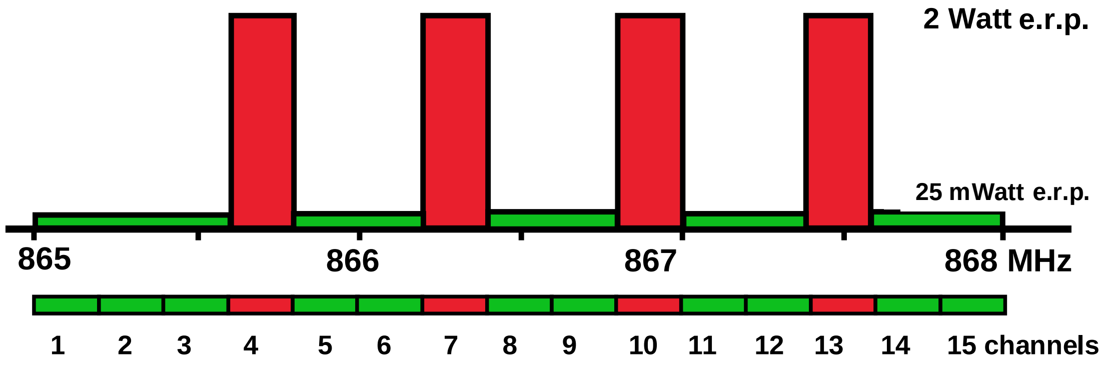


Figure B.2: Present RFID channel plan and occupied spectrum



NOTE 1: In the proposed channel plan, the spectrum can be used by RFID as well as generic SRDs under appropriate conditions.

NOTE 2: The figure of 25 mW e.r.p. in the low power channels relates solely to SRDs, which share the band with RFID.

Figure B.3: Proposed RFID channel plan and occupied spectrum

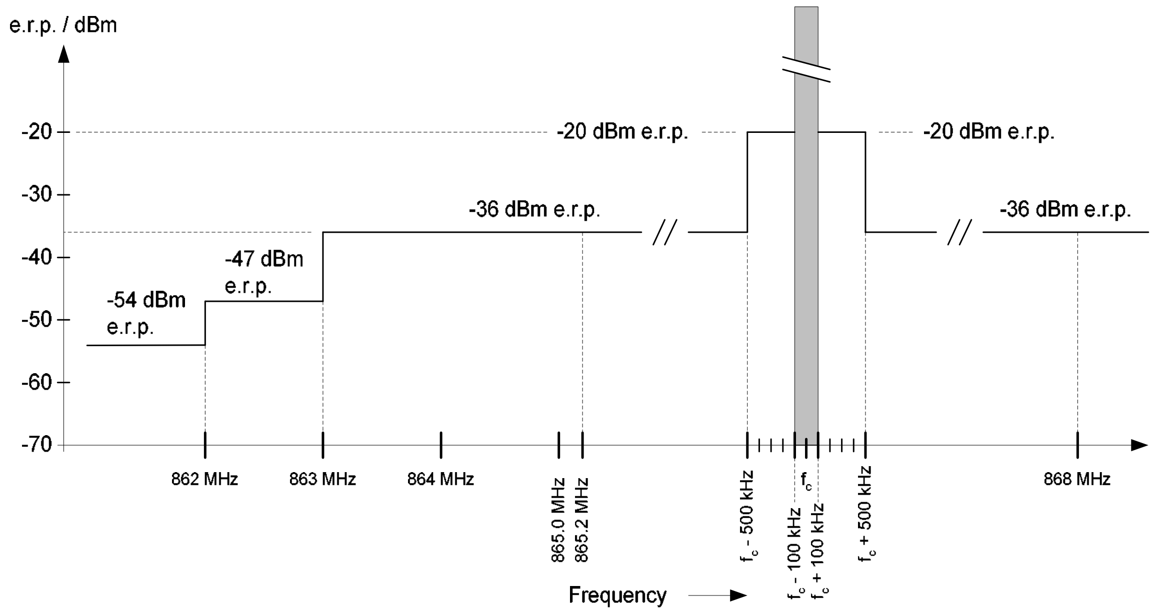
It can be seen that the spectrum efficiency is significantly increased with the proposed new RFID channel plan:

- The current frequency designation for RFID in annex 11 of ERC/REC 70-03 [1] is 3 MHz. Currently RFID is using mainly that part allowing ≤ 2 W e.r.p. which is 10 channels of 200 kHz spacing. The SRDoc proposes four high power channels without LBT_{rfid}, each of 200 kHz, spaced at equal intervals of 600 kHz. The remaining spectrum is available for the backscatter response from the tags at power levels below 10 uW e.r.p.

- The band 865 MHz to 868 MHz may also be shared with generic SRDs (≤ 25 mW e.r.p.) that incorporate LBT_{srd} and AFA, Generic SRDs without LBT_{srd} and AFA may use alternative spectrum access methods such as duty cycle provided they observe a suitable protection distance. In the four high power RFID channels, this may vary from 918 m (indoor) to 3,6 km (rural outdoor). In the remaining 2,2 MHz, where tags at -20 dBm e.r.p. occupy the spectrum, this may vary from 24 m (indoor) to 58 m (rural outdoor) (see table D.3).

The intentional transmissions from tags operating in the dense reader mode respond at a frequency that is offset from the carrier frequency of the interrogator. This offset frequency is called the link frequency and typically has a value of around either 200 kHz or 300 kHz. The bandwidth of the tag response is of the order of 200 kHz.

The spectrum mask shown at figure 9 of EN 302 208 [2] applies to tags that respond within the same channel as the carrier frequency of the interrogator. Since this is not applicable to a tag operating in the dense reader mode, it is necessary to define a new spectrum mask. The proposed new spectrum mask for the tag is shown in figure B.4.

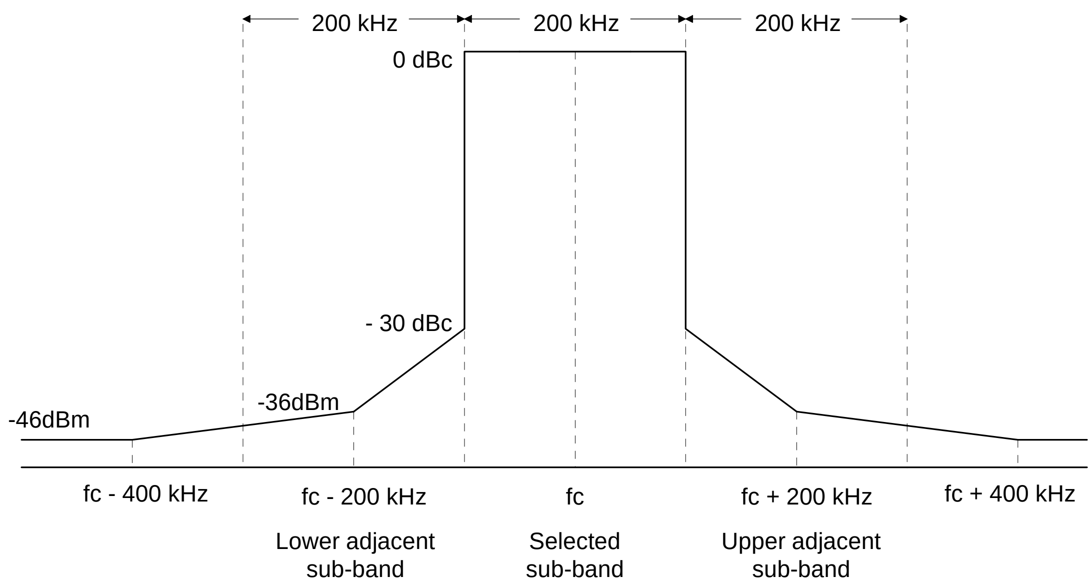


NOTE 1: Figure B.4 shows the spectrum mask, out of band emissions and emissions in the spurious domain for the tag.
NOTE 2: fc is the centre frequency of the carrier transmitted by the interrogator.
NOTE 3: The transmit channel occupied by the interrogator is shown in grey.

Figure B.4: Proposed spectrum mask for tag operating in the dense reader mode

It should be noted that, under the proposed plan, channel 1 (865,0 MHz to 865,2 MHz) is not occupied by RFID. It is therefore available solely for use by generic SRDs provided that the receiver characteristics are at least Class 2 as defined in EN 300 220 [14].

Below is the proposed spectrum mask for the interrogator operating on the four channels as described in table 2.



NOTE: For interrogators designed with lower transmit levels, the limit at the band edge should be interpreted as -30 dBc or -36 dBm, whichever is the greater.

Figure B.5: Proposed spectrum mask for interrogator

B.2 Technical justification for re-organization of existing spectrum between 865 MHz and 868 MHz.

B.2.1 Power

Up to 2 W e.r.p. RF power is required to meet the requirements of end users in accordance with ISO/IEC 18000-6 [9] and EPC™ Radio-Frequency Identity Protocols, [11]. It permits the necessary operating range of 2 meters to be achieved satisfactorily when reading densely packed goods.

This four channel proposal permits several interrogators to transmit simultaneously on shared channels thus significantly increasing the number of interrogators that may operate simultaneously in the same geographic space.

B.2.2 Frequency

Reorganization of the frequency spectrum according to figure B.3 is required to meet industry requirements for dense interrogators. In addition there is a need to provide immediate channel availability for time critical applications such as airline baggage identification and fast moving goods e.g. on conveyor belts [8]. This is achieved by the omission of LBT_{rfid} on the four high power channels used for powering the RFID tags.

Annex C:
Expected compatibility issues

C.1 Coexistence and sharing issues with other SRDs

ERM_TG 34 and ERM_TG 28 have conducted a feasibility study, which is shown in annex D. This feasibility study is based on a realistic and jointly agreed TG28/TG34 scenario of interference between RFID interrogators and SRDs within the band 865 MHz to 868 MHz. It uses more recent information on the anticipated deployment of UHF RFID devices than was available at the time when ECC Report 37 [10] was created.

The results of the 865 MHz to 868 MHz feasibility study show an improved situation for RFIDs as well as SRDs over the present regulations and demonstrate that generic SRDs may operate satisfactorily within the band if using LBT_{srd} with AFA. Generic SRDs without LBT_{srd} and AFA may use alternative spectrum access methods such as duty cycle provided they observe a suitable protection distance (see clause 7). Consequently, ERM TG 28 is in support of the proposal.

Some manufacturers of SRDs operating in the adjacent band 868,0 MHz to 870,0 MHz have expressed concerns over the risk of potential interference from RFID interrogators. These SRDs are used in the automation industry and, for commercial reasons, are designed with wide band receivers (e.g. 200 kHz). To protect SRDs in the old bands (868 MHz to 870 MHz) and the new band (865 MHz to 868 MHz), the new standard should include a clause stating that interrogators should cease transmitting as soon as possible, and no more than 20 seconds, after they have completed reading tags.

Annex D: Joint ERM TG28/TG34 feasibility study

D1 to D9

Feasibility analysis of interference between Short Range Devices (SRD) and an RFID system without LBT operating at four fixed channels in the 865 - 868 MHz band.

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D.1 Executive summary

The present document analyses optimization of RFID operation and spectrum use in the frequency band 865 MHz to 868 MHz with an RF power up to 2 W e.r.p.

The CEPT Recommendations for RFID in this frequency range are published in ERC/REC 70-03 [1] annex 11 and are based on a CEPT study published as ECC Report 37.

This specifies that RFID may operate with up to 15 channels with 200 kHz channel spacing. Under the current Regulation conditions, Listen before Talk (LBT_{rfid}) is mandatory in order to share the spectrum with Short Range Devices (SRD).

RFID has evolved rapidly since the above mentioned study was made and a new technique named "dense interrogator mode" has been developed and verified. This technique only requires four high power channels for the RFID interrogators, while the low power backscatter response from the tags occurs in the adjacent channels.

The present document specifically analyses the interference between SRDs and RFIDs operating on the four channels in the dense interrogator mode under the conditions mentioned above.

The results of the present study are as follows:

a) Multiple RFID transmitters can operate on the same channel and therefore the technique is very spectrum efficient. A direct result of this fact is that only four (4) high power channels are needed by RFID within the band 865 MHz to 868 MHz. The use of only four transmitter channels by RFID interrogators will provide improved availability of spectrum for generic SRDs using LBT_{srd} and AFA.

b) The current CEPT Recommendation for RFID operating in the band 865 MHz to 868 MHz mandates LBT_{rfid}. The present document concludes that the continued use of LBT_{rfid}/AFA in the four high power channels will offer minimal protection to SRDs. This is contrary to the predictions in ECC Report 37. The reason is that with RFID interrogators operating only on four channels, these channels will be occupied by RFID for most of the time. In addition SRDs with 25 mW e.r.p have significantly less coverage area than the RFID with 2 W e.r.p. and any RFID interference is always seen at longer distances by the SRD than an interference caused by SRD to an RFID receiver. The only exception to this scenario is if the two equipment are positioned close to each other and the SRD talks first. As already mentioned above, the probability for this latter event is low as RFID has a higher duty cycle than SRD.

c) Conclusively, RFID devices operating with LBT_{rfid}/AFA in the four RFID high power channels provide only very limited protection to SRDs and LBT_{rfid} is therefore an unnecessary burden for RFID. Conversely, if a SRD is equipped with LBT_{srd}/AFA then this does protect the SRD from interference by RFID. Therefore, LBT_{rfid}/AFA functionality can be removed from RFID.
For further details see clause 6.

d) It should be noted that SRDs with both LBT_{srd} and AFA, (also called Dynamic Frequency Selection (DFS)) will automatically detect the occupation of a channel by RFID and switch to a free channel.

e) Generic SRDs with LBT_{srd}/AFA will also react to RFID tag signals at close range and move to another channel, thereby avoiding interference.
For example for a tag signal of up to -20 dBm e.r.p, an SRD with LBT_{srd}/AFA will react at distances of less than 30 m.

f) Generic SRDs without LBT_{srd} and AFA may use alternative spectrum access methods such as duty cycle provided they observe a suitable protection distance. In the four high power RFID channels, this may vary from 918 m (indoor) to 3,6 km (rural outdoor). In the remaining 2,2 MHz, where tags at -20 dBm e.r.p. occupy the spectrum, this may vary from 24 m (indoor) to 58 m (rural outdoor) (see table D.3).

NOTE: The related changes in interference and protection distances in this study are calculated using CEPT and ITU-R published propagation models.

D.2 Background

RFID technology continues to evolve and services by these devices will rapidly increase from an already large base.

Two techniques are currently used:

a) Original versions of multi channel systems with individual RFID interrogators operating on different channels. These readers could not operate in close proximity at the same frequency and are therefore only useful for smaller sized installations.

b) A new development uses the so-called "Dense Interrogator Mode" where the transmitter and receiver of the interrogator operate at different frequencies. Such devices can operate in close proximity even with the transmitters at the same frequency. These devices can therefore operate in large systems with many RFID interrogators all at the same frequency.

The frequency band 865 MHz to 868 MHz is shared with Short Range Devices (SRDs). It is necessary to operate SRDs with an access protocol with adaptive frequency agility in order to avoid interference. This is already specified in EN 300 220 [14].

In summary RFID manufacturers have discovered that the dense interrogators mode offers improved spectrum efficiency and that it is possible to operate multiple RFID interrogators simultaneously at the same transmit frequency. Spectrum access for SRDs is granted by means of an LBT_{srd}/AFA protocol, which is already part of new designs for SRD equipment. It should be noted that the combination of LBT_{srd} and AFA offers full Dynamic Frequency Selection (DFS).

D.3 Calculation method

The interference calculation is based on the Minimum Coupling Loss (MCL) method. Protection distances are calculated for co-channel interference from which the cumulative probability of interference is derived.

The effect on SRDs of removing LBT_{rfid}/AFA from the four high power channels is determined by calculating the difference between the protected area with and without LBT_{rfid}/AFA.

D.3.1 Interference criteria

D.3.1.1 Co-channel interference

The interference is calculated based on the appropriate receiver threshold as defined for the systems:

a) RFID, sensitivity = -70 dBm.

b) SRD, LBT_{srd} threshold = -90 dBm.

c) SRD sensitivity degradation of 3 dB, I/N = 0 dB.

For SRD systems sharing the same band the interference criteria is based on the following:

The LBT_{srd} threshold or I/N are used as the interference criteria for co-channel interference.

D.3.2 Characteristics of systems

The characteristics of RFID are given by EN 302 208 [2] and ERC/REC 70-03 [1].

D.3.2.1 Victim and Interferer characteristics

D.3.2.1.1 Summary victim receiver characteristics

Victim characteristics are derived from clause 4 of the present document. The characteristics are shown in table D.1.

Table D.1: Characteristics of victim receivers

	Frequency Range. (span) Span $_{VIC}$ MHz	Interference level at receiver input dBm	Noise Equiv. Bandwidth (NEB) kHz	Antenna gain dBi	Antenna beam-width degrees	Antenna height m
RFID	0,8 (see note 3)	-70 (see note 2)	100	8	30	1,5
SRD	7 (see note 4)	-90 (see note 1)	100	2,1	360	1,5

NOTE 1: Threshold for LBT_{srd} according to EN 300 220 [14].
NOTE 2: Threshold for LBT_{rfid} according to EN 302 308 [2].
NOTE 3: RFID span is 4 x 200 kHz = 800 kHz.
NOTE 4: SRD is allowed to operate in the entire band 863MHz to 870 MHz.

D.3.2.1.2 Summary of interfering transmitter characteristics

The interfering characteristics of transmitters are shown in table D.2.

The values are reflective of numbers used in the Excel spread sheets, see clause 9.

Table D.2: Characteristics of interfering transmitters

	Hot-spot Unit density units/km^2	Maximum radiated Power (e.r.p.) dBm	Frequency range (span) SPAN $_{INT}$ MHz	Modulation Bandwidth (3dB) kHz	Estimated Duty Cycle (see note) %	Antenna Beam-width degrees	Antenna Height m
RFID	480	33	0,8	100	10	30	1,5
SRD	400	14	7	100	1	360	1,5

NOTE : The duty cycle is dependent on the application. This number is an overall average.

D.4 Calculation models

The following clauses describe the method of calculating the probability and deterministic model of interference.

D.4.1 Deterministic model

D.4.1.1 General

The deterministic model focuses on one interferer interfering with one victim.

The interference calculations using the MCL method are shown in spreadsheets annexed to the present document. The cumulative co-channel interference effects are considered under the probabilistic MCL method, see clause D.4.2.

D.4.1.2 Nominal receiver signal

For RFIDs the MCL study is based on interference to a receiver LBT threshold. The relevant receiver LBT thresholds are as follows:

a) RFID sensitivity = -70 dBm
(please note this is not in accordance with EN 302 208 [2]);

b) SRD receiver threshold = -90 dBm according to EN 300 220 [14]; and

c) SRD threshold, I/N = 0 dB.

For case c) the MCL study bases interference scenarios at MUS + 3 dB (this determines the reduction of the receiver sensitivity of 3 dB).

The minimum receive signal, P_{RX_MIN} is:

$$P_{RX\_MIN} = MUS + 3\,dB \quad \text{(D.1)}$$

where:

MUS = Maximum Usable Sensitivity

For the purpose of this study and case c) above, the MCL calculations use an interference criteria of MUS + 3 dB which is equal to I/N = 0 dB. For telemetry and data systems MUS is approximately equal to the receiver noise + 14 dB.

For case a) and b) above the relevant LBT threshold is used.

D.4.1.3 Indoor propagation model used for deterministic method

The discussion of this clause only applies to calculations performed using the deterministic method. Propagation models for the probabilistic method are discussed in clause D.4.2.

At 865 MHz, Path Loss, PL is:

a) for distances below 10 m free-space propagation applies:

$$PL = 30,2 + 20 \log d \quad \text{(dB) (D.2)}$$

b) for distances above 10 m:

$$PL = 50,2 + 35 \log \frac{d}{10} \quad \text{(dB) (D.3)}$$

where d is the distance in metres.

D.4.1.4 Minimum Coupling Loss (MCL) and protection distance

The protection distance, d_P, for any interference is determined by means of the Minimum Coupling Loss (MCL) method.

$$MCL = P_{RAD} - P_{RX} + C/I \quad \text{(D.4)}$$

where:

MCL = Minimum Coupling Loss in dB;
P_{RAD} = Radiated power (e.r.p.) for interfering transmitter in dBm;
P_{RX} = Victim received power in dBm;
C/I = Carrier to interference ratio specified for the Victim receiver in dB.

The calculated MCL can be obtained by pathloss, PL, over a certain protection distance, d_P. This can be derived from an appropriate in-door propagation model.

$$d = 10^{(PL - 30,2)/20} \quad \text{for PL < 50,2 dB; and (D.5)}$$

$$d = 10 \times \left(10^{(PL - 50,2)/35}\right) \quad \text{for PL} \geq 50,2 \text{ dB (D.6)}$$

D.4.1.4.1 Co-channel

The main interference mechanism is co-channel for services in band.

D.4.2 Probabilistic method

Interference probability analysis is a four-step process, leading to an interference assessment for different scenarios. Those steps are:

Step 1.

- Determine the "Minimum Coupling Loss (MCL)" between the interferer power and the victim threshold. The equation for this calculation is given in clause D.4.2.1.

Step 2.

- Convert the MCL result from step 1 into a minimum protection distance for a single interferer by means of an appropriate propagation model. Relevant propagation models are described in clause D.4.2.2.

Step 3.

- Calculate the number of potential interferers inside the interference area based on the estimated unit density. This calculation is described in clause D.4.2.3.

Step 4.

- Evaluate the cumulative probability of interference using equation D.20 described in clause D.4.3.

D.4.2.1 Minimum coupling loss

The Minimum Coupling Loss between the interfering transmitter power and victim receiver threshold determines the minimum protection distance. This cell size (radius) R_{INT} is identical to the calculated protection distance and has to be calculated by means of an applicable propagation model (see clause D.4.2.2) and minimum coupling loss.

The Minimum Coupling Loss (MCL) is the minimum path loss required to avoid interference, which is given by:

$$MCL = P_{srd} + G_t - Lf_t + G_r - Lf_r + 10 \log(B_r \cap B_t / B_t) - I \qquad (D.7)$$

where:

I: maximum permissible interference level at victim receiver.

P_{srd}: interfering transmitter conducted power.

G_t: interfering transmitter antenna gain.

G_r: victim receiver antenna gain.

Lf_t: interfering transmitter feeder loss.

Lf_r: victim receiver feeder loss.

B_t: interfering transmitter 3 dB bandwidth.

B_r: victim receiver 3 dB bandwidth.

$B_r \cap B_t$: overlapping part of the transmitter and receiver frequency band.

D.4.2.2 Propagation models

For MCL calculations different propagation formulas are used for each combination of the following environments: indoor, urban, and rural. For systems operating indoors, an additional 5 dB building attenuation, M_{WALL}, is assumed. All of the propagation formulas below predict the median value of path loss.

D.4.2.2.1 In- door propagation model

The indoor model uses the free space propagation formula, which applies for distances d of less than 10 metre (a path loss exponent of 2). Beyond 10 metre, the exponent is 3,5. The following indoor model is assumed valid from 10 m to 500 m:

$$Pl\,(r)\,(dB) = 50{,}2 + 35\log\left(\frac{d}{10}\right) + M_{WALL} \qquad \text{(D.8)}$$

where M_{WALL} is any appropriate wall attenuation.

Beyond 500 m, this model is not applicable since most indoor building areas are smaller than 500 m. The indoor propagation model is supported by numerous measurements found in literature, e.g. "Wireless Communications" by Theodore S. Rappaport, ISBN 0-13-375536-3.

D.4.2.2.2 Urban model

For the purposes of this study the CEPT SE21 urban model is used. This model is described in ITU-R Report 567-4 [17] and is valid for frequencies between 150 MHz and 1 500 MHz and is derived Hata model.

L_{CEPT}(urban, dB) = 124,04 + 10 log f - 13,82 log h_{tx} - a(h_{rx}) - a(h_{tx}) + (44,9 - 6.55 log $h_{tx)}$ log d (D.9)

where a(htx)) = Min [0, 20 log (htx/30)]

and a(h_{rx}) = (1,1 log f - 0,7) Min(10, h_{rx}) - (1,56 log f - 0,8) + Max [0, 20 log (h_{rx}×/10)]

are "antenna height gain factors" for the transmitter and receiver antennas respectively. The equations given above predict large negative values (e.g. negative 18 dB) for the transmitter's antenna height gain for low antennas. This arises because the CEPT/SE21 model assumes that the transmitter antenna is mounted high (above 30 m) and in the clear. But in the situations of interest in the present document, typically both transmit and receiver antennas are below 10 m, so that nearby ground clutter and reflections are no longer negligible.

For the purposes of this study for MCL calculations, the SE21 propagation model is extended by using the "height gain" equation:

a(h_{tx}) = (1,1 log f - 0,7) Min(10, h_{tx}) - (1,56 log f - 0,8) dB + Max [0, 20 log (ht$_{rx}$ /10)] (D.10)

when both antenna heights are less than 10m.

D.4.2.2.3 Rural model

The rural propagation model used within the radio line-of-sight in the present document is the CEPT SE21 rural model, also referred to as the modified free space loss model. The rural model assumes free space propagation until a certain break point distance, r_{BREAK} depending on the antenna heights for the interferer and victim:

Pl(r)(dB) = 20 log(4πr/λ) + M_{WALL} for r < r_{BREAK} = 4π.ht.hr/λ (D.11)

Pl(r)(dB) = 20 log(r²/(ht.hr)) +M_{WALL} for r > r_{BREAK} = 4π.ht.hr/λ (D.12)

D.4.2.3 Number of interfering units

The protection distance, R_{INT}, is equivalent to the path length d corresponding to the Minimum Coupling Loss (MCL), as determined in clause D.4.2.1. The protection distance d is used to calculate the interference area. The total number of interfering transmitters within this area, N_{INT}, is the product of the unit density and this area.

Additionally, the spatial distribution of the interfering transmitters is considered below.

Two different distribution models have been used to derive the cumulative probability of interference:

- a uniform distribution; and
- an exponential distribution.

The exponential distribution of interfering transmitters is used by MCL to assess hot-spot interference. Consequently the interference will mostly arise from clusters of interferers located near the victim receiver. This clustering is modelled by the exponential distribution given in equation D.13.

For further information on the numbers for the related unit density used, see clause D.3.2.1.2.

In the exponential distribution, the density of interferer decays as the distance from the victim increases. This is best described by the following formula:

$$N(r) = No \times \exp(-k \times r) \tag{D.13}$$

where:

N: represents the interferer's density versus distance from the centre of the interference area in units/ km^2.

No: represents the hot-spot unit density of interferers (units/km square) given in the data input sheet (see attached Excel spread sheet file contained in archive tr_10264901v010101p0.zip which accompanies the present document).

r: is the distance from centre (r = 0) to the periphery (r = d) of the interference area

k: is the decay constant that is set to k = 2 to represent expected distribution of interferers.

Figure D.1 illustrates exponential density:

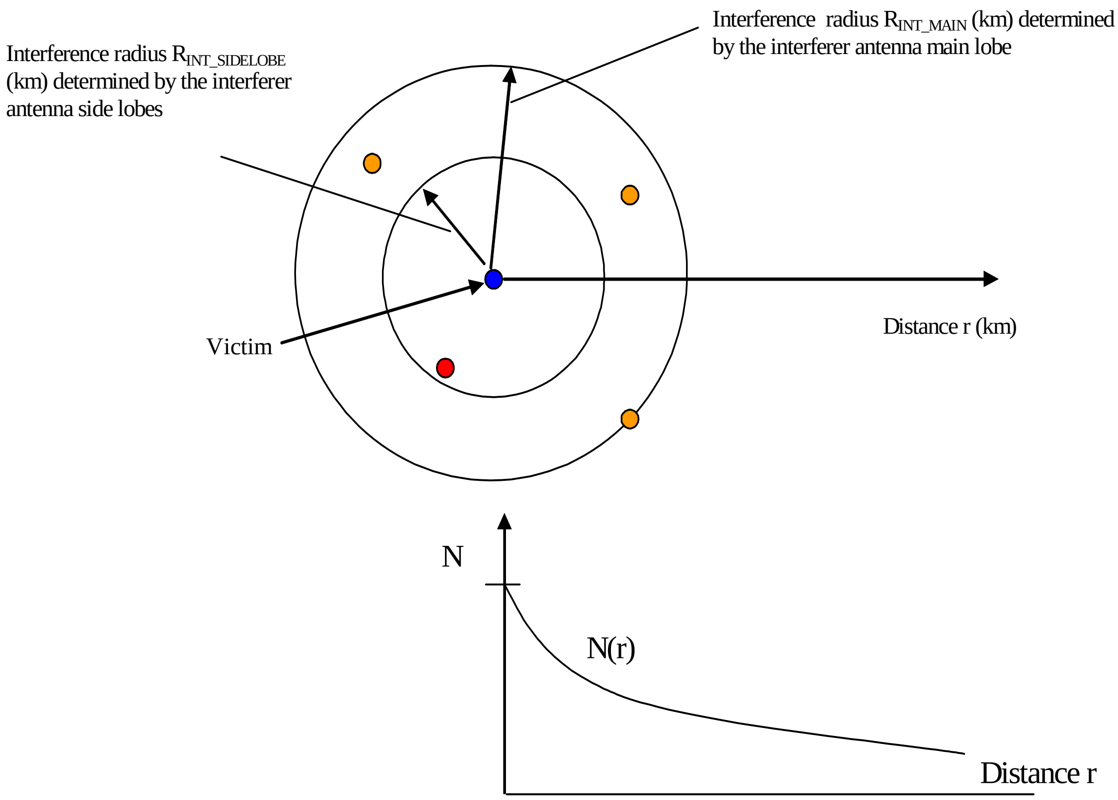

Figure D.1: Distribution of interferers within the interference areas for main and side lobes

In figure D.1, the larger interference area is determined using the gain of the interferer antenna in the direction of the main beam. The smaller area is determined using the gain of the antenna in other directions (side-lobes).

The total number of interferers in each of the interference areas is calculated by:

$$N_{INT}(R_{INT}) = \iint_{r\beta} N(r) \times r \times dr \times d\beta \tag{D.14}$$

Integration over r = (0, R_{INT}) and the angle beta, β over β = (0, 2 π) yields:

$$N_{INT}(R_{INT}) = \frac{2\pi No}{k^2} \times [1 - (k R_{INT} + 1) \times \exp(-k R_{INT})] \quad \text{(D.15)}$$

Equation (D.15) is used to calculate the number of interferers within each of the relevant interference areas.

D.4.2.4 Probability of antenna pattern, time, and frequency collision

D.4.2.4.1 Probability of alignment of antenna main beams

In the simplest case both interferer and victim have omni-directional antennas resulting in a pattern collision probability of 100 %. However, some systems of interest in the present document use directional antennas to reduce interference potential.

Where the main beam of the victim's antenna lies within the main beam of the interferer's antenna the interference probability for an antenna beam angle, β for both the victim and interferer is given by:

$$P_{PAT\_COL} = \frac{\beta_{VIC\_MAINBEAM}}{360} \times \frac{\beta_{INT\_MAINBEAM}}{360} \quad \text{(D.16)}$$

D.4.2.4.2 Added probability for antenna sidelobes

For interfering devices that use directional antennas, the interference arising from sidelobes may be significant. Where the main beam of victim's antenna lies within a side lope of the interferer's antenna, the additional interference probability is given by:

$$P_{PAT\_COL} = \frac{360 - \beta_{INF\_MAINBEAM}}{360} \times \frac{\beta_{VIC\_MAINBEAM}}{360} \quad \text{(D.17)}$$

The cumulative probability of interference from both main beam and sidelobes is given in clause D.4.2.5.

D.4.2.4.3 Probability for frequency overlap

D.4.2.4.3.1 Phenomena modelled by universal P_{FREQ_COL} formula

The probability of frequency collision is modelled using a universal P_{FREQ_COL} formula described below:

- For systems at fixed frequencies, it is the randomness of the frequency channel assignment that causes uncertainty of the "frequency collision event". Narrower channel bandwidths (either Tx or Rx) will contribute to a lower P_{FREQ_COL}. This occurs because narrowing either (or both) of these bandwidths results in a larger number of non-overlapping frequency windows available in the band and thus a larger number of non-overlapping BW_{TX} - BW_{RX} pairs.

- For dynamic frequency systems it is the randomness of the instantaneous frequency hop within the total set available channels used that causes probability of the frequency collision event.

- The most complex case is a system changing frequency over only a portion of the band. Such a system benefits from both the randomness of the "frequency span" position within the band as well as from the randomness of instantaneous frequency change.

D.4.2.4.3.2 Definition of the frequency collision events

The main reason for the difficulty in the calculation of the P_{FREQ_COL} is the lack of a clear definition of precisely what constitutes the "frequency collision event".

The difficulty of clearly defining the frequency collision event arises because it must properly describe a complex mix of interfering systems, having various signal bandwidths (relatively narrow or wide with respect to each other) and various frequency spectrum shapes. Also the spectrum overlap of the interfering systems (being analogue in nature) can be full or partial, resulting in different effects on the interference.

In the interest of consistency the following basic assumptions and definitions have been adopted in the present document.

The interfering transmitter and victim receiver channel bandwidths used in all P_{FREQ_COL} calculations are 3 dB bandwidths. In the case of the receiver, the uniform power density equivalent is the system-noise-bandwidth. MCL spreadsheets in clause 9 have appropriate input "cells" for these parameters (Tx 3-dB bandwidth and Rx system-noise-bandwidth).

In consideration of the discussion above, the P_{FREQ_COL} is determined only by the "instantaneous bandwidth" occupied by both the interferer and the victim, normalized to the total available bandwidth (for example, the entire 3 MHz in the 865 MHz to 868 MHz band).

The narrower this "instantaneous bandwidth" is, either of the victim receiver or the interfering transmitter, the lower the likelihood that they will overlap within the spectrum window of the full band.

The universal formula for P_{FREQ_COL} immediately follows from the following definition of "the frequency collision event":

- The frequency collision event involving two interfering systems with "system noise bandwidths" BW_{INT} and BW_{VICT} occurs if at least half of the spectrum of the narrower bandwidth system overlaps with the spectrum of the other (wider bandwidth) system.

Notice that it really does not matter which of the two systems is the victim or interferer here. It is only their instantaneous bandwidths that determine the probability of overlap.

The figure D.2 illustrates the essence of this definition of the "frequency collision events."

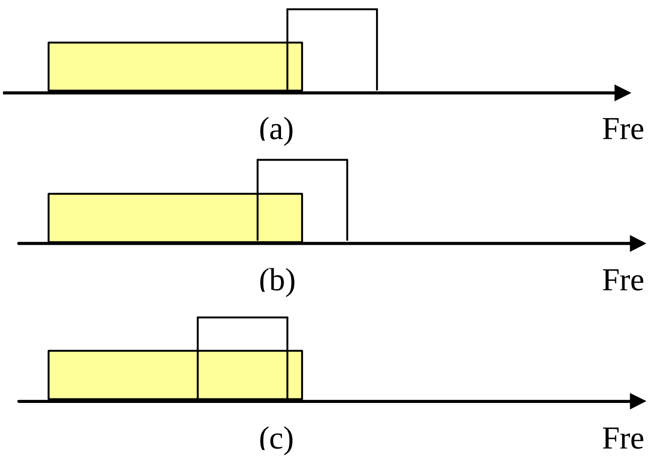

Figure D.2: Definition of instantaneous frequency collision event

The shaded area in figure D.2 represents the wider bandwidth (uniform spectral density equivalent) system spectrum. The shaded spectrum can be either interferer or victim.

Case (a) represents the situation with a marginal frequency overlap. In this case, only a small fraction (and thus below the interference threshold) of the interferer power falls within the victim receiver. Although the spectra overlap somewhat, this still is not considered to be harmful interference.

Case (c) represents a total frequency overlap that definitely would cause harmful interference, if the interfering signal were sufficiently strong.

Somewhere in between Cases (a) and Case (c) is the case when the frequency overlap is such that any further increase would lead to a harmful level of interference. Case (b) represents the case when half of the spectrum of the narrower BW system overlaps with the wider bandwidth one. In this case, approximately half of the narrower system bandwidth is corrupted by interference (in the case where the narrower bandwidth system is the victim) or penetrate the wider bandwidth victim (in the case where the narrower bandwidth system is the interferer). This would constitute a -3 dB overlap. We have used this "half-power" (-3 dB) case as the criteria for defining the "frequency collision event", as discussed above.

The benefits of dynamic frequency assignment in terms of reduction of the probability of frequency collision are realized if just one of the interference elements (the victim or interferer) is of that type. The interference situation generally does not improve by having both the transmitter and receiver changing frequency.

Additional interference mitigation measures such as optimized channel selection (frequency use planning) are not calculated in the analysis, although they can be used to reduce or sometimes even completely eliminate the interference. These techniques are applicable to all systems that feature a channel selection utility such as frequency "hopped systems", which adaptively select their "hopping channels".

D.4.2.4.3.3 Formula for frequency collision

Following the definition of P_{FREQ_COL} given in clause D.4.2.4.3.2, the formula is given by:

$$P_{FREQ\_COLL} = \frac{SPAN_{OVERLAP} \times Max(BW_{INT}, BW_{VIC})}{SPAN_{VIC} \times SPAN_{INT}} \quad \text{(D.18)}$$

where:

$SPAN_{OVERLAP}$: is the frequency overlap range for the interferer and the victim;

$SPAN_{VIC}$: is the allocated frequency range for the victim;

$SPAN_{INT}$: is the allocated frequency range for the interferer;

BW_{VIC} : is the receiver bandwidth of the victim;

BW_{INT} : is the transmit bandwidth of the interferer.

D.4.2.4.4 Probability for time collision

The probability for time collision, P_{time_col}, is given by:

$$P_{time\_col} = \text{transmitter duty cycle} \quad \text{(D.19)}$$

D.4.3 Cumulative probability of interference

Once the interference area is determined (minimum coupling loss translated into distance), a cumulative probability of interference by a single unit, P_{UNIT}, can be calculated as the combined probability of the following uncorrelated events:

a) Probability of antenna beams (interferer and victim) are crossing each other, $P_{PAT\_COL,}$ is the pattern collision probability;

b) Probability of frequency collision, P_{FREQ_COL};

c) Probability of interferer and victim colliding with each other in time domain, P_{TIME_COL}.

Also, one must assume a practical spatial density and calculate the corresponding total number of interferers in the area $N_{\mathbf{INT\_TOT}}$ as described in clause 4.2.3.

The probability of becoming a victim of any one of the potential interferer-s in the area can be calculated as:

$$P_{INTF\_TOT} = 1 - \prod_{N_{INTF\_TOT}(PAT\_COL)} (1 - P_{TIME\_COL} \times P_{FREQ\_COL} \times P_{PAT\_COL}) \quad \text{(D.20)}$$

The product designated by the pi notation in the equation (D.20) has two terms, when the Interferer's antenna is directional, which results in two interfering distances caused by the main beam and sidelobes respectively. Hence, the resulting formula for the total interference probability is:

$$P_{INTF\_TOT} = MIN(\frac{SPAN_{OVERLAP}}{SPAN_{VIC}}, (1-(((1-P_{TIME\_COL} \times P_{FREQ\_COL} \times P_{PAT\_COL\_MAIN})^{N_{INT\_MAIN}} \times (1-P_{TIME\_COL} \times P_{FREQ\_COL} \times P_{PAT\_COL\_SIDELOBE})^{N_{INT\_SIDELOBE}}))) \quad \text{(D.21)}$$

D.4.3.1 Comments on calculations of interference probability

The probabilities of interference are calculated in the Excel worksheets in an annexed file to the present document and the results are presented in clause 9.

Multiple columns per worksheet are sidebands related to a proposed RFID spectrum mask. Each sideband is calculated individually as an interferer. Interference to different victims of RFID and SRD is covered in separate worksheets.

The formulas used in each worksheet are presented in clause 4 and are consistent across the worksheets. Input data is entered on a separate input sheet. Each worksheet is organized in a similar manner, resulting in a set of sheets that is easy to compare, modify or expand by adding new sheets for other systems operating in the 865 MHz to 868 MHz band.

Clause 7 presents the most relevant subset of Interference Probability calculations.

D.5 Presentation of calculated results

D.5.1 Deterministic method

D.5.1.1 Protection distances for co-channel interference

The calculated protection ranges are given in table D.3:

Table D.3: Protection distances for worst case interference

Victim Receiver / Interfering transmitter	SRD receiver with a LBT_{srd} threshold = -90 dBm m	RFID receiver with a sensitivity = --70 dBm m	SRD receiver at I/N = 0 dB (note 3) m
RFID, 2W, e.r.p. BW = 100 kHz	937 (note 1) 515 (note 2)	20 (note 1) 10 (note 2)	3 677 (note 1) 2 040 (note 2)
Unwanted emission -36 dBm/100 kHz	10 (note 1 15 (note 2)	26 (note 1) 10 (note 2)	5 (note 1) 4 (note 2
SRD, 25 mW, BW = 100 kHz	270 (note 1) 147 (note 2)	123 (note 1) 63 (note 2)	805 (note 1) 583 (note 2)
Tag communication -20 dBm/100 kHz	24 (note 1) 35 (note 2)	13 (note 1) 18 (note 2)	31 (note 1) 58 (note 2)

NOTE 1: Indoor to outdoor propagation.
NOTE 2: Indoor to Indoor Propagation (limited to maximum size of building).
NOTE 3: Noise floor in the band is assumed to be +5 dB above KTB and Receiver noise figure of +10 dB.

D.6 Effect of LBT_{rfid} in RFID receivers

The effect of LBT_{rfid} in RFID receivers can be seen from figure D.3.

The boundary line between areas A and B gives the protection distance for an RFID interrogator at 33 dBm e.r.p. to an SRD receiver with an LBT_{srd} threshold of -90 dBm.

The boundary line between areas B and C gives the protection distance for an SRD at 14 dBm e.r.p. to an RFID receiver with an LBT_{rfid} threshold of -96 dBm.

The boundary line between areas A and D gives the protection distance for a tag at -20 dBm e.r.p. to an SRD receiver with an LBT_{srd} threshold of -90 dBm.

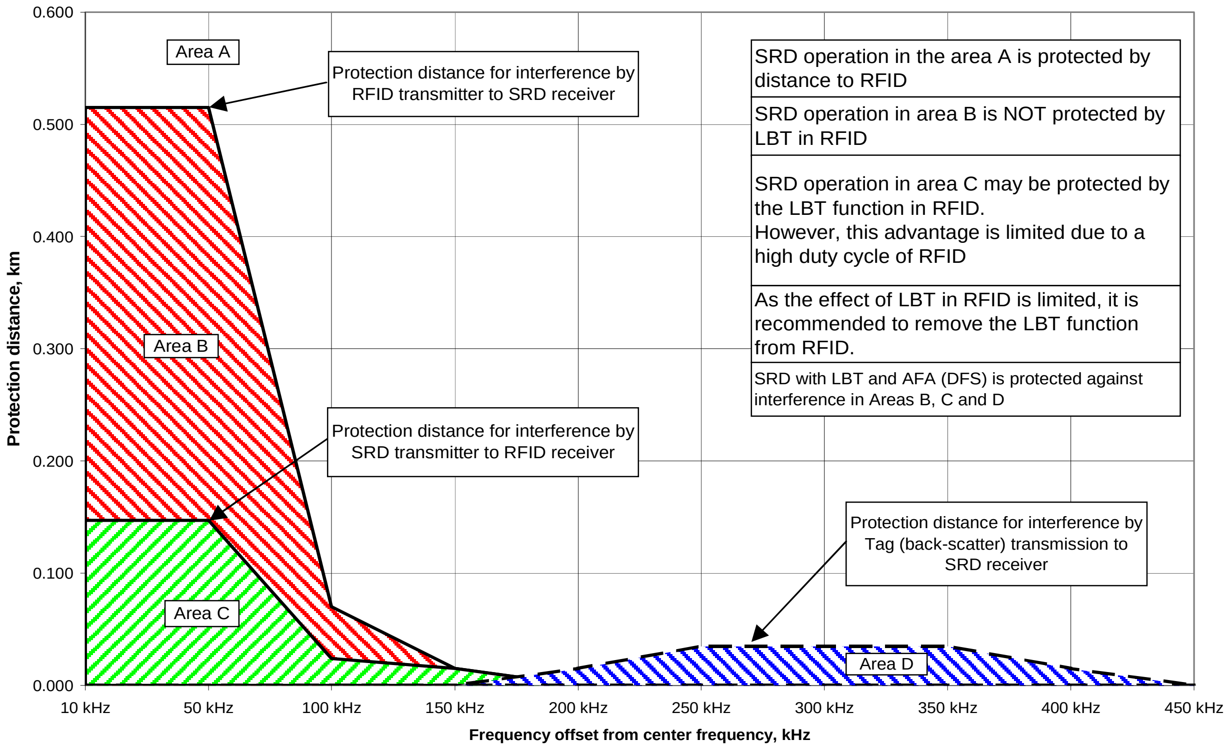

Figure D.3: Distance at which the radiated level is equal to the victim receiver threshold

The following facts from figure D.3 should be considered:

1) RFID is positioned at distance zero in figure D.3.

2) The upper boundary of area B in figure D.3 is the protection distance where RFID triggers the LBT_{srd} threshold of an SRD receiver.

3) It shall be noted that any SRD operation in area A, positioned above area B, is fully protected from interference by distance

4) The lower boundary of area B is the protection distance, below which, an SRD will activate an LBT_{rfid} threshold.

5) SRD operation in area B is not protected by LBT_{rfid} as SRD is not seen by RFID. Therefore the LBT_{srd} in the SRD must detect the transmission from the RFID and move to another channel.

6) SRD operation in area C is protected by LBT_{rfid}/AFA. This may be of limited benefit since the probability is that the channel will be occupied by RFID for much of the time.

7) Effective protection of SRDs from interference in the four high power RFID transmit channels can only be ensured if SRDs are provided with LBT_{srd}/AFA.

8) It should be noted that the area B in figure D.3 increases with increased difference in the radiated equipment power used in the band. (2 W and 25 mW for RFID and SRD respectively).
It should be noted that area B will be zero if the same radiated power level is used by both devices.

The conclusions from the above are:

a) RFID with LBT_{rfid}/AFA does not sufficiently protect SRDs from interference from RFID in the four high power channels;

b) RFID using four fixed high power channels offers improved spectrum access availability for SRDs using LBT_{srd} with AFA.

Based on these facts it is recommended to remove LBT_{rfid} in the 4 high power channels.

D.7 Probabilistic interference calculations

The interference calculations are performed for the selected scenarios. The results (interference probabilities) are calculated for each of the three victims. In order to display the results of the study in a more informative manner, all results are presented in separate graphs:

> The appropriate way of assessing the interference in the band is to calculate the absolute interference probabilities for realistically deployed existing and proposed systems.

D.7.1 Cumulative probability of interference

The cumulative probabilistic interference is shown below in the figures D.4, D.5 and D.6 as a comparison between a 2 W RFID, a tag, a SRD and an unwanted emission limit.

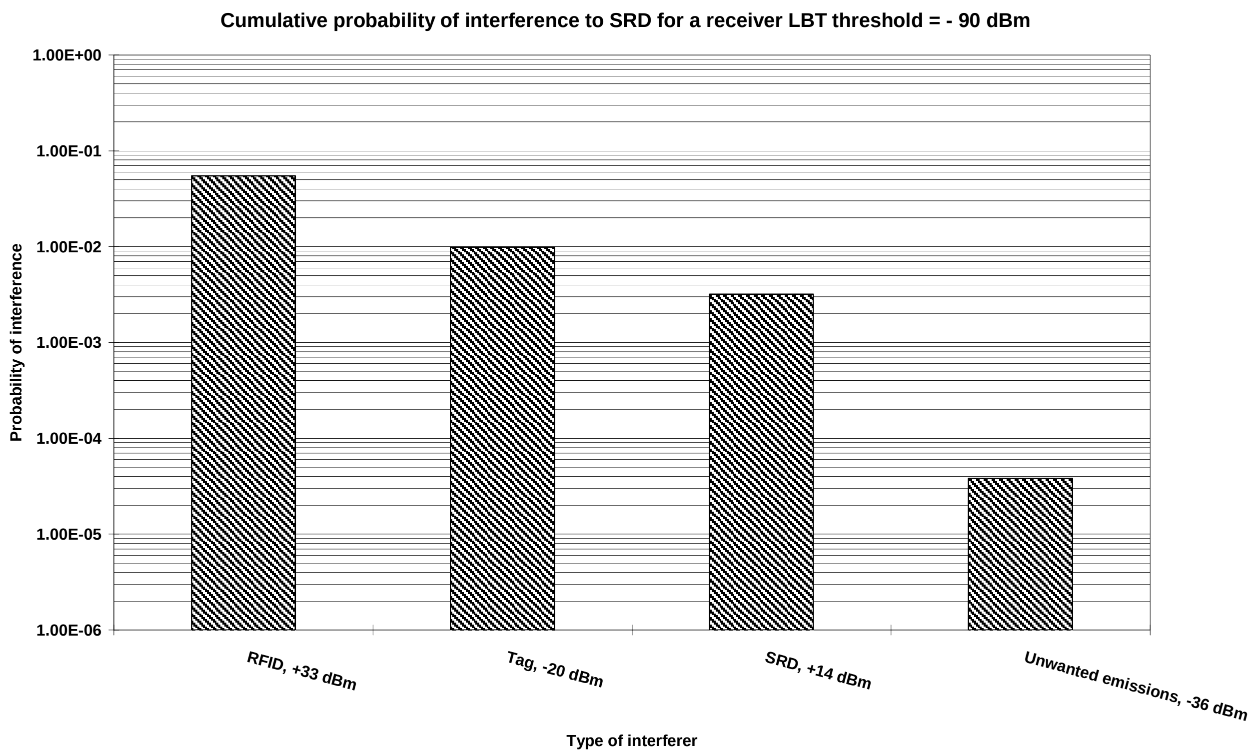

Figure D.4: Cumulative probability of interference to a SRD receiver with a LBT_{srd} threshold = -90 dBm

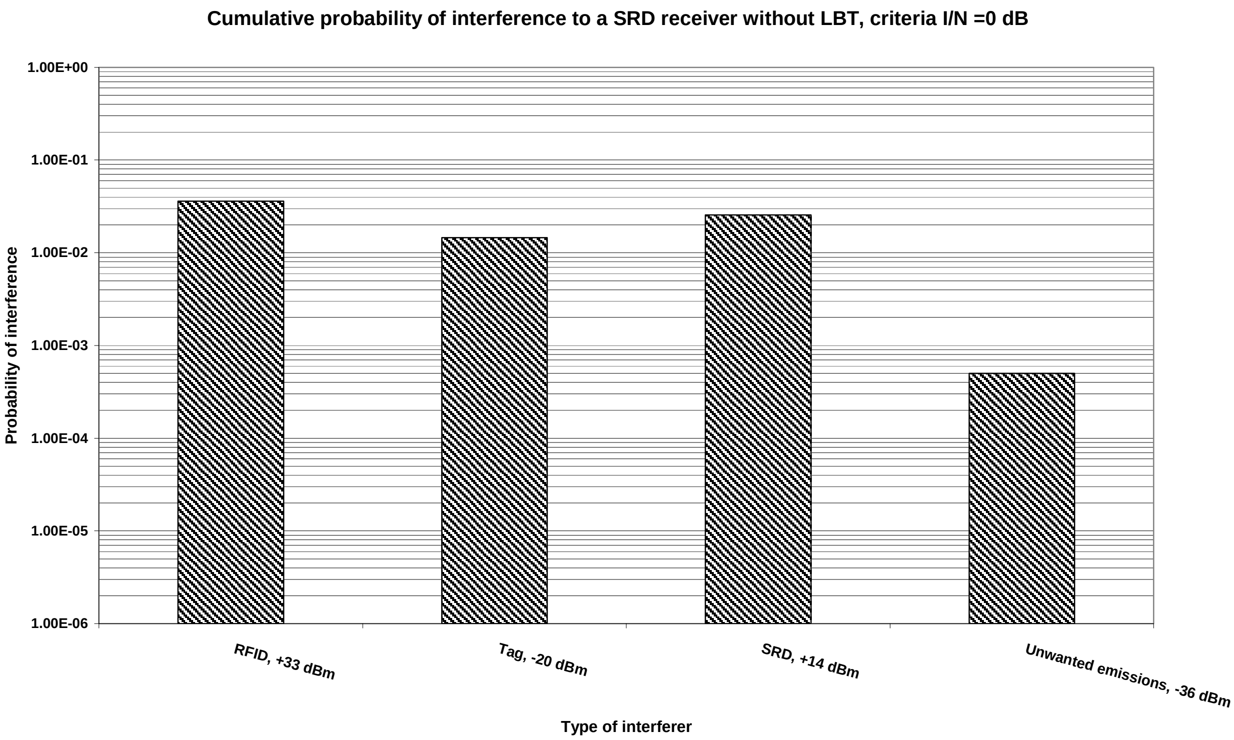

Figure D.5: Cumulative probability of interference to SRD receiver without LBT_{srd}/AFA (criteria I/N = 0 dB)

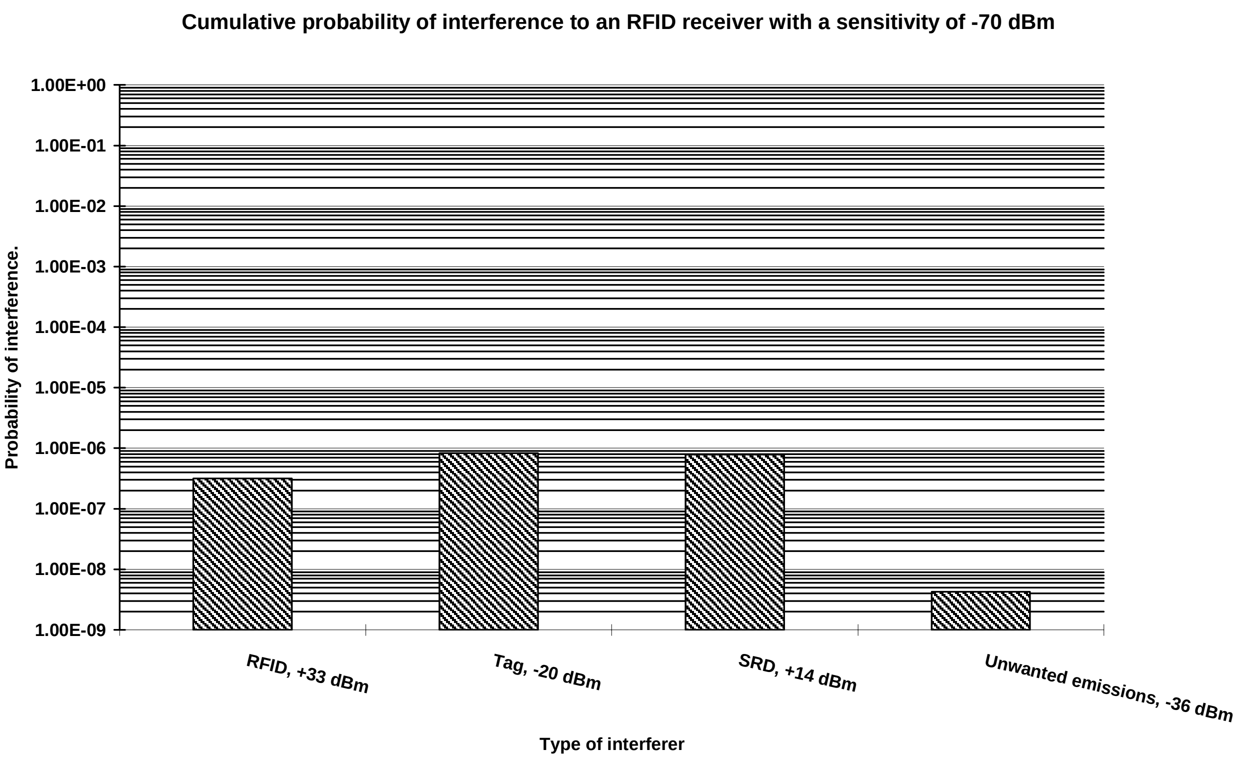

Figure D.6: Cumulative probability of interference to RFID receiver without LBT_{rfid}/AFA

D.8 Conclusions of the feasibility study

The conclusions from the present document are:

a) RFID interrogators can co-exist on the same high power channels as SRDs using LBT_{srd} with AFA, as SRDs will migrate to the low power channels used for the tag's response. RFID with LBT_{rfid} in the high power channels therefore serves no useful purpose.

b) For operational reasons (see example in annex F) end-users regard the use of RFID with LBT_{rfid} in the high power channels as unacceptable.

c) RFID using four fixed high power (2 W) channels offers improved spectrum access availability for SRDs (25 mW) using LBT_{srd}/AFA in the band 865 MHz - 868 MHz as specified in EN 300 220 [14].

d) RFID devices operating with LBT_{rfid}/AFA in the four RFID high power channels provide only very limited protection to SRDs and it is therefore an unnecessary burden for RFID. Conversely, if a SRD is equipped with LBT_{srd}/AFA then this does protect the SRD from interference by RFID. Therefore, LBT/AFA functionality can be removed from RFID.

e) Generic SRDs without LBT_{srd} and AFA may use alternative spectrum access methods such as duty cycle, provided they observe a suitable protection distance. In the four high power RFID channels, this may vary from 918 m (indoor) to 3,6 km (rural outdoor). In the remaining 2,2 MHz, where tags at -20 dBm e.r.p. occupy the spectrum, this may vary from 24 m (indoor) to 58 m (rural outdoor) (see table D.3).

D.9 Excel spread sheets for calculations

The spread sheets for the calculations including the input data are contained in archive tr_10264901v010101p0.zip which accompanies the present document.

Annex E: Dense interrogator scenario and test results

Tests were organized in order to answer questions raised at a meeting of TG34 in May 2006 [18]. These questions concerned the need to validate synchronization techniques fully and to assess the performance of large systems in a dense interrogator operational environment.

To test performance under real life conditions, a large RFID system was installed comprising at least 20 portals at a distribution centre in UNNA, Germany in September 2006. This system was exercised to its maximum capacity.

The test area was 100 m long by 50 m wide with dock doors distributed evenly on either side along the length of the building. The distance between each dock door was approximately 1,2 m. Five manufacturers took part in the tests.

The tests included investigation into alternative channel plans. The results are shown in the summary table E1. The tests validated that the 4 channel plan was preferred.

Pallets were pushed simultaneously through a row of adjacent dock doors. This can be seen in figure E.1. The pallets comprised 62 cartons containing materials that were known to be "rf unfriendly". The number of missed tags averaged over all dock doors was less than 1,5 %. If certain anomalies are excluded from the results, the figure is better than 1 %. It is believed that this level of performance is adequate to meet the operational needs of most end users.

In excess of 4,5 million records were logged during the course of the tests. These were subsequently processed using a special analyser tool and converted into meaningful data.

Table E.1: Summary of channel plan tests

Results of Channel Plan Tests

Test	Baseline tag reads	Missed tags 1,6 s	1,4 s	1,2 s	1 s	0,8 s	0,6 s
5 Channel plan							
Channels 4, 8 and 12	204	0	0	0	0	0,3	0,3
Channels 6, 8 and10	204	25,7	24,7	25	26	25,7	25
4 Channel plan							
Channels 4 and 10	319	0	0	0,3	0,3	2	2,3
Channels 4 and 13	326	0	0	0	0,3	0,7	2,7
Channels 7 and 10	326	0,3	0,3	0,3	0,7	2,7	1

Results of Synchronisation Tests

Type	Baseline	No interferer		1 interferer		2 interferers		3 interferers	
		PRC	%Missed	PRC	%Missed	PRC	%Missed	PRC	%Missed
Radio									
Av of two best results	3139	73,00%	0,53%	61,20%	0,73%	53,26%	1,04%	26,87%	0,91%
Hard wired									
Best	3666	76,89%	1,33%	68,02%	0,83%	53,66%	1,20%	51,63%	1,10%

Results of System Tests

Classification	No Interferer			One Interferer			Three Interferers		
	Wanted	Unwanted	Missed	Wanted	Unwanted	Missed	Wanted	Unwanted	Missed
Radio									
Av of two best	205	4,22%	1,27%	210	4,78%	1,82%	128	0,40%	2,69%
Excluding anomalies			0,91%			0,97%			
Hard wired									
Best	271	2,04%	0,63%	271	1,58%	0,30%	245	1,69%	1,61%
Excluding anomalies			0,21%			0,09%			0,09%

Highlighted results performed with interrogators provided by different manufacturer

	Big Pallet Test	
	Wanted	Missed Tags
One Pallet	494	0,00%
Two Pallets	616	0,01%

	Portal Shielding Test	
	Wanted	Missed Tags
With Shielding		
Without Shielding		

Reads in Database	
2 760 469	Reva
115 847	Symbol
1 652 152	All
4 528 468	**Total**

Figure E.1: Pallets being pushed simultaneously through a row of portals

Figure E.2: Pallet comprising 62 cartons containing materials known to be "rf unfriendly"

Figure E.3: Exterior of distribution centre

Figure E.4: Interior of distribution centre showing portals

Figure E.5: Portal with test tags

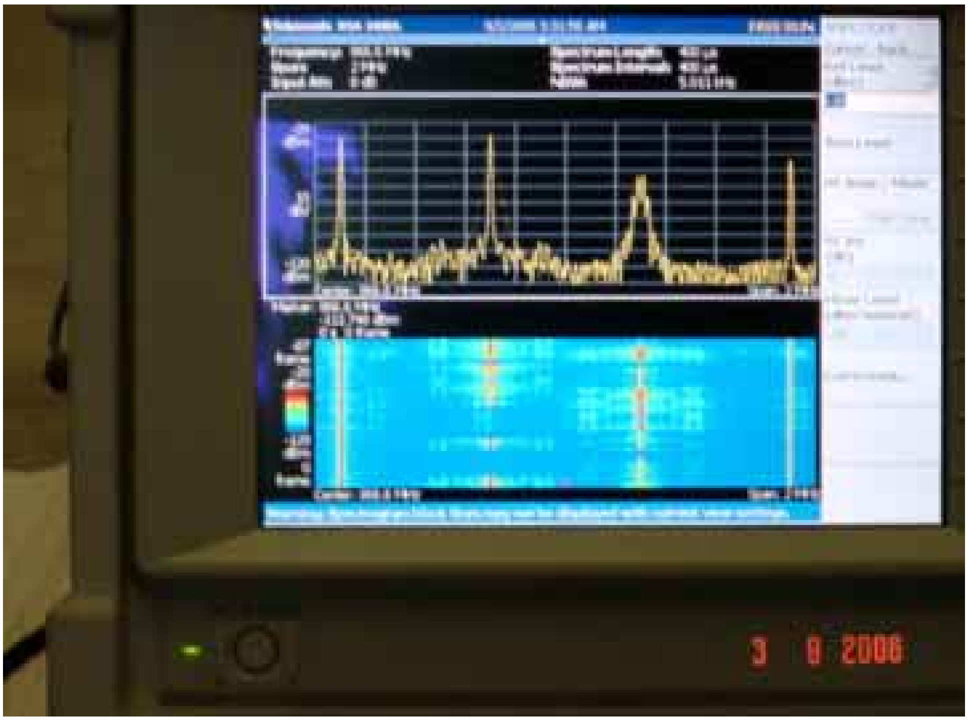

Figure E.6: Display of digital spectrum analyser

Figure E.7: Alternative portal design

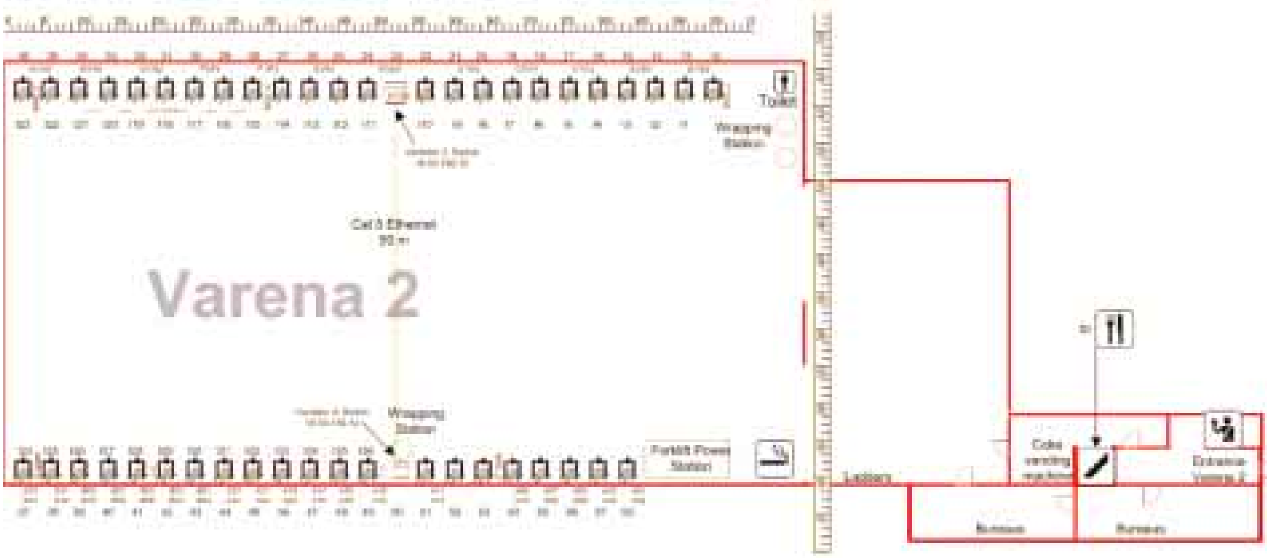

Figure E.8: Plan of test area

Annex F: International Air Transport Association

UHF RFID using LBT_{rfid} does not fulfil the operational requirements for airport baggage handling. This is reflected in the following letter [8]:

Andrew Price
RFID Project Manager
International Air Transport Association
Route de l'aéropot 33
PO Box 416
1215 Geneva 15 Airport
Geneva, Switzerland

Thursday September 14th 2006

Mr John Falk,

Chairman ETSI Task Group 34

Dear Mr Falck,

I am the RFID project manager for RFID in IATA, the International Air Transport Association. We represent 262 air carriers, including cargo airlines, around the globe. I am writing to you to express concerns raised to IATA about the current regulations governing the use of RFID in the UHF band.

IATA has a recommended practice for the use of RFID for baggage handling. This recommendation forms the basis for the adoption of RFID by the aviation community, and has been embraced by projects at Charles de Gaulle Airport, Amsterdam Schiphol Airport and Hong Kong International Airport.

IATA has estimated that using RFID would save the airlines over $760 million per year and that airports can also greatly improve efficiency.

The concern that has been raised is that in those countries governed by ETSI 302-208 there is an opportunity to attack the airport by blocking RFID reader/writers. The listen before talk mechanism means that should an attacker generate signals at the right frequencies then the reader/writers used to identify baggage would be unable to communicate with tags, leading to operational shut down of the baggage handling system. The chaos that this causes was seen during staff walkouts in LHR last year, with up to 70,000 baggage items per day remaining un-delivered.

Whilst the likelihood of an attack being successful is in doubt, as the baggage systems currently use both RFID and Barcodes for identification, the intention is to phase barcodes out over an extended period. Furthermore, I would expect campaigners against RFID to demonstrate the weakness of the system, damaging the credibility of the technology.

I understand that ETSI have made some investigations into this matter and will be meeting next week. I hope that ETSI will be able to offer some advice for resolving the perceived vulnerability. Please may I ask that you raise the concern of IATA and the airline industry to the meeting?

Yours Sincerely,

Andrew Price

History

Document history		
V1.1.1	April 2007	Publication