IEEE P802.11
Wireless LANs

Draft ERC report concerning the proposals for the future use of 2400-2483.5 MHz band based on compatibility studies

SE24(97)14 rev. 7
26 August, 1997

Covering letter to the draft ERC report concerning the proposals for the future use of 2400-2483.5 MHz band based on compatibility studies

Attached to this covering letter is a report concerning the proposals for the future use of 2400 - 2483.5 MHz ISM band based on compatibility studies. This work was requested by the ERC due to the conflicting requirements of a number of services wishing to use this band. There is a requirement for higher power levels for Radio Frequency Identification Devices (RFID) to meet certain operational needs. This report has been drawn up in PT SE24.

The results of the study show that in most cases in the urban environment the risk of interference does not increase significantly with increase in power level from 10 mW to 500 mW. It was also noted that the use of directional antennas for RFID with higher power levels would improve the sharing situation further. Based on this SE24 proposes that the band 2400 - 2483.5 MHz could be segmented according to Table I and RFID should be exempted from individual licensing for power outputs of at least 100 mW (consistent with RLAN arrangements). The power level of licence exempted SRDs shall remain 10 mW.

Table I : Proposed operational characteristics of different classes of RFIDs and a proposed segmentation of the band.

RFID	Power limit EIRP	Estimated System Range			Frequency band	Licensing
		10 kbit/s	100 kbit/s	1 Mbit/s		
Class I	10 mW	11 m	6 m	3 m	2400 - 2483.5 MHz[1]	licence exempted
Class IIa[2]	100 mW	18 m	10 m	6 m	2446 - 2454 MHz	licence exempted
Class IIb[2]	500 mW	27 m	15 m	9 m	2446 - 2454 MHz	[licence exempted or individual licences]

[1] 2400 - 2446 MHz band is prohibited in some CEPT countries.
[2] If RFIDs are exempted from individual licensing for power outputs up to 500 mW, classes IIa and IIb can be combined.

WG SE asks WG FM and WG RR to study the SE24 proposals and make the necessary decisions.

Some administrations have reservations to the proposed classes IIa and IIb, which they will consider by the date of next WGSE meeting. The results will be sent to WGFM.

Draft ERC report concerning the proposals for the future use of 2400-2483.5 MHz band based on compatibility studies

1. Summary

This report deals with the compatibility issues concerning the current and future use of 2400 - 2483.5 MHz. This work was requested by the ERC due to the conflicting requirements of a number of services wishing to use this band. There is a requirement for higher power levels for Radio Frequency Identification Devices (RFID) to meet certain operational needs.

The results of the theoretical calculations are presented in terms of minimum coupling loss (MCL) and minimum geographical distance between different systems. Monte Carlo analysis was not used because of the lack of relevant parameters. If probability factors were taken into account the sharing situation would be easier. Practical measurements were undertaken by one administration and a number of manufacturers, the results of this work were made available to SE24 and have been incorporated into this report.

This report takes into account the changes to recommendation T/R 60-01 [i] , which were agreed by the ERC-meeting in Nicosia, March 1994.

Interrogation equipment (Radio Frequency Identification Devices, **RFID**) was found to be one of the most demanding in terms of the power necessary either for higher link budget margin, more range or a higher data rate to meet the user requirements, and the study therefore focuses on this equipment. The use of RFIDs for many kinds of identification application is increasing rapidly and therefore a frequency band where this equipment can operate properly on harmonised basis should be found.

Tables 1a and 1b are summary tables of the required distances between RFID systems with power levels up to 500 mW, Short Range Devices (**SRD**) and Radio Local Area Networks (**RLAN**). These systems are included in the summary tables as they are the most harmonised existing systems in this band. The other systems were also studied and the complete results are summarised in chapter 4 in this report. The tables give an estimate of the required separation distances between RFIDs with power outputs of 10 mW, 100 mW or 500 mW and the other equipment.

The propagation models which have been used are urban model and modified free space model (see Annex I). Taking account of the likely environment in which this equipment will be used, the urban model is considered to be the most relevant. The modified free space loss results are included for completeness.

The results of the study show that in most cases in the urban environment the risk of interference does not increase significantly with increase in power level from 10 mW to 500 mW. Due to the demand for use of this band, and taking into account good spectrum engineering practice, it is

necessary to restrict the power levels of equipment to that needed for its proper operation. Also, taking account of the worst case interference scenario:
it is proposed to restrict operation at the higher power levels to a narrow sub-band where AVI is already allowed to operate with 500 mW. The use of directional antennas for RFID with higher power levels would improve the sharing situation further.

---

i) T/R 60-01: Short range radio equipment for detection, alert and interrogation using frequencies above 1000 MHz. This draft revision was not published by the ERC in view of the planned replacement of T/R 60-01 by the ERC recommendation on short range devices.

Table 2 is a summary of the operational characteristics of different classes of RFID-equipment, according to power output. A possible segmentation of the band 2400 - 2483.5 MHz is included.

Source -> Victim	**RFID 10mW, h=2m**	**RFID 100mW, h=2m**	**RFID 500mW, h=2m**	**RFID (Container ID) 500 mW, h=5m**
SRD1 (25 kHz)	0,074 - 0,088	0,088 - 0,118	0,099 - 0,186	0,163 - 0,313
SRD2 (1 MHz)	0,056 - 0,067	0,067 - 0,079	0,075 - 0,089	0,084 - 0,110
RLAN	0,051 - 0,060	0,060 - 0,071	0,068 - 0,081	0,074 - 0,091

Table 1a. Required distances (km) - Urban model.

Source -> Victim	**RFID 10mW, h=2m**	**RFID 100mW, h=2m**	**RFID 500mW, h=2m**	**RFID (Container ID) 500 mW, h=5m**
SRD1 (25 kHz)	2,2 - 3,9	3,9 - 7,0	5,9 - 10,4	5,9 - 10,4
SRD2 (1 MHz)	0,4 - 1,2	1,2 - 2,8	2,3 - 4,1	2,3 - 4,1
RLAN	0,2 - 0,6	0,6 - 1,9	1,4 - 2,9	1,4 - 2,9

Table 1b. Required distances (km) - Modified free space model.

RFID	Power limit EIRP	Estimated System Range			Frequency band
		10 kbit/s	100 kbit/s	1 Mbit/s	
Class I	10 mW	11 m	6 m	3 m	2400 - 2483.5 MHz[1]
Class II a	100 mW	18 m	10 m	6 m	2446 - 2454 MHz
Class II b	500 mW	27 m	15 m	9 m	2446 - 2454 MHz

[1] 2400 - 2446 MHz band is prohibited in some CEPT countries.

Table 2. Operational characteristics of different classes of RFID and a possible segmentation of the 2400 - 2483.5 MHz band.

2. The systems using the 2400 - 2483.5 MHz band

2.1. Description of the systems

The systems which are included in this report are listed in Tables 3a and 3b with relevant technical parameters.

The non-specific short range devices (**SRD**) have been divided into two groups: SRD1s are narrow band short range devices with a bandwidth (BW) of 25 kHz and SRD2s are wide band short range devices with a bandwidth of 1 MHz. It should be noted that there is no channel spacing in the relevant ETSI standard.

RLANs are local area networks where the transmission media is radio channels. The power limit of RLANs is 100 mW.

The Radio Frequency Identification Devices (**RFID**) are used in different situations to identify for instance a person or an object passing by an identification point. RFIDs are one of the most demanding in terms of the power necessary either for higher link budget margin, more range or a higher data rate to meet the user requirements, and the study therefore focuses on this equipment.

Container identification systems (**Container ID**) are used to control containers being shipped and stored around the world. The systems are based on ISO 10374 standard and the recommended power power level is up to 500 mW.

The **railways' AVI** system is an automatic vehicle identification system where the transponder will transfer information about the vehicle to the general traffic and vehicle management systems of the railway operator when the train equipped with a transponder tag passes the interrogator. The AVI system is active only when the train passes the interrogator. The power limit for AVI is 500 mW (EIRP).

Fixed radio relays and tactical radio relays are using channel 2425.5-2446.5 MHz in France. The interference calculations have only been made one way (interference from SRD to radio relays), because all information about radio relays was not available.

Measurements have been undertaken by one administration and a number of manufacturers. The systems studied are in Table 3b and the results of the study are in section 5, Table 5. The results of the measurements have also been converted to Minimum Coupling Losses (MCL) in table 6 so that the results can be compared with the theoretical studies. Mobile video-linking systems partly operating in the ISM band are used to link video from for instance vehicles up to helicopters. A company is installing a spread spectrum radio data network (RLAN) in the 2.4000-2.4835 GHz. Radio labels are used in different identification systems (RFIDs).

Amateur service which also uses this band on a secondary basis is excluded from this report, since the parameters of the amateur equipment varies very much and typical values are difficult to be determined.

2.2. Calculation of the receiver sensitivity

The sensitivity values ($P_{rx,min}$ [dBm]) in Table 3a have been calculated with the formula:

$$P_{rx,min} \, [dBm] = kTB \, [dBm] + NF \, [dB] + C/N \, [dB], \qquad (1)$$

where k= $1.38 \times 10^{-23} WK^{-1}Hz^{-1}$,
T=300 K,
B = receiver bandwidth
NF = Noise Figure,
C/N = Carrier to Noise

The sensitivity values in Table 3a have been calculated with typical values of NF (10 dB) and C/N (17 dB, RLAN 10 dB) and there may be differences between equipment. The ETSI standards covering SRDs do not normally define sensitivity limits for receivers.

The differences in NF, C/N and receiver antenna gains have been taken into account by calculating an estimated permissible interference power level range (dBm) from the sensitivity values by adding and subtracting 5 dB. There may, of course, be equipment which has maximum permissible interference values outside the range in Table 3a.

2.3. Relevant technical parameters of the systems using the 2400 - 2483.5 MHz band

System	EIRP [mW/dBm]	BW [MHz]	Sensitivity $P_{rx,min}$ [dBm]	Estimated permissible interference power level [dBm]	typical antenna height [m]
SRD1	10 / 10	0.025	-102.9	-97.9 ... -107.9	2
SRD2	10 / 10	1	-86.9	-81.9 ... -91.9	2
RLAN	100 / 20	20	-80.9	-75.9 ... -85.9	2
RFID 1 (distance 1m)	10 / 10	TX CW (0.025) RX 1	-86.9	-81.9 ... -91.9	2
RFID 2 (distance 3m)	25 / 14	TX CW (0.025) RX 1	-86.9	-81.9 ... -91.9	2
RFID 3 (distance 6m)	100 / 20	TX CW (0.025) RX 1	-86.9	-81.9 ... -91.9	2
RFID 4 (distance 10m)	500 / 27	TX CW (0.025) RX 1	-86.9	-81.9 ... -91.9	2
Container ID	500 / 27	TX CW (0.025) RX 1	-85	-80 ... -90	5
Railways' AVI 2446-2454 MHz	500 / 27 (vertical) 50 / 17 (horizontal)	1.6	-84 (draft ETSI)	-96 (C/I=12 dB)	1
Radio relays France	- (Tactical relays) - (Fixed relays)	1.5 21		-110,7 -103	17 50

Table 3a - systems using the 2400 - 2483.5 MHz band.

2.4. Relevant technical parameters of the measured equipment

System	EIRP [mW/dBm]	BW [MHz]	Sensitivity [dBm]
Mobile videolink	(12,6 W / 41) 39,8 W / 46	20	-87
RLAN/NCR	100 / 20	20	-82
radio-data/ECT	1000 / 30 vehicle 316 / 25	5	-102
RFID Amtech/ Radio Holland	500 / 27 (15,85 W / 42)	0.130	-100
RFID / NEDAP	2 W / 33 (200mW now)	0.010	-100
RFID/ PTT-Research	2 W / 33	0.400	-85

Table 3b - systems studied in the practical tests.

3. RFID's (Microwave transponder systems) in the 2400-2483.5 MHz band

3.1. System function

The system consists of interrogators and transponders (tags) operating at microwave ISM bands. The interrogator comprises a microwave transceiver using ASK transmit and PSK (or QPSK) receive modulation. The transponder in its simplest form consists of a low frequency data receiver, data logic circuits, a low frequency data transmitter, battery for the circuits, microwave antenna and diode, see figure 1.

The interrogator transmitted ASK modulation is AM-detected by the transponder microwave-diode, amplified, decoded by the data receiver and validated by the logic circuits. When the interrogator transmitter is unmodulated, the transponder is able to respond to the interrogator by modulating the received carrier and the modulated signal is then re-radiated from the transponder. One or both of the re-radiated side bands may be received by the interrogator.

The use of directional antennas will improve the functionality of RFID systems as well as the frequency sharing situation.

As the transponder is without any essential RF selectivity the transponder can interrogate within a wide frequency range. To prevent unwanted interrogations the transponder may be designed with an access protocol for the specific application and/or a RF level threshold. However, this is not the case for all of the present systems.

The transponder does not generate any microwave carrier frequency itself but uses the received carrier power from the interrogator. Consequently, within the bandwidth limits, the transponder will automatically track the interrogator frequency when used in a multi-channel or spread spectrum scheme.

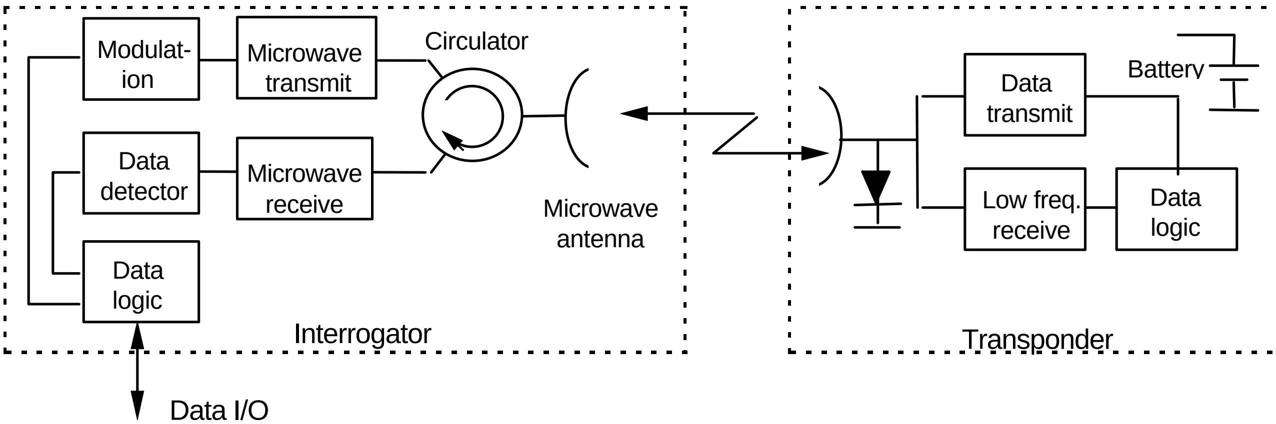

Figure 1. Transponder and interrogator principles.

3.2. Link budget for RFID

3.2.1. Power Link budget analysis.

Link budget margin (LBM) for a reflective transponder system is calculated below:

$$EIRP[dBm] - PL[dB] + G_{tag}\ [dB] - CL_{tag}\ [dB] + G_{tag}\ [dB] - PL[dB] + G_{rx}[dB] - P_{rx,min}\ [dBm] = LBM[dB]$$

$$\Leftrightarrow\ EIRP[dBm] - 2*PL[dB] + 2*G_{tag}\ [dB] - CL_{tag}\ [dB] + G_{rx}[dB] - P_{rx,min}\ [dBm] = LBM[dB] \qquad (2)$$

where

EIRP = interrogator power level,

$$PL = 20\log_{10}\frac{4\pi D}{\lambda}\quad[dB] \text{ = path loss,} \qquad (3)$$

G_{tag} = transponder (= tag) antenna gain,
CL_{tag} = transponder (= tag) conversion loss,
G_{rx} = interrogator receiver antenna gain,
$P_{rx,min}$ = interrogator receiver sensitivity

For 2.45 GHz in equation (3) inserted in (2):

$$EIRP[dBm] - 80.4[dB] - 40*\log d[m] + 2*G_{tag}[dB] - CL_{tag}[dB] + G_{rx}[dB] - P_{rx,min}[dBm] = LBM[dB] \quad (4)$$

or

$$EIRP[dBm] = 80.4[dB] + 40*\log d[m] - 2*G_{tag}[dB] + CL_{tag}[dB] - G_{rx}[dB] + P_{rx,min}[dBm] + LBM[dB] \quad (5)$$

The terms ($-2*G_{tag}$ [dB] + CL_{tag} [dB]) are often summarised in an overall transponder gain G_{tr} [dB], when the Equation (5) can be reduced:

$$EIRP[dBm] = 80.4[dB] + 40*\log d[m] - G_{tr}[dB] - G_{rx}[dB] + P_{rx,min}[dBm] + LBM[dB] \quad (6)$$

3.2.2. Example of Link Budget:

The required EIRP [dBm] is calculated using the following data:

Communication range	d	= max 10 m
Frequency	f	= 2.45 GHz
Data rates	Dr	= 10 kbit/s, 100 kbit/s or 1 Mbit/s
Receiver noise figure	NF	= 10 dB
Carrier to noise ratio	C/N	= 17 dB (for BER = 10^{-6})
Sensitivity /data rates	$P_{rx,min}$	= -80.9 dBm / 10 kbit/s
(see Annex II)	$P_{rx,min}$	= -90.9 dBm / 100 kbit/s
	$P_{rx,min}$	= -101 dBm / 1 Mbit/s
Interrogator antenna gain	G_{rx}	= 10 dB, (4 patch array)
Tag antenna gain	G_{tag}	= 4 dB, (Single patch)
Tag conversion loss	CL_{tag}	= 7 dB
Link Budget Margin	LBM	= 0 dB

The above data used in equations (3) and (6) and the calculated result is shown in figure 2 below (for calculation details see Annex II):

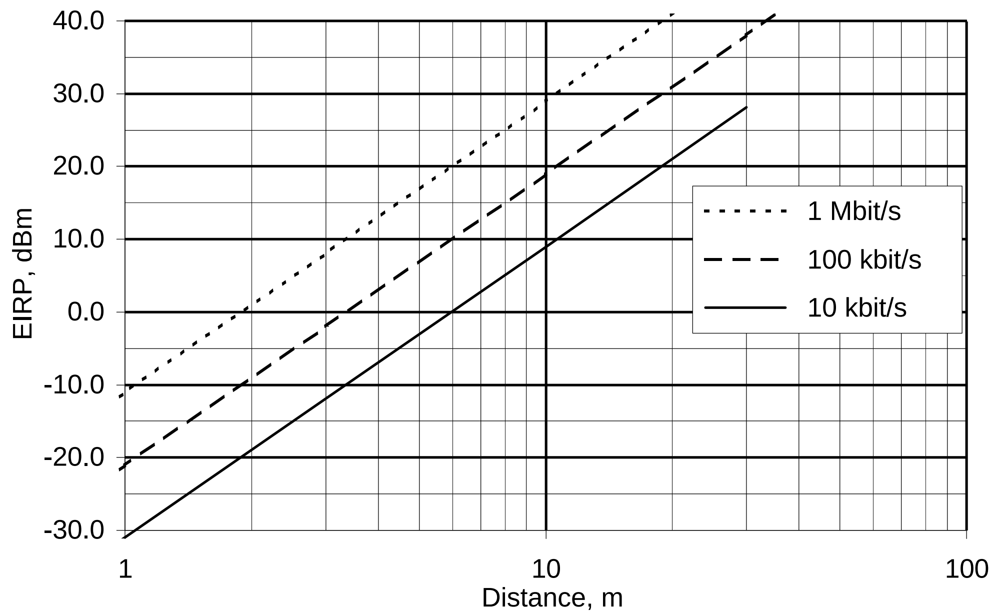

Figure 2: EIRP vs distance d at 2.45 GHz.

Assuming a link budget margin of 0 dB, Figure 2 indicates that a EIRP of 10 mW (+10 dBm) supports transponder system ranges of 3 m, 6 m and 11 m for a data rate of 1 Mbit/s, 100 kbit/s and 10 kbit/s respectively.

However, some systems require either a higher link budget margin, more range or a high data rate for proper operation. A high EIRP is needed in these cases. As an example, the ISO 10374 standard for world wide container identification recommends an EIRP of 500 mW (+27 dBm) and 13 meters range for a data rate of approx. 65 kbit/s.

4. Calculations

The minimum coupling loss (MCL) between the source (s) and the victim (v) has been calculated by using the formula:

$$MCL[dB] = EIRP_s\,[dBm] + 10\log(BW_v / BW_s) - Max\ perm.\ interference_v\,[dBm] \qquad (7)$$

if $BW_V > BW_S$, then $10\log(BW_V/BW_S) = 0$

The distance (d) has been calculated by using urban model and modified free space model (rural case), see Annex I.

		MCL(dB)										
2450	**MHz**	**TX ant. height (m)**	2	2	2	2	2	2	2	5	1	1
		EIRP (dBm)	10	10	20	10	14	20	27	27	27	17
		BW / TX (MHz)	0.025	1	20	0.025	0.025	0.025	0.025	0.025	1.6	1.6
BW	**Max perm.**											
RX	**interf.**		**source**									
(MHz)	**(dBm)**		SRD1	SRD2	RLAN	general ID1	general ID2	general ID3	general ID4	Container ID	Railways'	AVI
		victim									(vertical)	(horiz)
0.025	-97.9	SRD1	*	91.9	88.9	107.9	111.9	117.9	124.9	124.9	106.8	96.8
0.025	-107.9		*	101.9	98.9	117.9	121.9	127.9	134.9	134.9	116.8	106.8
1	-81.9	SRD2	91.9	*	88.9	91.9	95.9	101.9	108.9	108.9	106.9	96.9
1	-91.9		101.9	*	98.9	101.9	105.9	111.9	118.9	118.9	116.9	106.9
20	-75.9	RLAN	85.9	85.9	*	85.9	89.9	95.9	102.9	102.9	102.9	92.9
20	-85.9		95.9	95.9	*	95.9	99.9	105.9	112.9	112.9	112.9	102.9
1	-81.9	general ID1	91.9	91.9	88.9	*	95.9	101.9	108.9	108.9	106.9	96.9
1	-91.9		101.9	101.9	98.9	*	105.9	111.9	118.9	118.9	116.9	106.9
1	-81.9	general ID2	91.9	91.9	88.9	91.9	*	101.9	108.9	108.9	106.9	96.9
1	-91.9		101.9	101.9	98.9	101.9	*	111.9	118.9	118.9	116.9	106.9
1	-81.9	general ID3	91.9	91.9	88.9	91.9	95.9	*	108.9	108.9	106.9	96.9
1	-91.9		101.9	101.9	98.9	101.9	105.9	*	118.9	118.9	116.9	106.9
1	-81.9	general ID4	91.9	91.9	88.9	91.9	95.9	101.9	*	108.9	106.9	96.9
1	-91.9		101.9	101.9	98.9	101.9	105.9	111.9	*	118.9	116.9	106.9
1	-80	Container ID	90.0	90.0	87.0	90.0	94.0	100.0	107.0	*	105.0	95.0
1	-90		100.0	100.0	97.0	100.0	104.0	110.0	117.0	*	115.0	105.0
1.6	-96	Railways' AVI	106.0	106.0	105.0	106.0	110.0	116.0	123.0	123.0	*	*
1.5	-110.7	Tactical FH	120.7	120.7	119.5	120.7	124.7	130.7	137.7	137.7	137.4	127.4
21	-103	Fixed FH	113.0	113.0	123.0	113.0	117.0	123.0	130.0	130.0	130.0	120.0

Table 4a - Calculated Minimum Coupling Losses (MCL).

d (km) urban model	**source**									
	SRD1	SRD2	RLAN	general ID1	general ID2	general ID3	general ID4	Container ID	AVI 500	mW
victim	10 mW	10 mW	100 mW	10 mW	25 mW	100 mW	500 mW	500 mW	(vertical)	(horiz)
SRD1	*	0.056	0.053	0.074	0.079	0.088	0.099	0.163	0.070	0.060
	*	0.067	0.063	0.088	0.094	0.118	0.186	0.313	0.083	0.070
SRD2	0.056	*	0.053	0.056	0.060	0.067	0.075	0.084	0.070	0.060
	0.067	*	0.063	0.067	0.071	0.079	0.089	0.110	0.083	0.070
RLAN	0.051	0.051	*	0.051	0.054	0.060	0.068	0.074	0.066	0.056
	0.060	0.060	*	0.060	0.064	0.071	0.081	0.091	0.077	0.066
general ID1	0.056	0.056	0.053	*	0.060	0.067	0.075	0.084	0.070	0.060
	0.067	0.067	0.063	*	0.071	0.079	0.089	0.110	0.083	0.070
general ID2	0.056	0.056	0.053	0.056	*	0.067	0.075	0.084	0.070	0.060
	0.067	0.067	0.063	0.067	*	0.079	0.089	0.110	0.083	0.070
general ID3	0.056	0.056	0.053	0.056	0.060	*	0.075	0.084	0.070	0.060
	0.067	0.067	0.063	0.067	0.071	*	0.089	0.110	0.083	0.070
general ID4	0.056	0.056	0.053	0.056	0.060	0.067	*	0.084	0.070	0.060
	0.067	0.067	0.053	0.067	0.071	0.079	*	0.110	0.083	0.070
Container ID	0.057	0.057	0.054	0.057	0.062	0.070	0.081	*	0.075	0.062
	0.070	0.070	0.066	0.070	0.076	0.086	0.099	*	0.090	0.075
Railways' AVI	0.069	0.069	0.068	0.069	0.074	0.082	0.092	0.118	*	*
Tactical FH	0.248	0.248	0.229	0.248	0.322	0.477	0.753	1.364	0.607	0.316
Fixed FH	0.238	0.238	0.471	0.238	0.313	0.471	0.760	1.411	0.618	0.312

Table 4b - Calculated minimum required distance (urban model).

d (km) modif. free space	source									
	SRD1	SRD2	RLAN	general ID1	general ID2	general ID3	general ID4	Container ID	AVI 500	mW
victim	10mW	10mW	100 mW	10 mW	25 mW	100 mW	500 mW	500 mW	(vertical)	(horiz)
SRD1	*	0.383	0.271	2.200	2.769	3.912	5.853	5.853	2.069	0.677
	*	1.210	0.855	3.912	4.925	6.956	10.408	10.408	3.680	2.069
SRD2	0.383	*	0.271	0.383	0.608	1.213	2.330	2.330	2.072	0.679
	1.213	*	0.857	1.213	1.922	2.769	4.144	4.144	3.684	2.072
RLAN	0.192	0.192	*	0.192	0.305	0.608	1.361	1.361	1.361	0.430
	0.608	0.608	*	0.608	0.963	1.922	2.934	2.934	2.934	1.361
general ID1	0.383	0.383	0.271	*	0.608	1.213	2.330	2.330	2.072	0.679
	1.213	1.213	0.857	*	1.922	2.769	4.144	4.144	3.684	2.072
general ID2	0.383	0.383	0.271	0.383	*	1.213	2.330	2.330	2.072	0.679
	1.213	1.213	0.857	1.213	*	2.769	4.144	4.144	3.684	2.072
general ID3	0.383	0.383	0.271	0.383	0.608	*	2.330	2.330	2.072	0.679
	1.213	1.213	0.857	1.213	1.922	*	4.144	4.144	3.684	2.072
general ID4	0.383	0.383	0.271	0.383	0.608	1.213	*	2.330	2.072	0.679
	1.213	1.213	0.857	1.213	1.922	2.769	*	4.144	3.684	2.072
Container ID	0.308	0.308	0.218	0.308	0.488	0.974	2.089	*	1.725	0.545
	0.974	0.974	0.689	0.974	1.544	2.482	3.714	*	3.303	1.725
Railways' AVI	1.944	1.944	1.739	1.944	2.482	3.507	5.247	5.247	*	*
Tactical FH	4.596	4.596	4.277	4.596	5.786	8.173	12.229	12.229	12.033	6.767
Fixed FH	2.950	2.950	5.247	2.950	3.714	5.247	7.850	7.850	7.850	4.415
Tactical FH (free space)	10.564	10.564	9.149	10.564	16.743	33.407	74.788	74.788	72.414	22.899
Fixed FH (free space)	4.353	4.353	13.767	4.353	6.900	13.767	30.820	30.820	30.820	9.746

Table 4c - Calculated minimum required distance (modified free space model). Note: the last two rows have been calculated both with the modified free space model and the free space model.

5. Results from the measurements

Measurements were made by one administration and a number of manufacturers in 1993. A short description of the systems operating in the band and their relevant technical specifications can be found in sections 2.1 and 2.4 (table 3b).

The interference between different systems were measured. Table 5 contains the measurement results in terms of C/I . These C/Is are valid for systems with the same centre frequency or in case of the spread spectrum systems (RLAN/NCR, radiodata-RLAN/ECT) the most unfavourable frequency.

Source -> Victim	**RFID**	**Mobile Video Link**	**RLAN / NCR**	**Radiodata / ECT**	**CW**
RFID	***	-15	-20	-15	+10
Mobile Video Link	+31	***	+27	+15	+31
RLAN / NCR	+12	+7	***	+25	+12
Radiodata / ECT	-12	0	-10	***	-5

Table 5. Measured C/I-values (Carrier to Interference).

The Minimum Coupling Losses (MCL) have been calculated from the C/I-values in table 5 with the formula:

$$MCL\ [dB] = EIRP_s\ [dBm] - P_{rx,min,v}\ [dBm] + C/I\ [dB] \qquad (8)$$

Source-> Victim MCL	**RFID 33 dBm**	**Mobile Video Link 46 dBm**	**RLAN / NCR 20 dBm**	**Radiodata / ECT 25 dBm**
RFID	***	131	100	110
Mobile Video Link	**151**	***	134	127
RLAN / NCR	**127**	**135**	***	**132**
Radiodata / ECT	**123**	**148**	112	***

Table 6. Calculated MCL-values. The direction, which determines the necessary MCL is marked with bold text.

The results of the theoretical calculations in section 4 show that the minimum coupling loss (MCL) between RFID with a power of 500 mW and RLAN shall be about 103 - 113 dB. If the power of the ID would be 2W as in the measurements, the MCL would be 109 - 119 dB. The MCL-values calculated in Table 6 between RFID and RLANs are 123 and 127 dB. The difference between measured values in Table 6 and calculated values shows how difficult it is to evaluate the risk of interference because the receiver parameters of devices are not standardized.

6. Conclusions and proposed solution.

The results of the study show that in most cases in the urban environment the risk of interference does not increase significantly with increase in power level from 10 mW to 500 mW. Due to the demand for use of this band, and taking into account good spectrum engineering practice, it is necessary to restrict the power levels of equipment to that needed for its proper operation. Also, taking account of the worst case interference scenario:
it is proposed to restrict operation at the higher power levels to a narrow sub-band where AVI is already allowed to operate with 500 mW. The use of directional antennas for RFID with higher power levels would improve the sharing situation further.

Table 7 is a summary of the operational characteristics of different classes of RFID-equipment, according to power output. A possible segmentation of the band 2400 - 2483.5 MHz is included.

RFID	Power limit EIRP	Estimated System Range			Frequency band
		10 kbit/s	100 kbit/s	1 Mbit/s	
Class I	10 mW	11 m	6 m	3 m	2400 - 2483.5 MHz[1]
Class II a	100 mW	18 m	10 m	6 m	2446 - 2454 MHz
Class II b	500 mW	27 m	15 m	9 m	2446 - 2454 MHz

[1] 2400 - 2446 MHz band is prohibited in some CEPT countries.

Table 7. Operational characteristics of different classes of RFID and a possible segmentation of the 2400 - 2483.5 MHz band.

Class II a and Class II b in Table 7 above have identical restrictions by the proposed frequency band. Consequently, the Classes II a and II b could be combined into one common Class II with a 500 mW power limit. This reduces Table 7 to Table 8 below:

RFID	Power limit EIRP	Estimated System Range			Frequency band
		10 kbit/s	100 kbit/s	1 Mbit/s	
Class I	10 mW	11 m	6 m	3 m	2400 - 2483.5 MHz[1]
Class II	500 mW	27 m	15 m	9 m	2446 - 2454 MHz

[1] 2400 - 2446 MHz band is prohibited in some CEPT countries.

Table 8. Reduced table 7.

The proposed frequency band restriction for Class II, 2446 - 2454 MHz, is already allocated and in use for Railways' AVI (AVI = Automatic Vehicle Identification) using an EIRP of 500mW (+ 27 dBm). Therefore, combining the Railways' AVI and RFID transponder applications would offer maximum utilisation of the band 2446 - 2454 MHz. The minimum required distances between RFID output powers of 100 mW and 500 mW are below 100 m (calculated with the urban model. This distance is even smaller, when the horizontal coupling loss, about 10 dB, is taken into account.

ANNEX I

Urban model:

(derived from an empirical formula described in ITU-R Report 567-4 (extended version, approved by PT SE21)

L (dB): propagation loss
f (MHz): frequency
Hm (m): shorter antenna height
Hb (m): taller antenna height
d (km): distance between the receiver and the transmitter

d > 100m:

a(Hm) = (1.1 log(f) - 0.7).min(10;Hm) - (1,56 log(f) - 0.8) + max(0;20 log(Hm/10))
b(Hb) = min(0;20 log(Hb/30))

f < 150 MHz:

L(d) = 126.61 - 20 log(150/f) - 13.82 log(max(30;Hb)) + (44.9 - 6.55 log(max(30;Hb))) log(d) - a(Hm) - b(Hb)

150 MHz < f < 1500 MHz:

L(d) = 69.6 + 26.2 log(f) - 13.82 log(max(30;Hb)) + (44.9 - 6.55 log(max(30;Hb))) log(d) - a(Hm) - b(Hb)

1500 MHz < f < 2000

L(d) = 46.3 + 33.9 log(f) - 13.82 log(max(30;Hb)) + (44.9 - 6.55 log(max(30;Hb))) log(d) - a(Hm) - b(Hb)

2000 MHz < f :

L(d) = 125.19 + 10 log(f) - 13.82 log(max(30;Hb)) + (44.9 - 6.55 log(max(30;Hb))) log(d) - a(Hm) - b(Hb)

If **d < 40m**, then L(d) = 32,4 + 20log(f) + 20log(d)

If **40m < d < 100m**, then L(d) = L(40) + (log(d)-log(40))/(log(100)-log(40))*(L(100)-L(40))

Modified free space model:

L[dB]: propagation loss
d[m]: distance between the receiver and the transmitter
h_t [m]: the transmitter antenna height
h_r [m]: the receiver antenna height

$L(d) = 20\log(4\pi d[m]/\lambda)$, if $d < 4\pi h_t h_r/\lambda$,

$L(d) = 20\log(4\pi d[m]^2/\lambda) - 20\log(\lambda/4\pi h_t h_r)$, if $d > 4\pi h_t h_r/\lambda$,

Annex II

EIRP vs Distance for different data rates

Summary af data A, B & C (from below)

	0.1	0.3	1	3	10	30	100
1 Mbit/s	-51.0	-31.9	-11.0	8.1	29.0	48.1	69.0
100 kbit/s	-61.0	-41.9	-21.0	-1.9	19.0	38.1	59.0
10 kbit/s	-71.0	-51.9	-31.0	-11.9	9.0	28.1	49.0

A. Data rate = 1 Mbit/s

Distance, m	0.1	0.3	1	3	10	30	100
Receiver sensitivity, dBm	-80.9	-80.9	-80.9	-80.9	-80.9	-80.9	-80.9
Interrogator antenna gain, dB	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Transponder total gain, dB	1	1	1	1	1	1	1
Total pathloss, up and down link, dB	40.4	59.5	80.4	99.5	120.4	139.5	160.4
System margin, dB	0	0	0	0	0	0	0
Effective Isotropic Radiated Power, dBm	-51.0	-31.9	-11.0	8.1	29.0	48.1	69.0

B. Data Rate = 100 kbit/s

Distance, m	0.1	0.3	1	3	10	30	100
Receiver sensitivity, dBm	-90.9	-90.9	-90.9	-90.9	-90.9	-90.9	-90.9
Interrogator antenna gain, dB	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Transponder total gain, dB	1	1	1	1	1	1	1
Total pathloss, up and down link, dB	40.4	59.5	80.4	99.5	120.4	139.5	160.4
System margin, dB	0	0	0	0	0	0	0
Effective Isotropic Radiated Power, dBm	-61.0	-41.9	-21.0	-1.9	19.0	38.1	59.0

C. Data rate = 10 kbit/s

Distance, m	0.1	0.3	1	3	10	30	100
Receiver sensitivity, dBm	-101	-101	-101	-101	-101	-101	-101
Interrogator antenna gain, dB	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Transponder total gain, dB	1	1	1	1	1	1	1
Total pathloss, up and down link, dB	40.4	59.5	80.4	99.5	120.4	139.5	160.4
System margin, dB	0	0	0	0	0	0	0
Effective Isotropic Radiated Power, dBm	-71.0	-51.9	-31.0	-11.9	9.0	28.1	49.0

Receiver sensitivity calc

Data rate	10 kbit/s	100 kbit/s	1 Mbit/s
Rx bandwidth	20 kHz	200 kHz	2 MHz
KTB	-130.9 dBm	-120.9 dBm	-110.9 dBm
Noise figure	10 dB	10 dB	10 dB
Carrier to noise ratio for BER = 1 *E-06	17 dB	17 dB	17 dB
Receiver sensitivity	-103.9 dBm	-93.9 dBm	-82.9 dBm