Electronic Communications Committee (ECC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

COMPATIBILITY OF SRD IN THE FM RADIO BROADCASTING BAND

Hradec Kralove, October 2005

EXECUTIVE SUMMARY AND CONCLUSIONS

This report details both exhaustive laboratory test campaigns and field trials which have been carried out to assess the impact of Short Range Devices (SRDs) on broadcasting reception in Band II (87.5 MHz to 108 MHz), also known as the "FM band". SRD devices, operating on a global market basis in the band 88 – 108 MHz, are typically used for the purpose of listening to MP3/CD players on a home or car FM radio receiver. The findings of these studies may be used to inform the debate within CEPT regarding potential amendments to ETSI Standard EN 301 357 [1] for the inclusion of Band II (FM-Band) SRD devices and focussed on:

- What radiated radio frequency power level(s) would be required to provide satisfactory domestic and in-car SRD performance;
- What would be the compatibility issues relating to a given radiated power level, e.g. required frequency separation to prevent interference to radio programme reception in adjacent channels.

In addition, to these practical tests, the section 4 of the report provides results of statistic SEAMCAT simulations to assess the impact of SRDs on broadcast receivers in the FM band, based on the practical characteristics provided in sections 2 and 3.

Overall structure of the report:

- Section 1 provides a general introduction;
- Section 2 details tests carried out to assess radiated power levels of SRDs operating in the Band II broadcasting band (87.5 MHz to 108 MHz);
- Section 3 provides details of the further tests undertaken on seven SRDs;
- Section 4 provides determination of the impact of SRDs on FM broadcasting receivers based on SEAMCAT simulations;

The section 5 of the reports provides overall findings and conclusions of the study. It was found that:

- The majority of the SRDs tested are currently available on the open market and have e.r.p. levels in the range of 9.2 to 95nW, with the power of the SRD varying over its tuning range;
- Proposed e.r.p. of 10nW and 15nW have been shown to be insufficient for acceptable reception and therefore might not ensure intended SRD functionality;
- Practical test performed with higher powered SRDs (30 – 50nW e.r.p.) demonstrated that the problem of the SRD reception would be alleviated by a power increase of this order;
- For an e.r.p. of 50nW, no interference was generated at a 200 kHz frequency offset, but interference occurred systematically in case of co-channel operation when SRD was in the vicinity of FM receiver, depending on the capture ratio between the wanted and unwanted signals.
- With e.r.p. of 50nW and interference frequencies uniformly spread over the whole 88–108 MHz band, the SEAMCAT simulations showed that probability of interference was 3%, taking into account the number of available channels and a 10% penetration rate (see section 4). Based on the presented measurement results and the practical tests carried out, it was shown that in the worst case scenario (traffic jam), SRDs at a distance of more than 10 m would not interfere with FM radio receivers even in co-channel operation. Additionally, this interference probability may be decreased further by the fact that SRD user is likely to tune away from broadcast transmission frequencies if they want to receive their signal interference free.

The studies conducted by WGSE show that the choice of power limit for these devices will need to take into account the conflicting requirements of on the one hand, the need for sufficient power for the correct operation of the SRDs and on the other hand, the need of to protect broadcasting. The studies indicate that the value chosen would be likely to be in the range 30 to 50nW e.r.p. In addition, SRDs should be required to operate with random selection of one of the frequencies in the whole 88 – 108 MHz frequency range.

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1 INTRODUCTION

This report details both exhaustive laboratory test campaigns and field trials which have been carried out to assess the impact of Short Range Devices (SRDs) on broadcasting reception in the Band II (87.5 MHz to 108 MHz), also known as the "FM band". SRD devices, operating on a global market basis in the band 88 – 108 MHz, are typically used for the purpose of listening to MP3/CD players on a home or car Band II (FM) radio receiver.

The requirements for using such micro-transmitting SRD devices is largely due to the market success of consumer audio devices in a category of "Pocket Jukeboxes", also referred to as MP3 players, or iPods. These devices recently became hugely popular as they allow the user to download and legally store up to 10,000 songs on miniature hard drive storage systems, they are easy to use and even became a fashion item. Recent systems using AAC (Advanced Audio Codec) technology provide sounds indistinguishable to that of CD player.

To further improve user friendliness of such devices, some manufacturers started production of plug-in modules, which being a very low power FM transmitter allow iPod/MP3 players to be heard through a standard car/home FM radio. The range of such link is about 1 m, which e.g. allows a playing MP3 device to be placed in a car glove compartment and to listen to music over the car radio and its loud speaking system.

CEPT in cooperation with other interested parties have considered this demand and concluded that if Europe does not provide standards for such equipment, they would spread to the European market in a highly unregulated manner and would potentially create interference to broadcasting reception. Therefore ETSI was invited to develop a standard for such equipment and CEPT was requested to propose a suitable radiation limits and any other considerations to ensure compatibility of such SRD devices. For the purpose of this study, first the results of some practical tests were considered. The section 2 of the report outlines the results of first of these tests, which were carried out to establish the actual transmit powers of real SRD listening devices in subject band. Further tests were carried out as reported in section 3, which considered some six specimens of SRDs of different manufacturers/types.

Results of these tests allowed then to carry out the theoretical statistical evaluation of the probability of interference from SRD listening devices into the FM radio receivers, using the Monte-Carlo simulations with the SEAMCAT-2 tool. Results of these studies are described in section 4 of the report.

2 TESTS CARRIED OUT AT THE UK OFCOM LABORATORY IN WHYTELEAFE

2.1 Introduction

This report details the test methods used and results obtained during investigations into the compatibility issues relating to the radio frequency power levels of Short Range Devices (SRD) operating in the Band II broadcast band (87.5 MHz to 108 MHz).

Initial laboratory simulations were carried out to determine:

- What protection (frequency separation) would be required to prevent an SRD interfering with broadcast stations on adjacent channels (Section 22.2)
- Whether e.r.p. levels, as proposed by the sponsor, of 10nW and 250µW would provide reliable performance with both car and home stereo radio systems (Section 22.3)

Subsequent practical tests were carried out using two commercially available SRDs, namely Equipment A (49nW e.i.r.p.) and Equipment B (15nW e.i.r.p.). These tests were of a more subjective nature to assess typical domestic and in-car performance (Section 22.5).

2.2 Protection Ratio

2.2.1 Test Method

The test setup used to determine the degree of protection (channel separation) required to prevent an SRD causing adjacent channel interference is shown in Figure 2.1 overleaf.

A Marconi 2026 multi-source signal generator provided both the wanted (broadcast – Gen A), and unwanted (SRD – Gen B) signals. Both signals were modulated with a 19 kHz pilot tone to activate the receiver's stereo decoder, and essentially represented stereo signals with identical right and left hand channel programme material, i.e. no difference signal to modulate the 38 kHz suppressed sub carrier. 99.65 MHz was chosen as the test frequency to minimise levels of local broadcast interference.

The RF output level of Generator A was set to 41.6 dBµV p.d. (50Ω) to provide a receiver input level of 37.7 dBµV p.d.(75 Ω) after the matching pad. This input would result (ignoring feeder losses) from a resonant dipole antenna in an incident field strength of 44 dBµV/m. The figure of 44 dBµV /m (10dB down on the edge-of-service-area planning level of 54 dBµV /m at 10m), was chosen to approximate that which exists in a rural environment, 1.5m above ground level ignoring building losses [2]. The receiver envisaged in this scenario would typically be equipped with a telescopic whip antenna. However, in the absence of performance data for such antennas, a somewhat optimistic dipole characteristic was used.

The signal generator level (Vgen 50 Ω) to produce the required receiver input voltage (75Ω) was calculated as follows:

$$\text{Vgen} = [\text{Field Strength (dB}\mu\text{V/m)} - \text{Antenna Factor(dB/m)}] + \text{Matching Pad Adjustment}$$

$$= [44 - 6.3] + 3.94 = 41.64 \text{ dB}\mu\text{V p.d.}$$

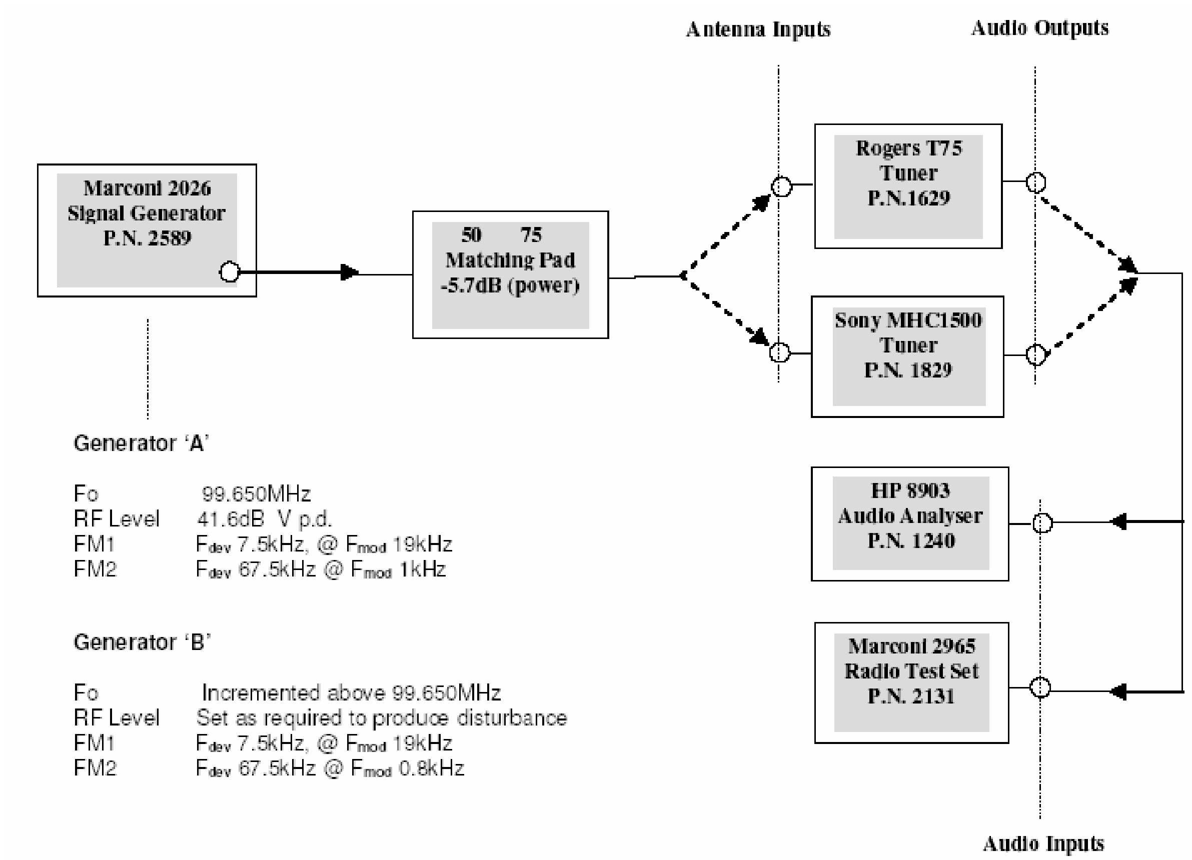


Figure 2.1: Protection Ratio Test Setup

Two Band II stereo tuners were used in the tests, a Rogers type T75 and a Sony type MHC1500, the latter being part of a "Mini Hi-Fi System". At a receiver input level of 37.7dBµV p.d, both tuners produced a S+N/N ratio of approximately 51dB. The Rogers tuner produced a 50dB S+N/N ratio for an input level of approximately 35.2dBµV, 2.2dB worse than the specified sensitivity of 33dBµV.

S+N/N measurements were performed using the ratio (dB relative) function of an H.P. 8903 Audio Analyser with 30 kHz low pass filtering selected. Signal quality was also monitored using the oscilloscope and loudspeaker facilities of a Marconi 2965 Radio Test Set.

While observing the S+N/N ratio produced by Generator A (1 kHz modulating tone off), the signal from Generator B (800 Hz modulating tone on) was introduced at various frequency offsets above 99.65 MHz. At each offset, the output level of Generator B was adjusted until the resulting disturbance fell just below the level of audibility, and the generator level was noted. Figures were recorded up to an offset of +600 kHz for both tuners.

2.2.2 Test Results

The figures obtained are reproduced below in the plot of Figure 2.2. A third curve (red) extending up to only 300 kHz separation, represents protection ratio figures used by Band II planning authorities [3].

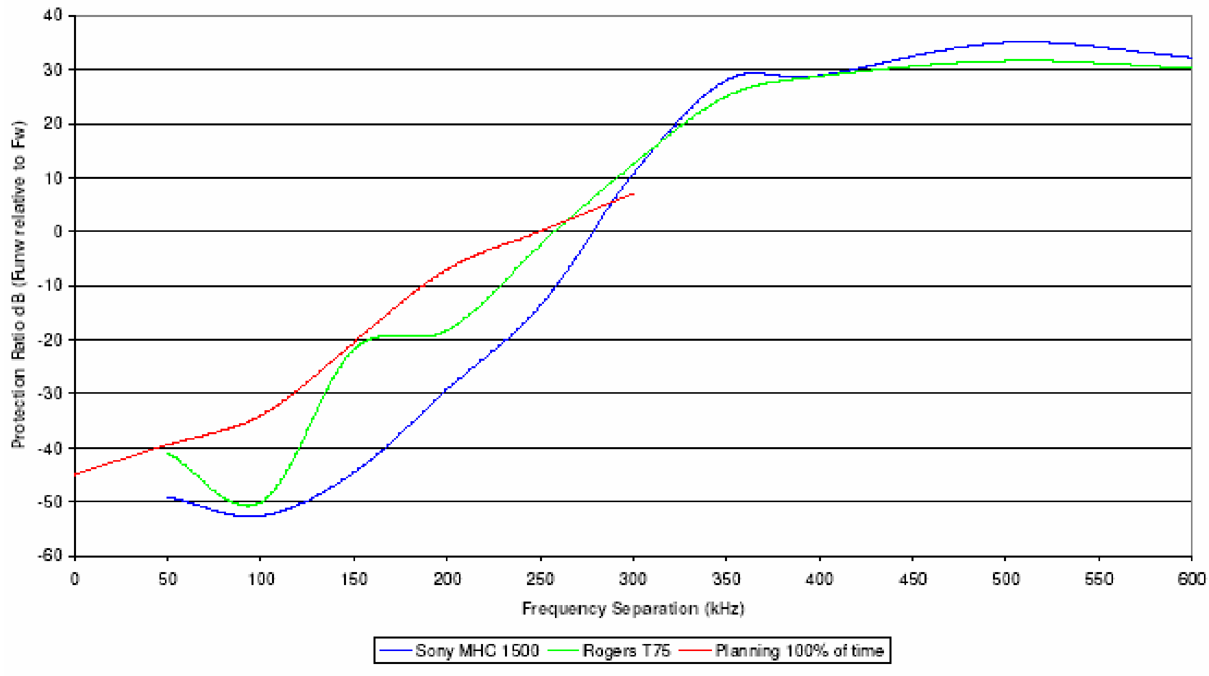


Figure 2.2: Band II Protection Ratio Plot

The curves show frequency offset plotted against the required protection ratio calculated from the relative amplitudes of the signals from Generators A and B as shown below.

Protection Ratio (dB) = 20 Log10 (Vgen B / Vgen A)

As an example of how the information in the curves should be interpreted, it will be noted that where an SRD produces a field strength approximately 10dB higher than a broadcast station, then a 300kHz frequency separation will be required to prevent interference from the SRD.

It should be noted that as the signal from Generator A was unmodulated by an audio tone (but with stereo pilot tone enabled), the test method used probably represents a worst case as programme modulation would tend to mask lower level interference effects. This tends to be supported by the generally lower frequency separations indicated by the planning curve.

2.3 Proposed SRD Power Levels and Operating Range

2.3.1 General

Tests carried out in this phase of the work were designed to determine the effectiveness of SRDs when operated in the domestic and in-car environments at the proposed power (e.r.p.) levels of 10nW and 250µW.

In terms of the home application, tests were based on a horizontally polarised receiving antenna (dipole) erected outdoors at a height of 10m. Car tests were carried out using an electrically short dipole antenna as a probe within the passenger compartment of various vehicles, each vehicle being equipped with a different receiving antenna configuration.

2.3.2 Test Method – Domestic Operation

An initial confidence test was carried out using two horizontally polarised EMCO dipole antenna kits (P.N. 3220 and 3221), set up as shown in Figure 2.3 below.

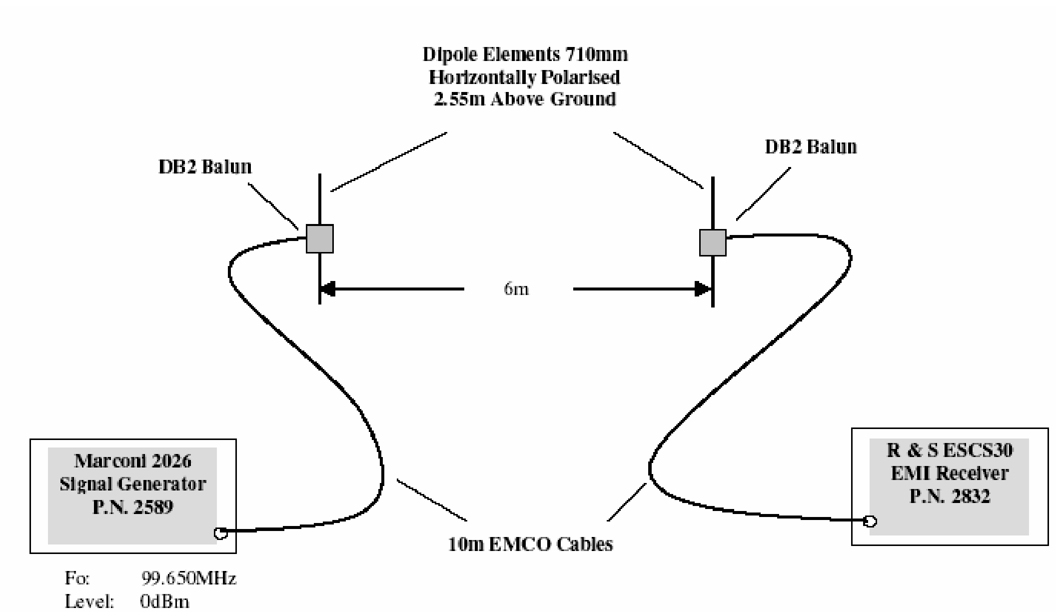


Figure 2.3: Antenna Confidence Test Setup

With the signal source set at an output level of 0dBm, the expected field strength (ignoring feeder losses) was calculated from:

$$\text{Field Strength (V/m)} = \frac{(30 \times P \times G)^{0.5}}{d}$$

$$\text{Field Strength (V/m)} = \frac{(30 \times 10^{-3} \times 1.6)^{0.5}}{6} = 0.037\text{V/m} = 91.4\text{dB}\mu\text{V/m}$$

At a specified antenna factor of 8.2dB/m, the expected receiver input voltage would be 91.4 – 8.2 = 83.2dBµV p.d. The actual level measured was within 0.5dB of this calculated value, providing a satisfactory degree of confidence in the test dipole antennas.

The test setup was then reconfigured as shown below in Figure 2.4.

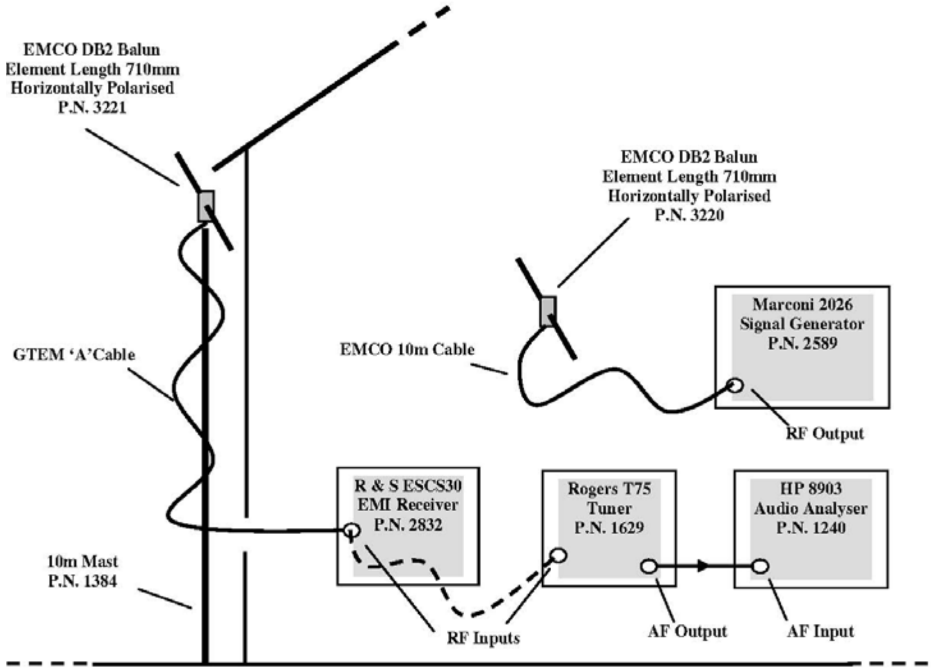


Figure 2.4: Test Equipment Setup in the Building

A fully extended 10m mast was used to support a horizontally polarised EMCO dipole antenna outside the Building. This was connected to an EMI measuring receiver via a cable having a measured loss of less than 1dB at 100MHz. A second horizontally polarised EMCO dipole was set up inside the Building (1.33m above ground level) and connected to the RF output of a Marconi 2026 Signal Generator, modulated as shown for Generator A in Figure 2.1.

The signal generator was set to a frequency of 99.65 MHz at the following output levels, and the signal was monitored on the EMI measuring receiver.

- -50dBm for an e.r.p. of 10nW
- -6dBm for an e.r.p. of 250µW

2.3.3 Test Results

At an e.r.p. of 10nW, the signal monitored on the EMI receiver was just perceptible above the receiver noise floor. This indicated that a 10nW SRD operating inside a house to a Band II receiver with an outside antenna at 10m, would probably not provide an adequate service.

At an e.r.p. of 250µW, the input signal level at the EMI receiver was recorded at 56dBµV. At a specified antenna factor of 8.2dB/m, this represented a field strength of 56 + 8.2 = 64.2dBµV/m, some 10dB up on the edge-of-service-area planning level of 54dBµV/m at 10m a.g.l. As 250µW is 44dB above 10nW, this implied a field strength of 20.2dBµV/m (64.2 – 44) for 10nW e.r.p..

The feeder cable from the outside dipole antenna was disconnected from the EMI receiver and connected (via a 50Ω - 75Ω matching pad) to the input of the Rogers T75 tuner. A S+N/N figure of 50dB was recorded for the 250µW e.r.p., as previously recorded in the laboratory for an input level equivalent to a field strength of approximately 44dBµV/m. This apparent degradation of S+N/N performance was almost certainly due to the noisier outside antenna environment. Some audio was just detectable on 99.65 MHz on the 10m antenna with the pseudo SRD (signal generator) switched off.

It was therefore concluded that an e.r.p. of 250µW would be required to provide adequate performance when operating into a 10m outside antenna, having a well screened feeder, from an SRD on the ground floor.

2.3.4 Test Method – In-Car Operation

To facilitate the production of SRD test signals within the passenger compartment of a vehicle, it was necessary to use an electrically short dipole driven at higher RF power levels to produce the required 10nW and 250µW e.r.p. levels. The test equipment setup used is shown in Figure 2.5 below.

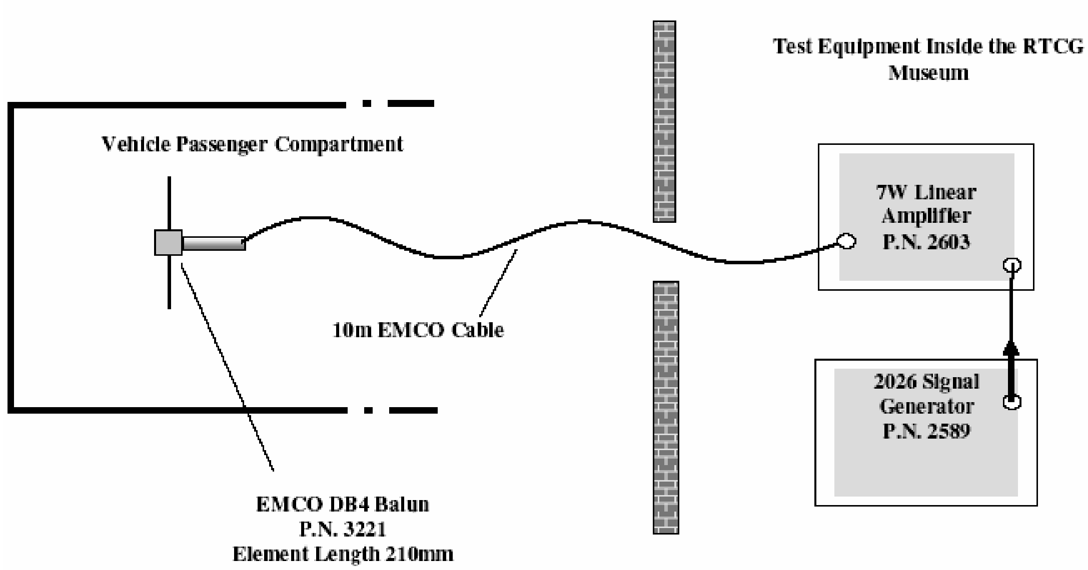


Figure 2.5: Vehicle Test Setup

The RF power level required to drive the electrically short dipole was first determined as follows:

- The electrically short dipole was placed in the same position (horizontally polarised) as the full-size dipole that had previously produced a field strength of 64.2dBµV/m for an e.r.p. of 250µW.
- The output level from the signal generator feeding the linear amplifier was gradually increased until the received signal level, as indicated on the EMI receiver, represented a field strength of 64.2dBµV/m. This was achieved at a signal generator level of -7.5dBm, representing an e.r.p. of 250µW.
- As 10nW is 44dB below 250µW, the required signal generator level for 10nW e.r.p. was calculated as -7.5 - 44 = -51.5dBm.

In-car tests were carried out on three vehicles as follows:

- Mitsubishi Pajero with a nearside front wing mounted telescopic car radio antenna
- Nissan Almera with car radio antenna mounted centrally at the rear of the roof
- BMW 535i with heated rear window element car radio antenna.

As noise was found to be present on 99.65 MHz, the frequency used for all in-car tests was changed to 87.5 MHz. With the test signal modulated with 1 kHz and 19 kHz tones (as per Gen A Fig. 2.1), and the car radio tuned to 87.5 MHz, the short dipole was moved around the interior of each vehicle while monitoring received signal quality. This procedure was performed at both the 10nW and 250µW e.r.p. levels. Note that no occupants were present in the vehicles while this procedure was carried out.

2.3.5 Test Results

With the test signal set at 10nW e.r.p.. it was found possible to locate deep nulls at various locations in the passenger compartment of all three vehicles. Although not investigated, it was felt that the presence of occupants inside the vehicle might have exacerbated this situation.

With the test signal set at 250µW e.r.p. it was not possible to locate any position, in any of the vehicles that produced any perceptible degradation in signal quality.

It was therefore concluded that an e.r.p. in excess of 10nW would be required for reliable in-car operation of an SRD, although tests were not carried out at levels between 10nW and 250µW.

2.4 Conclusions – Laboratory Simulations

2.4.1 10nw SRD Effective Radiated Power

The findings indicate that 10nW e.r.p. would only be suitable for operation over unobstructed paths up to a maximum distance of approximately 3m. This would be typified by the use of an SRD in the same room as a Band II radio equipped with a whip antenna. At 3m, the SRD would produce a field strength of approximately 47dBµV/m, i.e. potentially 3dB higher than the field strength of an edge-of-service-area broadcast signal (1.5m a.g.l.) at a rural site ignoring building losses. Under such conditions, the protection ratio plots (Fig.2) indicate that the SRD frequency should be spaced some 250 kHz to 300 kHz from broadcast signals being received on other radios within a 3m radius.

An e.r.p. of 10nW would almost certainly be unsuitable for a domestic application requiring transmission from an SRD inside the house to an outside antenna at 10m above ground level. By implication, interference to a Band II radio system in a neighbouring property would also be most unlikely. In vehicle applications at 10nW e.r.p. the presence of signal nulls would probably detract from the degree of flexibility required in terms of where an SRD can be sited.

2.4.2 250µW SRD Effective Radiated Power

Tests indicate that an SRD e.r.p. of 250µW would provide acceptable service in a domestic application requiring transmission from an SRD inside the house (ground floor), to an outside horizontal Band II antenna at 10m a.g.l. The simulation produced a field strength of 64dBµV/m at the outside antenna for 250µW e.r.p., i.e. 10dB up on the edge-of-service-area planning level of 54dBµV/m. This apparently effective inter household communication, would, however, also create valid cause for concern regarding potential interference in domestic (inter-household and inter-property) applications.

As stated above, the use of 10nW e.r.p. was described for a domestic scenario in which an SRD operated 3m from a Band II radio would produce a field strength of approximately 47dBµV/m. This represents a point approximately +3dB on the protection ratio plot (Fig. 2.2), indicating a required frequency separation of between 250 kHz and 300 kHz. The field strength that would be produced at 3m by an SRD operating at an e.r.p. of 250µW would be approximately 91dBµV/m (+44dB on 10nW), i.e. a point that would occur at +47dB on the protection ratio plot (Fig 2.2). Reference to Figure 2.2 will show that a protection ratio of this magnitude is not defined, the maximum being a point +30.3dB for the Rogers T75 Tuner requiring a frequency separation of 600 kHz. However, a single spot check on the Rogers Tuner, representing an SRD e.r.p. of 250µW at 3m, suggested that a frequency separation of 1.3 MHz would be required from a broadcast signal being received at a field strength of 44dBµV/m. This is thought to be due to tuner overload.

Vehicle tests suggest that an e.r.p. greater than 10nW would be required for reliable in-car operation. Although 250µW e.r.p. would almost certainly be significantly more than required to achieve acceptable in-car performance, the transitory nature of interference from a mobile source would be less problematic than in a domestic environment.

It must, however, again be stressed that the protection ratio figures given in this paper are based on disturbances to an unmodulated wanted signal. Programme modulation would tend to mask low level interference effects; the protection figures should therefore be considered as worst case.

2.5 Practical Tests Using Commercially Available SRDs

2.5.1 General

Two commercially available SRDs were used for the practical phase of the work as follows:

- Equipment A
- Equipment B

It will be noted that both units have a short screened lead terminated in a 3.5mm stereo jack plug for audio input from a CD player/iPod etc. Both may be powered by two internal “AAA” alkaline cells, or by a 12V vehicle supply.

The Equipment A SRD enables operation on one of four switched frequencies, namely 88.1 MHz, 88.3 MHz, 88.5 MHz and 88.7 MHz. The Equipment B SRD is considerably more flexible, and will operate on any frequency between 88.1 MHz and 107.9 MHz in 100 kHz increments. It also allows up to four frequencies to be stored in memory.

Both manufacturers claim compliance with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. Both manufacturers also claim an operating range of up to 30 feet, but suggest a range not exceeding 10 feet will provide the best interference-free reception.

2.5.2 E.i.r.p. Measurements

Measurements were carried out in the Fully Anechoic Chamber to determine the equivalent isotropically radiated power (e.i.r.p.) of both the SRDs.

EMCO Max e.i.r.p. automatic software was used to control the measurement process by rotating the SRD under test, changing the measuring antenna height and polarisation, while constantly measuring the received power level until a maximum is found. Using this technique, the following e.i.r.p. levels were determined:

- Equipment B 14.99nW
- Equipment A 49.09nW

2.5.3 In-Car Tests

Tests were performed with both SRDs in the same three vehicles used in the simulations of Section 2.3.4, namely:

- Mitsubishi Pajero with a nearside front wing mounted telescopic car radio antenna Car Radio Type: JVC KD-G301
- Nissan Almera with car radio antenna mounted centrally at the rear of the roof Car Radio Type: Nissan LW-MW-FM with Cassette Player – Type A
- BMW 535i with heated rear window element car radio antenna Car Radio Type: Kenwood KDC-8024

The tests were of a purely subjective nature, and consisted of monitoring the signal from the SRD on the vehicle radio while changing the position of the SRD within the vehicle.

The modulating signal applied to the SRD was a 1 kHz (mono) tone from a Casio PZ810 CD player. All tests were carried out on 88.3MHz, which although not a totally clear channel, was the clearest channel available in the car park.

To take account of the effects of signal absorption by vehicle occupants, all tests were conducted with five occupants in the vehicle in which the SRD was being tested. During tests, the vehicles were positioned side-by-side with a spacing of approximately 1.5m (see Figure 2.6 overleaf). To assess the potential for inter-vehicle interference, the SRD signals were also monitored in the two unoccupied adjacent vehicles not containing the SRD.

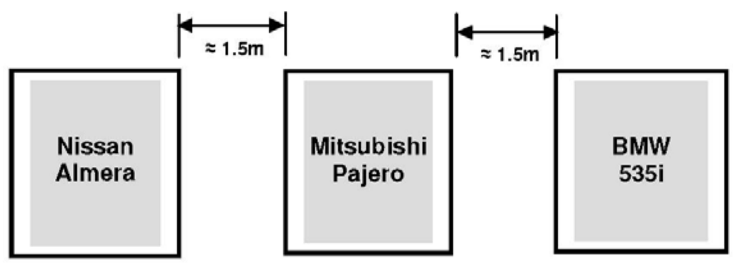


Figure 2.6: Relative Test Vehicle Positions

2.5.4 In-Car Test Results

The results of the in-car tests are summarised in Table 2.1 below.

Test Vehicle	Equipment B	Equipment A	Adjacent Vehicles
Nissan Almera	Signal nulls with SRD positioned adjacent to rear passengers' feet. Signals satisfactory in what would be considered more practical locations.	No signal nulls found.	Equipment A audible in Pajero, and just discernible in the BMW. Equipment B audible in Pajero, but not in BMW.
Mitsubishi Pajero	Nulls easily located with the SRD in both the front and rear of the vehicle.	Some nulls detected, but to a much less extent than with the Equipment B.	Equipment B strong signal in the Almera, and strong enough to be annoying in the BMW. Equipment A strong in both Almera and BMW
BMW 535i	No signal nulls found	No signal nulls found	Both SRDs audible in both the Almera and Pajero.

Table 2.1

It should be noted that the Mitsubishi Pajero has a heated front windscreen which might account for the relatively poor SRD performance, i.e. heating elements between the SRD and wing mounted car radio antenna.

2.5.5 Domestic Range Tests

A further subjective test was carried out to determine over what range the SRDs would give acceptable performance in a domestic environment. This test would, of course, also indicate the interference potential of the SRDs.

The principle used in the tests is shown in Figure 2.7 below. The SRD and CD player were mounted on a wooden support, and the maximum range that an acceptable signal could be received was determined. The receiver used was a Grundig Yacht Boy (YB400) with its whip antenna fully extended, and vertically polarised. The receiver was simply walked 360º around the SRD, while carefully assessing the range at which the signal from the SRD was perceived to fully quieten the receiver, and eliminate any trace of other broadcast signals. During tests it was found that signal quality degraded rapidly within a few metres beyond the recorded maximums.

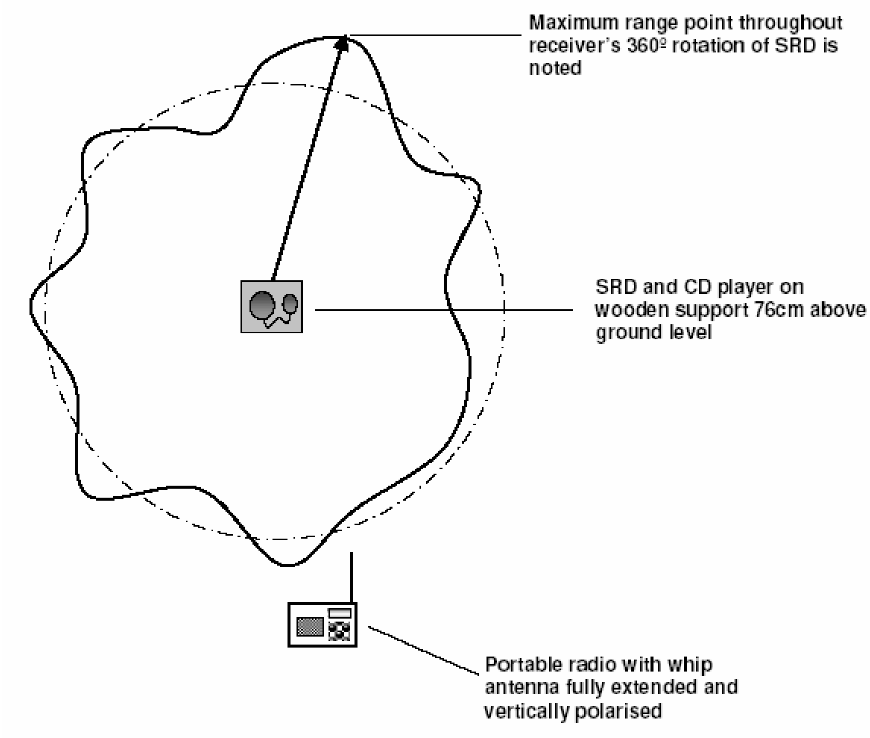


Figure 2.7: Maximum Range Test

2.5.6 Domestic Range Test Results

Based on the assessment criterion of an acceptable signal given in Section 5.5, the following maximum ranges were obtained:

- Equipment B 4.1m
- Equipment A 8.0m

From the maximum range and SRD power levels it is possible to calculate the field strength at the receiver as follows:

$$\text{Field Strength (V/m)} = \frac{(30 \times P \times G)^{0.5}}{d}$$

$$\text{Equipment B} = \frac{(30 \times 14.99 \times 10^{-9} \times 1)^{0.5}}{4.1} = 164\mu V/m = 44.3dB\mu V/m$$

$$\text{Equipment A} = \frac{(30 \times 49.09 \times 10^{-9} \times 1)^{0.5}}{8} = 151.4\mu V/m = 43.6dB\mu V/m$$

The relatively close correlation (<1dB) between the calculated field strengths gave satisfactory confidence in terms of the consistency of the results of the subjective range tests. It is also interesting to note that the maximum range calculated field strengths tend to support the choice of 44dBμV/m to represent an edge-of-service-area broadcast field strength.

2.6 Conclusions

2.6.1 In-Car Tests

The results of tests given in Table 2.1 clearly indicate that a lower power SRD (15nW e.i.r.p.) makes the task of locating a suitable operating position within a vehicle more difficult. The results also suggest that the location of the car radio antenna might have a significant bearing on this problem, a front wing mounted antenna appearing least favourable.

Increasing the SRD power by some 5dB (49nW e.i.r.p.), would appear to significantly alleviate the problem of sitting an SRD. The results of tests showed that no signal nulls could be detected on the Nissan and BMW test vehicles, and were appreciably reduced on the Mitsubishi.

In terms of signal reception in adjacent vehicles, the results do not highlight a major problem in terms of interference potential as this would be of a transitory nature under most conditions. However, in the light of the domestic range test results (see 2.6.2), it is not surprising that signals were audible in the relatively closely spaced vehicles.

2.6.2 Domestic Range Tests

It must first be stressed that the range figures measured are probably best-case by virtue of the fact that the test site was totally unobstructed, and the receiver used (Grundig YB400) is probably more sensitive than radios used by the average SRD user.

Although as previously indicated, both manufacturers claim to comply with Part 15 of the FCC Rules [4], measurements suggest that only the B product meets the FCC requirement, i.e. field strength of any emissions within the 200 kHz bandwidth shall not exceed 250µV/m at 3 metres. At 14.99nW e.i.r.p., the B SRD would produce a field strength of approximately 224µV/m (47dBµV/m) at 3 metres. The A SRD at 49.09nW e.i.r.p. would, however, produce a field strength of approximately 405µV/m (52dBµV/m) at 3m.

It should be noted that neither of the SRDs would be capable of providing satisfactory quality signals when operating from a ground floor room to an outdoor antenna at 10m above ground level. The only practical domestic scenario for the use of both SRDs would be operating into a receiver in close proximity, typically in the same room as intended by the manufacturer.

In terms of interference potential, it is felt that this would be restricted to within the household in which the SRD is being operated, and could therefore be managed locally.

Considering the 44dBµV/m planning level (1.5m above ground level, in a rural environment, ignoring building losses), at 3m both the SRDs would produce field strengths 3dB and 8dB above this level respectively. The protection ratio plot of Figure 2.2 indicates that a 300 kHz frequency separation should negate interference effects from either SRD.

3 TESTS CARRIED OUT AT TDF FACILITIES IN METZ, FRANCE

3.1 Introduction

The tests described in this section were composed of two phases:

- measurements aiming to characterize SRD transmitters and to assess their impact on the FM broadcast service in laboratory and in situ conditions;
- simulations using SEAMCAT aiming to assess the impact of SRD transmitters on the FM broadcast service in various scenarios.

This section presents the results of laboratory measurements and in situ tests carried out at TDF-Metz (France).

- Sub-section 3.2 presents the results of laboratory measurements;
- Sub-section 3.3 presents the results of in situ tests;
- Sub-section 3.4 presents the conclusions.
- Results of laboratory measurements and in situ tests are presented in Appendix 2 to section 3.

3.2 Laboratory measurements

The major contribution of laboratory measurements is to characterize SRD transmitters and to assess their impact on the FM broadcast service in laboratory conditions.

But the measurement results will also be used to define technical parameters of SRD transmitter for use in SEAMCAT simulations and to verify the reliability of the outcome of simulations.

The measurements which have been carried out are:

- PSD measurements;
- Radiation pattern measurements;
- e.r.p measurements;
- Spurious emission measurements;
- FM broadcast receiver SNR measurements in the presence of an interfering SRD signal.

Except for the PSD measurements, all the measurements have been carried out in anechoic chamber. The measurement antenna as well as the SRD antenna has been placed at 1.6 m above the floor in order to reduce coupling between the measurement antenna and the ground.

In these conditions, due to the SRD antenna size (D ≈ 20 cm) and the wave length of the FM carrier (λ = 3.4 m at the lowest frequency of the band II), the point between near and far field “d_r” (radian wavelength) may be calculated as:

$$\begin{aligned} d_r\,(m) &= 1.6\lambda(m) \\ &= 1.6*3.4 \\ &= 5.4\ m \end{aligned}$$

Note that 1.6 used in the above formula does not stand for the SRD antenna height. For $D < \frac{1}{3\lambda}$ the operative criterion is

$$d_r > 1.6\lambda.$$

However, the distance used between the SRD antenna and the measurement antenna was 4m, because the size of the anechoic chamber of TDF did not allow a measurement at a distance more than 4 m.

3.2.1 Tested Short Range Devices

All SRD transmitters tested are commercially available on the USA and Asian markets.

Identification	Mark	Model	Availability	Characteristics
SRD1	Arkon Sound Feeder	SF250	USA	Power supply: battery Frequency range: 88.1 - 88.9 MHz 107.1 - 107.9 MHz step = 200 kHz Antenna: audio cable
SRD2	Digiana Audia X	DGT 201	South Korea	Power supply: battery Frequency range : 88.1 - 107.9 MHz step = 100 kHz
SRD3	MIC Carfree	W243-9021	South Korea	Power supply : cigar lighter Frequency range: 88.1 - 90.1 MHz step = 200 kHz Micro allowing to send a radio message
SRD4	MIC Popspa	PT-100	South Korea	Power supply : cigar lighter Frequency range: 88.1 - 90.1 MHz step = 200 kHz
SRD5	MIC Ipop	FM Transmitter (BP-11017F)	South Korea	Power supply : battery/cigar lighter Frequency range: 106.7 - 107.9 MHz step = 200 kHz
SRD6	BELKIN (15 nW)	F8V367	USA	Power supply : battery Frequency range : 88.1 - 88.7 MHz step = 200 kHz FCC compliant (ID: K7SF8V367)
SRD7	BELKIN (50 nW)	F8V3080	Not available	Power supply : battery/cigar lighter Frequency range: 88.1 - 107.9 MHz step = 100 kHz BELKIN FCC model with RF stage tuned for 50 nW for these tests

Table 3.1: List of tested SRD transmitters

The FCC regulations Part 15, Section 15.239 [4] defines the field strength limit of SRD band II transmitters as indicated below.

FCC limit for low-power, non-licensed transmitters Operation in the band 88 - 108 MHz (B_{ref}=200 kHz)				
E (µV/m) at 3 m	E (dBµV/m) at 3 m	e.i.r.p (dBm)	e.i.r.p (nW)	e.r.p (nW)
250	48	-47,3	18,6	11,4

Table 3.2: FCC limit - field strength limit of SRD band II

3.2.2 SRD transmitter PSD measurement

The objectives of this measurement are:

- to understand the impact of SRD transmitters on a FM broadcast radio, when SRD transmits through an adjacent FM broadcast channel;
- to define the spectrum mask of SRD transmitter for use in SEAMCAT simulations.

The conformity of SRD transmitters to any OOB domain emission limit has not been verified. Measurement results obtained have been compared with the spectrum mask of FM transmitters defined in EN 302 018-2 [6] (see also Table 3.3) only for information.

3.2.2.1 Methodology

PSD measurements have been carried out with a narrow measurement bandwidth (BW<1 MHz) according to EN 302 018-2 [6], Section .2.2. The RF signal was picked up by means of a current probe (BW > 108 MHz). The SRD cable was inserted through the probe (see Figures 3.1 and 3.2). These measurements are relative measurements. Consequently, the current probe correction has not been taken into account.

Audio signal characteristics:

- Modulating signal: 1 kHz sinusoidal signal;
- FM deviation = ±75 kHz;
- Mode: Stereophonic (symmetric audio signal on channels A and B).

Low noise amplifier characteristics:

- NF ≤ 3 dB;
- G ≥ 20 dB;
- P_{max} 10 dBm).

Spectrum analyser configuration:

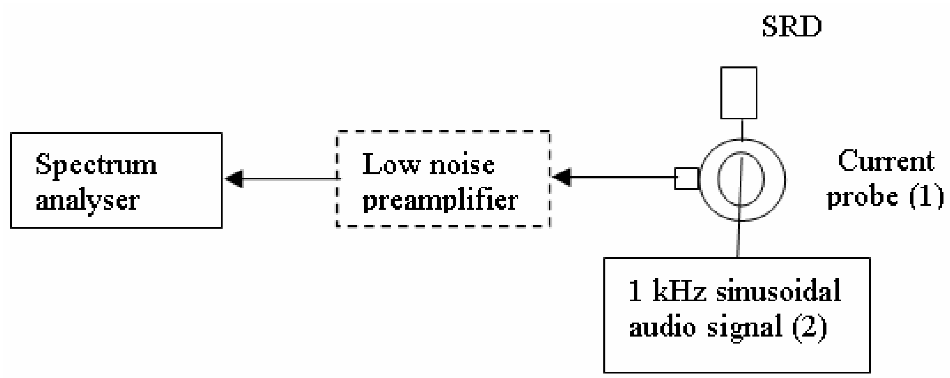
- RBW = VBW = 1 kHz;
- Sweep time = 15 s;
- Detector: RMS;
- RF Attenuation = 0 dB;
- Span = 800 kHz (100 kHz/div).

Break points of spectrum mask for FM broadcast transmitters [5]	
Frequency relative to the centre of the channel (kHz)	Relative level (dBc)
-500	-85
-300	-85
-200	-80
-100	0
100	0
200	-80
300	-85
500	-85

Table 3.3: Break points of spectrum mask for FM broadcast transmitters

3.2.2.2 Test set-up

The test set-up used for PSD measurements is shown in Figures 3.1 and 3.2.



(1) Current probe BW : 1 kHz - 500 MHz

(2) MP3 player or audio analyser

Figure 3.1: Test set-up for PSD measurements

3.2.2.3 Measurement results

In the following section only the PSD of SRD6 and SRD7 with power levels of 15 nW and 50 nW respectively are presented.

3.2.2.4 Analysis of the results

The SRD6 and SRD7 PSDs measured are shown in Figures 3.3 and 3.4 respectively. Due to the low sensitivity of the current probe used, it has not been possible to measure these PSD in the frequency range of f_c±500 kHz. SRD7 PSD has been measured by using a low noise preamplifier to overcome the low sensitivity of the current probe.

Nevertheless, it is possible to derive from PSDs measured a quite accurate SRD transmitter spectrum mask for use in SEAMCAT simulations. Two preliminary proposals are shown in Figures 3.2 and 3.3. The related break points are given in Tables 3.4 and 3.5.

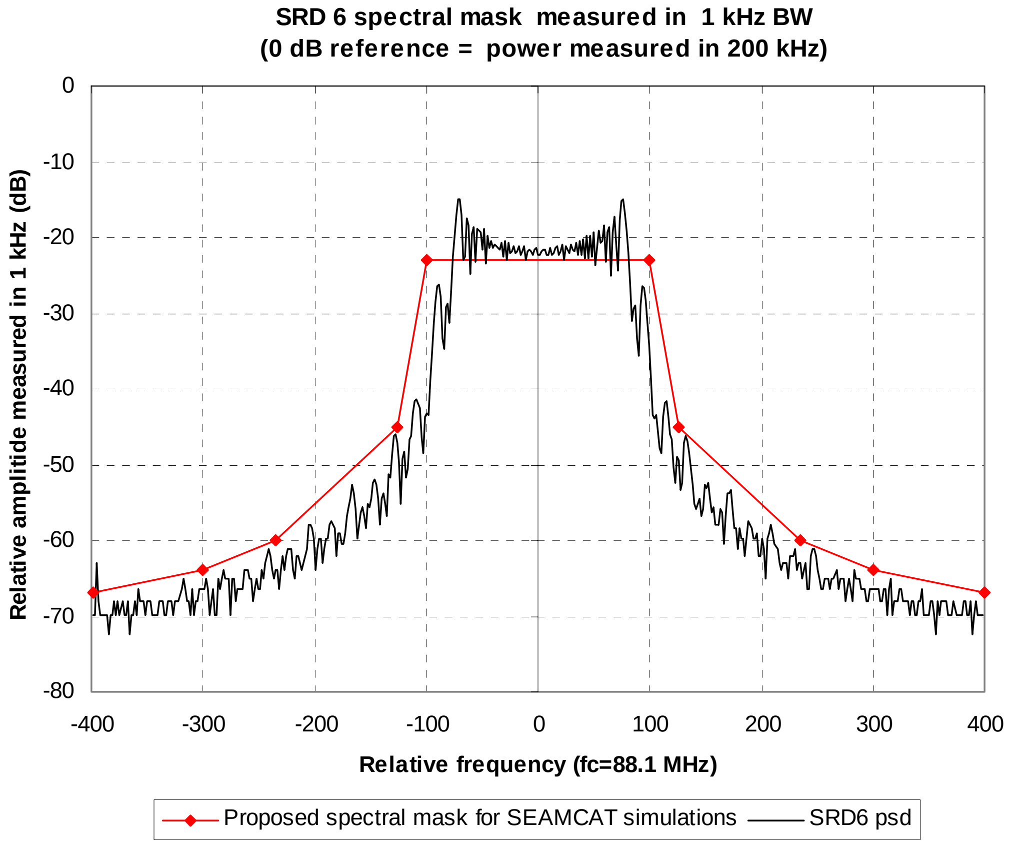


Figure 3.3: SRD-6 spectrum mask

Break points of spectrum mask proposed for SRD6 (15 nW)	
Frequency relative to the centre frequency of the modulated SRD signal (kHz)	**Relative level (dB)**
0	-23
±100	-23
±126	-45
±300	-64
±400	-67
±500	-67

Table 3.4: spectrum mask for SRD6

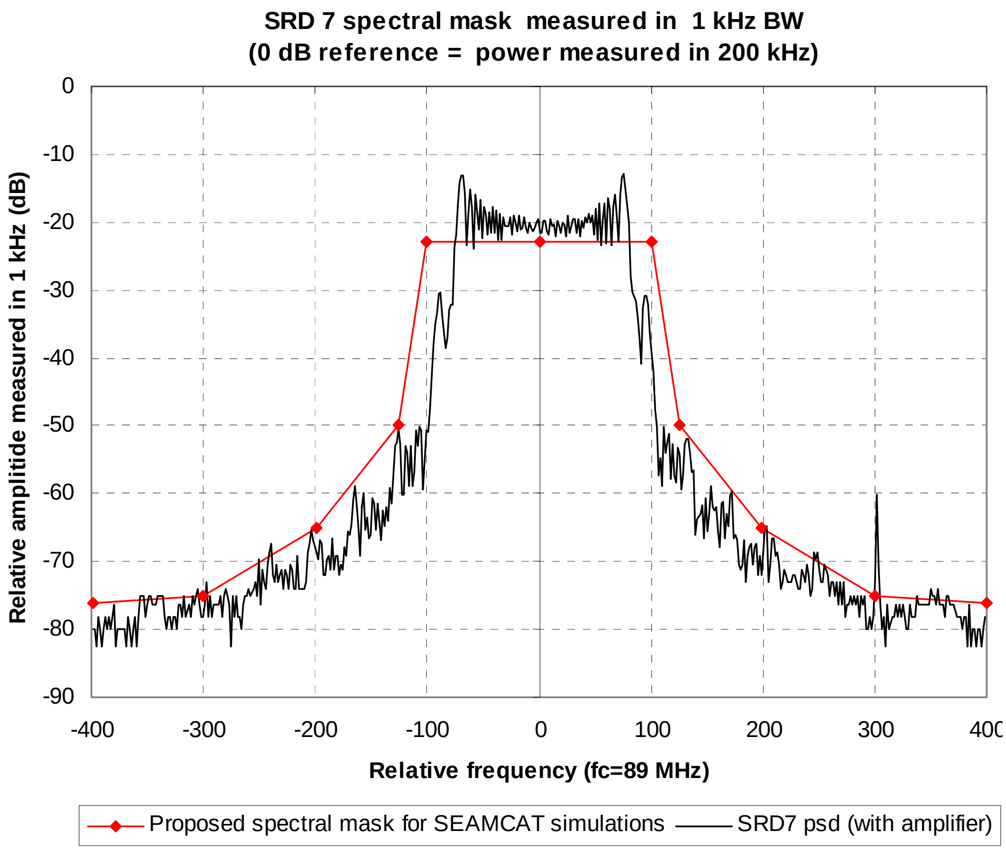


Figure 3.4: spectrum mask for SRD7

Break points of spectrum mask proposed for SRD7 (50 nW)	
Frequency relative to the centre frequency of the modulated SRD signal (kHz)	**Relative level (dB)**
0	-23
±100	-23
±126	-50
±300	-75
±400	-76
±500	-76

Table 3.5: spectrum mask for SRD7

3.2.3 SRD transmitter maximum frequency deviation measurement

The objective of this measurement is to verify the maximum frequency deviation allowed by SRD transmitter. In normal operation the frequency deviation of a Broadcast FM transmitter should not exceed ± 75 kHz. Beyond this maximum frequency deviation a Broadcast FM transmitter may cause severe adjacent channel interference. Consequently, it could also be expected that SRD transmitter complies with maximum frequency deviation of ± 75 kHz.

3.2.3.1 Methodology

The measurement set-up used was identical to that used for PSD measurements (see Figures 3.1). Two different modulating signal sources (MP3 player and UPL audio analyser) have been used to carry out the measurements.

The methodology defined below has been used to verify the maximum frequency deviation allowed by SRD transmitter design:

Step1. Measure the peak level of the SRD carrier without modulation;

Step2. Select a reference line and locate it at -23 dB from the measured peak level;

Step3. Modulate SRD transmitter with a 1 kHz sinusoidal audio signal in order to obtain a frequency deviation of ± 45 kHz (60% of ±75 kHz);

Step4. Locate two markers on the reference line to indicate the allowed maximum frequency deviation range (±75 kHz) relative to SDR transmitter carrier frequency (f_c);

Step5. Increase the modulating signal level by 20 dB. SRD transmitter PSD exceeding the reference line shall be delimited by the markers indicating the allowed maximum frequency deviation range (±75 kHz).

Audio signal characteristics:

- Audio = 1 kHz sinusoidal signal;
- FM deviation = see methodology described above;
- Mode: Stereophonic (symmetric audio signal on A and B channels).

Spectrum analyser configuration:

- RBW = VBW = 1 kHz
- Sweep time = 15 s
- Detector : RMS
- RF Attenuation = 0 dB
- Span = 750 kHz (75kHz/div)

3.2.3.2 Measurement results

The measurement results are given in Table 3.6.

SRD under test	Modulating signal source	Modulating signal level	Measured frequency deviation (kHz)
SRD6	MP3 player	Level for obtaining Δf = ±45 kHz + 20 dB	±123,5 kHz
SRD6	UPL audio analyser	Level for obtaining Δf = ±45 kHz + 20 dB	±144,5 kHz
SRD7	MP3 player	Level for obtaining Δf = ±45 kHz + 20 dB	±198 kHz
SRD7	UPL audio analyser	Level for obtaining Δf = ±45 kHz + 20 dB	±243 kHz

Table 3.6: measurement results

3.2.3.3 Analysis of the results

The measurement results clearly show that no frequency deviation limiter is implemented in SRD transmitters. Consequently, a very wide range of frequency deviation can be reached depending on modulating signal level. This may cause severe adjacent channel interference to FM broadcast radio in the range of about 3 m.

It should be noted that the subjective audio quality of MP3 player has not been verified during these measurements, but in practice-the reception of the SRD would probably be unacceptable to the user.

3.2.4 Radiation pattern measurement

The objective of this measurement is to record the radiation pattern of SRD antenna permitting to understand the behaviour of SRD transmitter when used in a vehicle. Note that some SRD transmitters use their audio cable as antenna (e.g. SRD6 and SRD7), others use a loop antenna integrated on the circuit board.

3.2.4.1 Methodology

Measurements have been carried out in fully anechoic conditions in vertical and horizontal planes respectively. SRD transmitters have not been modulated except SRD7 (SRD 7 requires an audio input to initiate transmissions). The measurement antenna has been placed 4 m from SRD transmitter and 1.6 m above the floor. This height has been chosen in order to reduce coupling between the measurement antenna and the ground. Moreover, it is representative of the typical height of a rod antenna used on vehicles.

The measurement procedure used is described below:

Step 1: SRD is placed at 1.60 m above the floor in the middle of the turntable with its audio cable placed in vertical plane.

The front face of the SRD is used as the reference position (0°).

Step 2: The turntable angular is positioned at 0°.

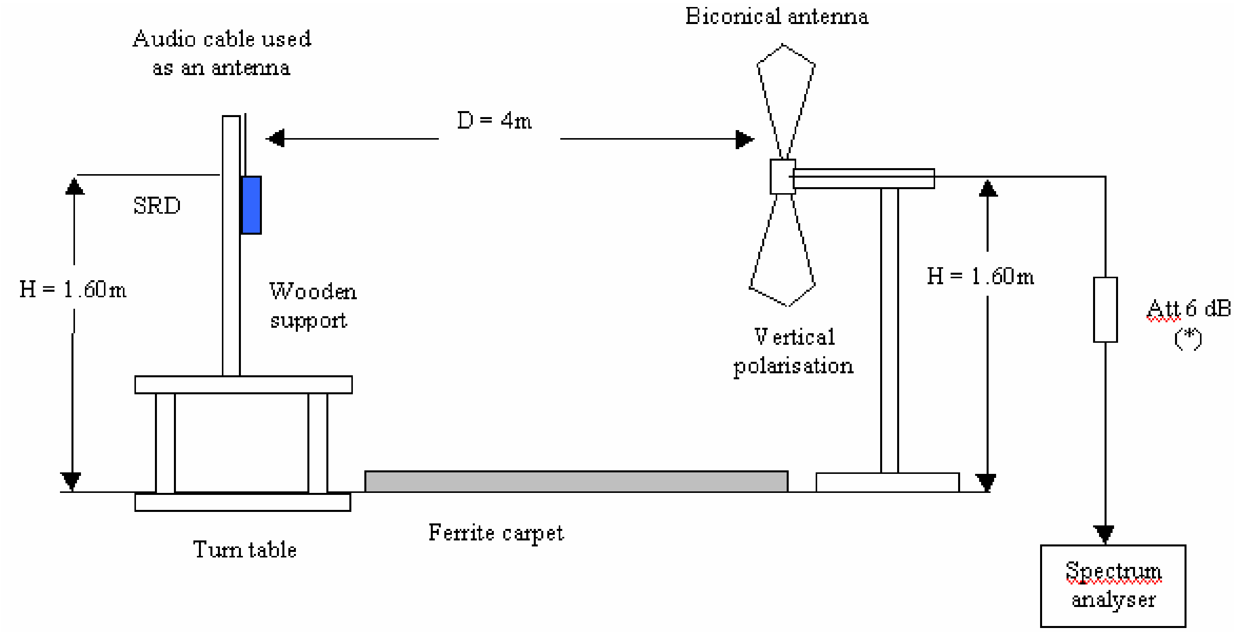
Step 3: The configuration of the spectrum analyser is:

- Span = 0
- Attenuation = 0 dB
- RBW = VBW = 1 kHz
- Detector : RMS
- Sweep time: single mode 88 s corresponding to the time needed for complete rotation (360°) of the turntable.

Step 4: The rotation of the turntable (from 0° to 360° in the clockwise) and the sweep of the spectrum analyser are activated at the same time.

3.2.4.2 Test set-up

The test set-up used for radiation pattern measurements is shown in Figures 3.4.



(*) The -6dB attenuator is used to improve impedance matching between the biconical antenna and the RF generator and to reduce the measurement uncertainties. Note that the use of a FM antenna could be more appropriate for this measurement.

Figure 3.4: Test set-up for radiation pattern measurement

3.2.4.3 Measurement results

Figures 3.5 and 3.6 show the measured radiation patterns of SRD6 and 7 with power levels of 15 nW and 50 nW respectively. SRD6 has been supplied by battery while SRD7 has been supplied by 12V cigarette lighter cable.

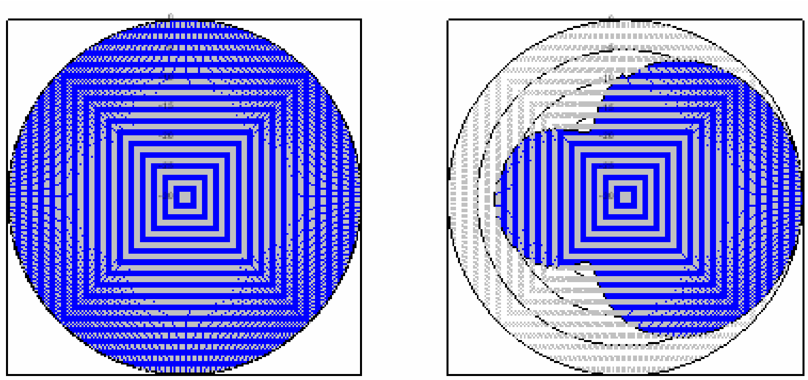


Figure 3.5: SRD6 radiation patterns (H-cut and V-cut)

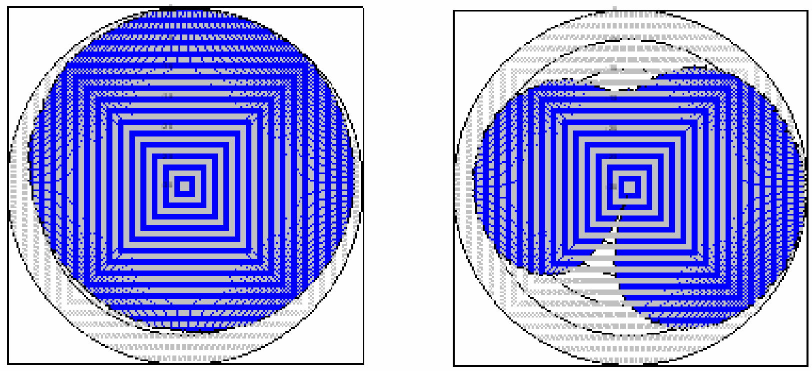


Figure 3.6: SRD7 radiation patterns (H-cut and V-cut)

3.2.4.4 Analysis of the results

In the vertical plane SRD audio cable reacts as an omnidirectional antenna. In case of the use of a cigar lighter cable to supply SRD transmitter, this cable reacts as a part of SRD antenna and modifies the radiation pattern in both vertical and horizontal planes. The importance of this impact depends on the structure of both SRD audio and cigarette lighter cables.

The cross polarisation provides an attenuation varying from 0 to 30 dB depending on SRD antenna type and structure.

3.2.5 Effective Radiated Power (e.r.p.) measurement

3.2.5.1 Methodology

Substitution method

SRD transmitter is placed at 1.6 m above the floor. Its audio cable is oriented for vertical polarisation. The measurement antenna is vertically polarized and placed at the same height as SRD transmitter.

Ferrite carpets and RF absorbers are put on the floor and turntable of the anechoic chamber to reduce the reflections from the ground. SRD transmitter under test is not modulated.

The measurement is carried out in four steps:

Step 1: the e.r.p. of SRD transmitter is measured at its carrier frequency.

Step 2: A half wave vertically polarized dipole substitution antenna is installed to replace SRD transmitter. The centre of phase of the dipole antenna is placed in the same position as SRD transmitter. It is connected to a RF signal generator and tuned to SRD carrier frequency.

Step 3: The level of the RF signal generator is adjusted until an equal e.r.p. to that measured from SRD transmitter is obtained in the spectrum analyser.

Step 4: Calculate SRD e.r.p. as follows:
e.r.p. (dBm) = Reference RF signal power (dBm) + half wave dipole antenna cable loss (dB)

Remarks about the half wave dipole antenna:

Ferrite rings have been fixed all along the antenna cable to reduce its impact on measurements. Moreover, it is placed in horizontal plane on a length ≥ 1m.

Before each measurement:

- the half wave dipole antenna has been matched to SRD transmitter carrier frequency as follows:
    - Wire length at f_c = 107.5 MHz = 67 cm;
    - Wire length at f_c = 88.5 MHz = 81 cm (see Figure 9).

Wire length was calculated by the formula given below:

$$Wl = 0.96\left(\frac{\lambda}{4}\right) = 0.96[(300/f_c)/4)]$$

where, 0.96 is effective length coefficient and λ is the wavelength of the carrier.

Antenna matching was verified with a vectorial network analyser.

- the cable loss has been measured in the band II in order to be used in SRD transmitter e.r.p. calculation.

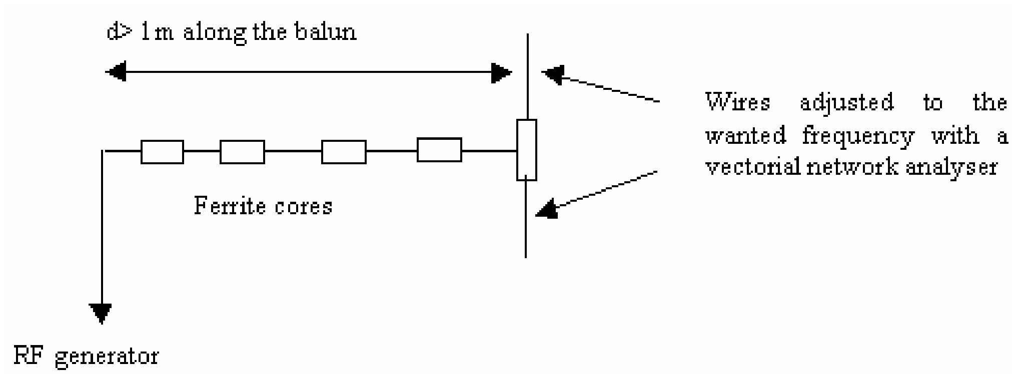


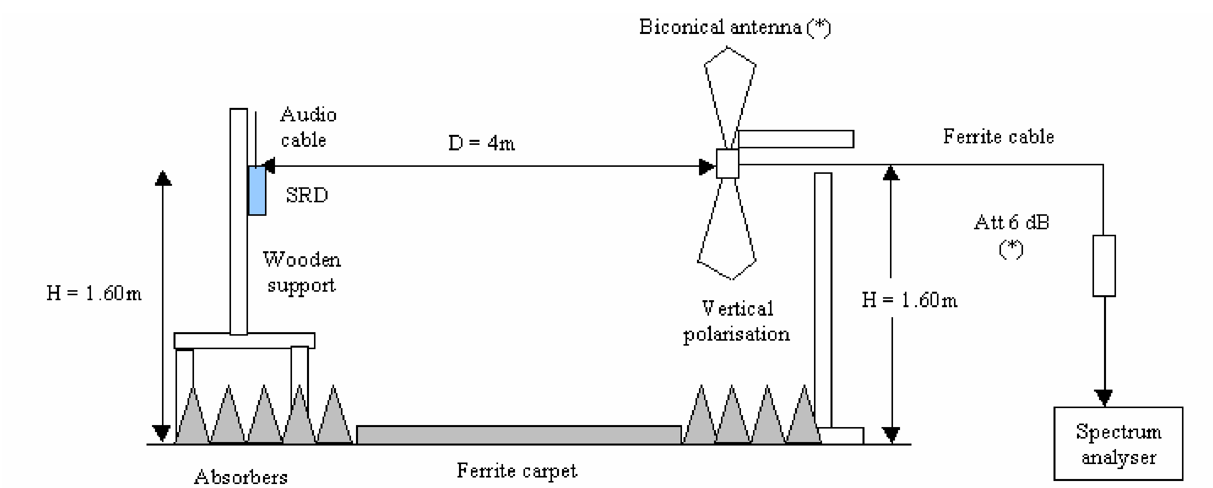
Figure 3.7: Measurement antenna set-up

Spectrum analyser configuration:

- RBW =1 kHz
- Sweep time = 1 s

3.2.5.2 Test set-up

The test set-up used for e.r.p. measurements is shown in Figures 3.8 and 3.9.



(*) 6dB attenuator is used to improve the impedance matching between biconical antenna and RF generator and consequently to reduce the measurement uncertainties. The use of a FM antenna should be more appropriate for this measurement.

Figure 3.8: Test set-up for e.r.p. measurement (1st step)

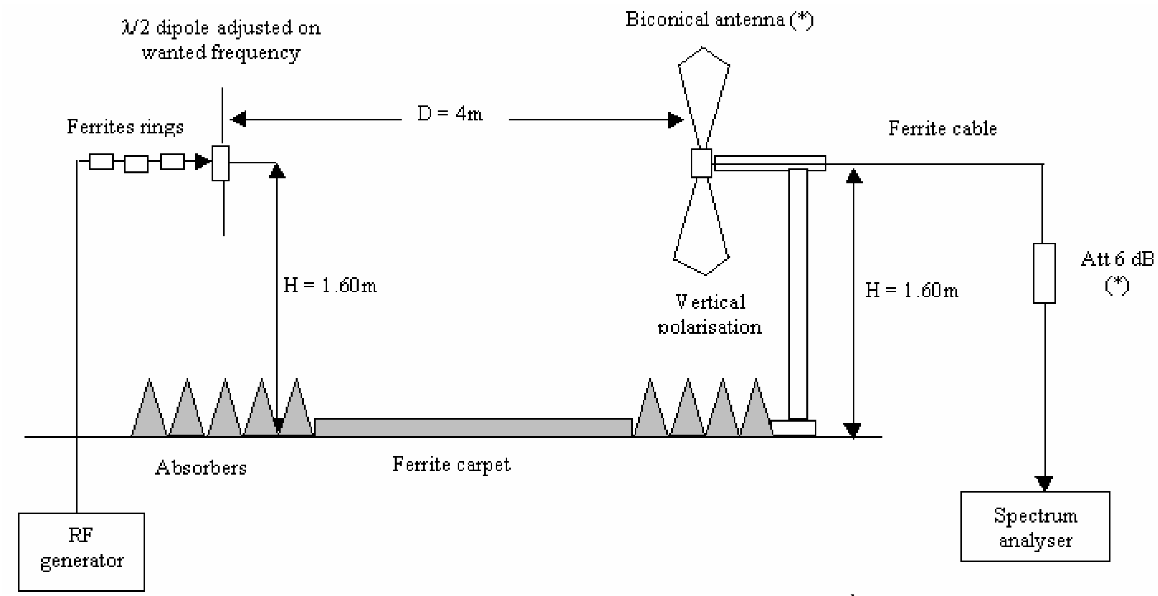


Figure 3.9: Test set-up for e.r.p. measurement (2nd step)

3.2.5.3 Measurement results

Tables 3.7 and 3.8 show the SRD e.r.p. measured. Note that more extensive measurements have been carried out on SRD7 because of its flexible frequency coverage.

e.r.p. measurement results (Combined uncertainty = 1.4 dB, Expended uncertainty = 2.8 dB)					
	SRD carrier frequency = 88.5 MHz		**SRD carrier frequency = 107.5 MHz**		
SRD	**e.r.p. (dBm)**	**e.r.p. (nW)**	**e.r.p. (dBm)**	**e.r.p. (nW)**	**Observations**
SRD1 battery	-40.2	95	Not measured	Not measured	Instability at 107 MHz frequency range
SRD2 battery	-21.9	6412	-15.4	28510	
SRD4 cigar lighter	-22.9	5093	Not measured	Not measured	107 MHz frequency range not available
SRD5 cigar lighter	Not measured	Not measured	-37.4	180	88 MHz frequency range not available Can be used both with cigar lighter and battery
SRD6 battery	-47.5	17.6	Not measured	Not measured	107 MHz frequency range not available
SRD7 battery	-41.9	64.1	-48.5	14	Can be used both with cigar lighter and battery

Table 3.7: e.r.p. measurement results

SRD7 e.r.p. measurement results (Combined uncertainty = 1.4 dB, Expended uncertainty = 2.8 dB)			
SRD carrier frequency (MHz)	**e.r.p. (dBm)**	**e.r.p. (nW)**	**Observations**
88.1	-40.63	86.50	SRD7 e.r.p. decreases as its transmitter carrier frequency increases
88.5	-41.93	**64.12**	
90	-42.6	54.95	
95	-43.55	44.16	
97	-44.02	39.63	
98	-47.9	16.22	
107.5	-48.55	**13.96**	

Table 3.8: SRD7 e.r.p measurement results

3.2.5.4 Analysis of the results

Measurement results show that:

- SRD transmitters e.r.p.. levels are not homogeneous. They vary depending on the SRD transmitter type.
- The e.r.p. level of an individual SRD transmitter is not constant over band II:

  SRD2: e.r.p. = 6412 nW at f_c = 88.5 MHz and 28510 nW at f_c = 107.5 MHz

  SRD7: e.r.p. = 64.1 nW at f_c = 88.5 MHz and 14 nW at f_c = 107.5 MHz

  This difference may be due to the audio cable length which is very short in comparison with the FM broadcast wavelength (note that SRD2 and SRD7 are not FCC compliant).
- In case of the use of a spiral audio connector (e.g. SRD2), SRD antenna can be extended from 10 cm to 50 cm. Consequently, SRD transmitter e.r.p. may vary at the same carrier frequency depending on its antenna extension.

  In case of the use of a short straight audio cable (e.g. $L < \lambda_{FM}/10$ for SRD6), SRD transmitter e.r.p. is more stable.

3.2.6 Spurious emissions measurement

The objective of this measurement is to verify the conformity of SRD spurious emission levels with the values defined in EN 300 220-1 [7].

3.2.6.1 Methodology

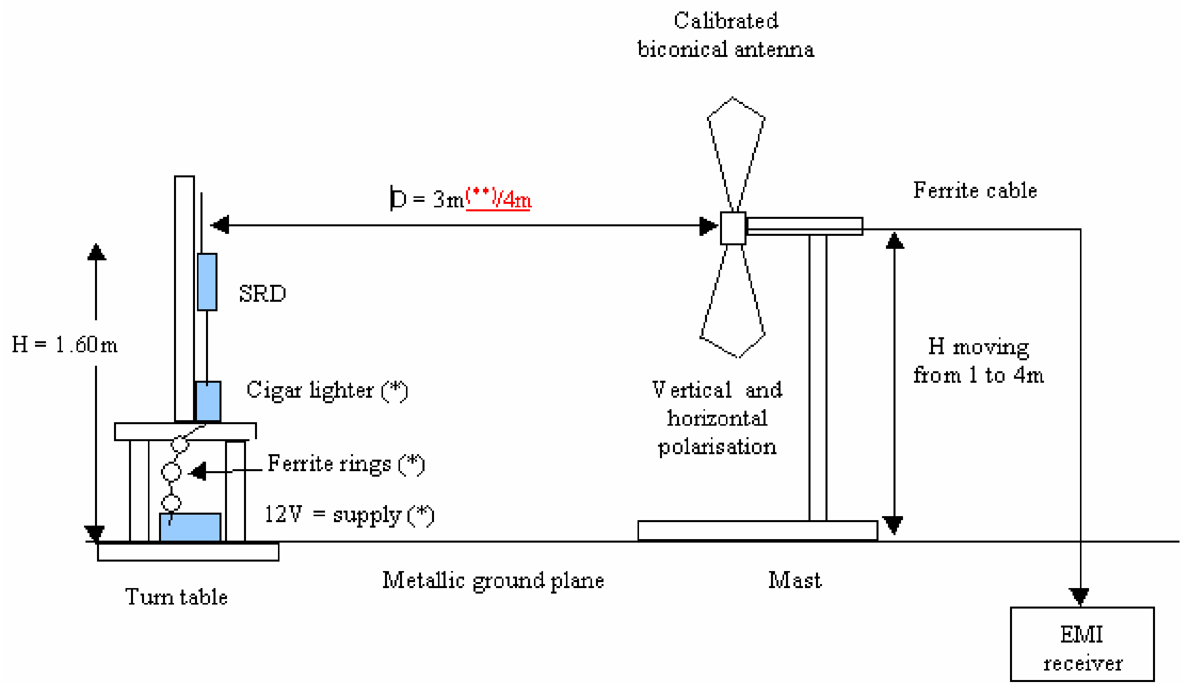
The measurement method used is the substitution method defined in ETSI EN 300 220-1, sub clause 8.7.3 [7]:

The measurement configuration used is:

- RBW = 120 kHz;
- Preliminary measurement mode: Peak detector;
- Measurement on out of limit spurious: Quasi-peak detector;
- Sweep time: 135 ms/MHz;
- Frequency step: 75 kHz;
- Frequency range 1: 30 - 200 MHz (measurement with biconical antenna);
- Frequency range 2: 200 - 1000 MHz (measurement with log periodic antenna).

3.2.6.2 Test set-up

The test set-up used for spurious emissions measurements is shown in Figures 13 and 14.



(*) only for cigarette lighter 12 V supply cable

(**) only for EN 55022 methodology

Figure 3.10: Test set-up for spurious measurement

3.2.6.3 Spurious emission level calculation

The spurious emission levels have been calculated from SRD transmitter field strength (dBµV/m) measured at 3 m by using the following formula:

$$P\ (dBm) = E\ (dB\mu V/m) + 20 \log (d) - 107.77 = E\ (dB\mu V/m) - 98.23\ dB \text{ for } d = 3m$$

Spurious emissions shall not exceed the values defined in EN 300220-1 [7], Table 3.2 (4 nW in active mode see EN 303 108 [6]).

The conversion of the power from dBm into nW can be done by using the following formula:

$$P\ (nW) = 10^{P(dBm)/10}.10^{6}$$

3.2.6.4 Measurement results

The measurements results obtained are given in Table 3.9.

SRD transmitter spurious emission measurement results (Combined uncertainty = 1.4 dB, Expended uncertainty = 2.8 dB)							
SRD	**SRD fc (MHz)**	**SRD e.r.p. (nW)**	**Spurious frequency (MHz)**	**Harmonic**	**Spurious (nW)**	**Comments**	**Limit (nW)**
SRD4 with cigarette lighter cable supply	88.5	5093	177	H2	3.2	The other harmonics are negligible	3 (limit defined in EN 55022 [8])
SRD5 with cigarette lighter cable supply	107.5	180	104.4 110.55		42.1 not measured with Q-P detector	Spurious emissions at fc ± 3.1 MHz	
SRD6 with battery supply	88.1	17.6		H2	0.02	The other harmonics are negligible Measurements carried out by substitution method	4 (limit defined in EN 300 220-1 [7])
SRD7 with cigarette lighter cable supply	88.1	86.5		H2	0.05		

Table 3.9: Spurious measurement results

Note that SRD4 and SRD5 spurious emission levels have been measured by using the method defined in EN 55022 [8]. Actually this method is very time consuming and does not provide better results than the results obtained by the substitution method defined in ETSI EN 300 220-1 [7].

3.2.6.5 Analysis of the results

SRD4 spurious emissions are mostly below 3 nW measured in quasi-peak detection mode. Only H2 is slightly above 3nW defined in EN 55022 [8]. Note that SRD4 is in full conformity with EN 300 220-1 [7].

SRD5 spurious emissions are well above 3 nW measured in quasi-peak detection mode. They are located at ± 3.1 MHz from SRD transmitter carrier frequency. Consequently, SRD5 is in conformity neither with EN 55022[8] nor with ETSI EN 300 220-1 [7].

SRD6 and 7 spurious emissions are well below 4nW measured in quasi-peak detection mode. Consequently, they are in conformity with ETSI EN 300 220-1 [7].

3.2.7 SNR degradation of FM broadcast receiver in presence of SRD signal (d = 3m)

The objective of this measurement is to assess the impact of SRD transmitter on the FM broadcast radio in laboratory and in situ conditions. The SRD transmitter is placed at 3 m from FM receiver.

3.2.7.1 Methodology

The measurements have been carried out for different frequency separations between victim FM receiver and interfering SRD transmitter. Only the impact of SRD7 on the particular FM receiver under test has been assessed, because its carrier can be adjusted over the whole of band II to provide a wide range of e.r.p. (see Table 3.7).

The FM receiver is placed on a wooden table at 0.8 m above the floor. Its antenna is fully extended in vertical polarisation.

The input signal to FM antenna is adjusted in level until a field strength of 44 dBμV/m is obtained at 1.60 m above the floor (it should be noted that this value is derived from ITU-R BS.412 using a correction factor of 10dB compared to the 10m antenna height).

Modulation characteristics:

- Left and right channels : 1 kHz sinusoidal audio signal with a 19 kHz pilot tone.
- Frequency deviation: ±75 kHz

Audio analyser configuration:

- Detector: Quasi-peak;
- Audio impedance = 600Ω;
- Output signal: 1 kHz sinusoidal audio signal with a 19 kHz pilot tone. Its level is adjusted is adjusted until a frequency deviation of ±75 kHz is obtained. Pilot tone frequency deviation is ±7.5 kHz.

FM receiver configuration:

The volume of FM receiver should be adjusted until the maximum audio signal is obtained without affecting its SNR.

The acceptable FM receiver SNR degradation in the presence of an interfering signal = 6 dB

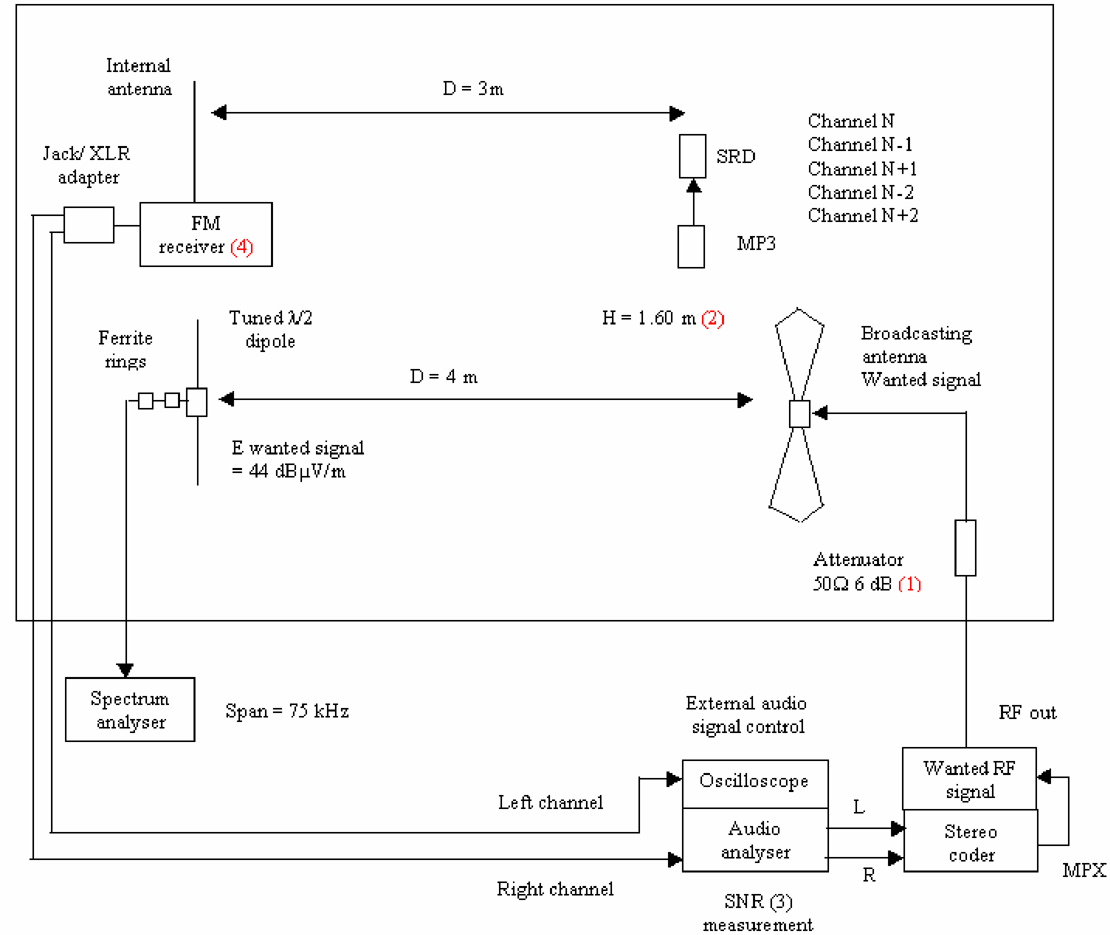
SNR measurement:

The SNR measurement has been carried out in stereo mode on the both left and right channels with on/off audio signal (automatic mode on UPL audio analyser).

Note that at the present time monophonic mode is practically never used.

3.2.7.2 Test set-up

The test set-up used to assess the impact of SRD transmitter on the FM broadcast service is shown in Figure 3.11.



(1) The 6dB attenuator is used in order to improve the impedance matching between biconical antenna and RF generator.

(2) H =1.60 m for both SRD, broadcast and half dipole antennas. The FM receiver is placed at h = 0.80 m with its internal antenna entirely extended in vertical position.

(3) The audio signal is send in symmetric mode on both A and B channels.

(4) (4) The FM receiver is placed on a wooden table at 0.8 m from the floor.

Figure 3.11: Test set-up for SNR degradation measurement

3.2.7.3 Measurement results

The measurement results obtained are given in Table 3.10.

Impact of SRD transmitter on FM receiver for different frequency separations				
FM Receiver	**SRD**	**Separation distance (m)**	**SNR without SRD**	**Acceptable SNR degradation (dB)**
Grundig	SRD7 (50 nW e.r.p. at 88.5 MHz)	3	51	6
FM carrier frequency (MHz)	**Unwanted signal (MHz)**	**Δf (MHz)**	**Measured SNR**	**SNR degradation**
88.5	88.1	-0.4	49	2
	88.2	-0.3	49	2
	88.3	-0.2	40.5	10.5
	88.4	-0.1	15.8	35.2
	88.5	0	4.5	46.5
	88.6	0.1	23	28
	88.7	0.2	43	8
	88.8	0.3	49	2
	88.9	0.4	50.8	0.2
	89	0.5	51.6	-0.6
FM Receiver	**SRD**	**Separation distance (m)**	**SNR without SRD**	**Acceptable SNR degradation (dB)**
Grundig	SRD7 (15 nW e.r.p. at 98 MHz)	3	48.9	6
FM carrier frequency (MHz)	**Unwanted signal (MHz)**	**Δf (MHz)**	**Measured SNR**	**SNR degradation**
98	97.6	-0.4	48.5	0.4
	97.7	-0.3	48.2	0.7
	97.8	-0.2	27.1	21.8
	97.9	-0.1	26.8	22.1
	98	0	13.3	35.6
	98.1	0.1	15.1	33.8
	98.2	0.2	35.8	13.1
	98.3	0.3	48.7	0.2
	98.4	0.4	48.4	0.5

Table 3.10: The measurement results

3.2.7.4 Analysis of the results

The measurement results obtained clearly show that, in the presence of a co-channel SRD signal at d =3 m from the FM receiver (with e.r.p. of 50 nW and 15 nW respectively) the SNR of the latter is drastically reduced. For a minimum guaranteed field strength of 44 dBμV/m and an audio SNR degradation of less than 6 dB a frequency separation of at least 300 kHz is needed between the victim FM receiver and interfering SRD transmitter.

The SNR degradation depends on SRD e.r.p..

However it is reasonable to expect that the user of the SRD would also be in control of the Broadcast receiver and therefore mitigate the problem.

From impromptu tests carried out in the conference room at TDF with a Sony portable receiver and SRD 7 on a broadcast station it was found that:

1. A movement of a few inches changed the FM capture ratio and allowed either the SRD or the Broadcast station to be received
2. Alignment of the Sony rod aerial achieved the same results as 1.

3.3 In situ test on SRDs operating in vehicles

Two different type of in situ tests have been carried out:

- Static tests aiming to understand the behaviour of SRDs when they are used in vehicles and to evaluate their impact on FM broadcast service in traffic jam or red traffic light conditions.

- Dynamic in situ tests aiming to verify if SRD transmitter could ensure an acceptable reception to its user while transmitting through a free FM channel without disturbing an adjacent distant/local FM radio or while transmitting through the channel of a distant or a local FM radio.

It should be noted that tests have been carried out with the SRD at gearbox level following practical tests which show that it was impractical and unsafe to use the SRD and MP3 player at dashboard level when car is in motion.

3.3.1 Technical parameters

SRD characteristics					
	Type	**Frequency range**	**FCC compliant**	**Power level claimed**	**Measured power level**
SRD6/battery only	BELKIN fixed frequency	Four fixed frequencies: 88.1, 88.3, 88.5 and 88.7 MHz	Yes (FCC ID: K7SF8V367)	15 nW	18 nW
SRD7/battery and 12 volt lead connection	BELKIN Manual tuning with LCD screen	87,5 – 108 MHz	(FCC ID: K7SF8V3080)* *FCC spec other then RF stage tuned to 50 nW	50 nW	87 nW at 88.1 MHz 64 nW at 88.5 MHz; 55 nW at 90 MHz; 44 nW at 95 MHz 40 nW at 97 MHz 16.2 nW at 98 MHz 14 nW at 107.5 MHz

FM channels used		
	Local radio programmes (Metz)	**Distant radio programmes**
SRD6	No local channels in the frequency range 88-89 MHz	88 MHz SR1 (German radio) 88.7 MHz France culture (Nancy) 88.9 MHz RTL-LUX (Luxembourg)
SRD7	89.2 MHz Radio Peltre loisir (French radio) 89.7 MHz Luttange France Musique 99.8 MHz France Inter	88 MHz SR1 (German radio) 88.7 MHz France culture (Nancy) 88.9 MHz RTL-LUX (Luxembourg)

Received FM signal strengths (in static conditions in the car park at TDF)					
Local radio programmes (Metz)			**Distant radio programmes**[1]		
f_c (MHz)	E_V (dBμV/m)	E_H (dBμV/m)	f_c (MHz)	E_V (dBμV/m)	E_H (dBμV/m)
89.2	52	44	88.0	42	42
89.7	56	60	88.7	23	43
99.8	63	65	88.9	27	44

Vehicles to be used			
	Type	**Antenna position**	**Other details**
Vehicle 1	Ford Fiesta	See Figure 3.12	Rod antenna inclined by 45°
Vehicle 2	Mazda 3	See Figure 3.12	Rod antenna inclined by 45
Vehicle 3	Toyota Land Cruiser	See Figure 3.12	Vertical road antenna
Vehicle 4	VW Passat	See Figure 3.12	Rod antenna inclined by 45

[1] These radio programmes may be substituted for radio programmes received in urban areas or at the border in FM Broadcast service area.

Table 3.10 : SNR degradation measurement results

3.3.2 Test scenarios

3.3.2.1 Static in situ test

Static tests have been carried out to understand the behaviour of SRDs when they are used in vehicles and to evaluate their impact on FM broadcast service in traffic jam or red traffic light conditions.

3.3.2.1.1 Impact of SRDs on FM service

Four vehicles were positioned in the car park at TDF according to two-lane road and single-lane road scenarios (see paragraphs 3.3.2.1.3 and 3.3.2.1.4). The SRD under test was placed at the gearbox level in one of the vehicles. Then**,** it was tuned to the channel/adjacent-channel of a local radio and its impact on the quality of reception of this transmission in other vehicles has been recorded.

Then the tests were repeated on the channel of a distant Broadcast station.

After that the SRD was placed in another vehicle and the tests were repeated.

The objective of these tests is firstly, to verify if the SRD under test can ensure an acceptable reception to its user while transmitting through the channel/adjacent-channel of a local radio secondly, to verify its impact on the quality of reception of the local radio channel in the other vehicles.

3.3.2.1.2 SRDs transmission quality through a free FM channel with power levels of 15 nW and 50 nW

The SRD under test was placed at the gearbox level in one of the vehicles; it was then tuned to an unused FM channel. The quality of reception of this channel has been recorded with the transmission powers of 15 nW and 50 nW respectively.

3.3.2.1.3 Two-lane road scenario

SRD was placed at the gearbox level.

d ≈ 1 m

• = Vehicle antenna position

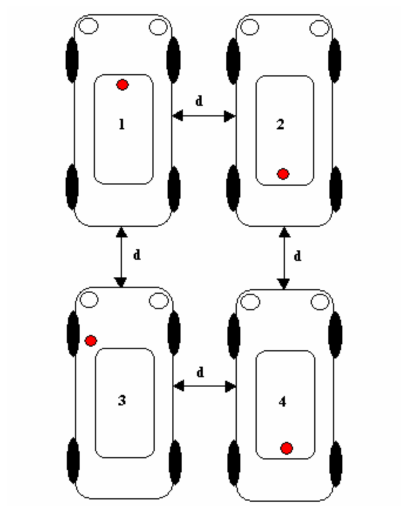


Figure 3.12: two-lane set up

3.3.2.1.4 Single-lane road scenario

SRD was placed at the gearbox level.

d ≈ 1 m

• = Vehicle antenna position

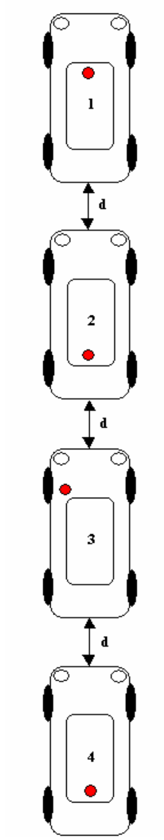


Figure 3.13: one lane set-up

3.3.2.2 Results of static in situ tests

Static in situ test results are given in Appendix 2 to Annex 2.

3.3.2.3 Analysis of static in situ test results

The tests of SRD transmitters operating at 15nW or 50nW e.r.p. show that:

- If SRD is tuned to an in service broadcast channel, then, interference may occur to adjacent vehicles depending on the strength of the broadcast signal;

- Adjacent vehicles may receive SRD if tuned to the same frequency;

- Providing SRD is 200 kHz or more from a broadcast station adjacent vehicles do not receive interference;

- The use of RDS in some vehicle receiver's may cause the receiver to move automatically away from the channel used by the SRD transmitter. Interference to FM broadcast radio on same channel to the SRD was observed in some adjacent vehicles depending on the broadcast field strength. Note that, most of the observed interference was due to a 50 nW SRD transmitter.

3.3.2.4 Dynamic in situ test

Dynamic in situ tests have been carried out to verify if SRD transmitter could ensure an acceptable reception to its user while transmitting through a free FM channel without disturbing an adjacent distant/local FM radio or while transmitting through the channel of a distant or a local FM radio.

3.3.2.4.1 SRD transmitting through the channel of a local/distant radio

The dynamic tests have been carried out in vehicle 4 travelling in the vicinity of TDF-Metz and in Metz. The SRD under test was placed at the gearbox level and was tuned to the channel/adjacent-channel of different distant radios. The behaviour of the SRD has been recorded by the operator accompanying the driver during the travel.

The objective of this test is to verify if SRD under test can ensure an acceptable reception to its user while transmitting through the channel of a local/distant radio.

The test was repeated on the frequency of different local broadcast channels.

3.3.2.4.2 SRD transmitting through a free FM channel

The SRD under test was placed at the gearbox level and had been tuned to a free FM channel adjacent to a local radio channel. The behaviour of SRD has been recorded by the operator accompanying the driver during the travel.

The objective of this test is to verify if SRD under test can ensure an acceptable reception to its user while transmitting through a free FM channel, without disturbing a local radio programme using an adjacent channel.

3.3.2.4.3 Dynamic in situ test results

SRD under test				
Type	**Frequency range**	**FCC compliant**	**Power level claimed**	**Measured power levels**
SRD7 (BELKIN Manual tuning with LCD screen) supplied by 12V cigarette lighter cable	87,5 – 108 MHz	FCC ID: K7SF8V3080* * FCC spec other than RF stage tuned to 50 nW	50 nW	64 nW at 88.5 MHz; 55 nW at 90 MHz
Test condition				
Test itinerary	Tests have been conducted in a car travelling in the vicinity of TDF-Metz and in Metz.			
Type of the car used	Volkswagen / Passat with 4 Passengers			
SRD is place at	the gearbox level			
Observation during the tests				
Case 1: SRD on Broadcast Channel				
Channel used	88.7 MHz: distant radio programme “France culture”. Observations: The FM transmitter is located at Nancy which is approximately 39 km from Metz.			
Was the reception quality of this programme acceptable, when SRD off?	Yes. Good quality “France culture” reception was recorded during the whole travel by regularly switching the SRD off. .			
SRD was tuned to	88.7 MHz			
Was the reception quality of the signal transmitted by SRD acceptable?	Yes. Good quality SRD reception was recorded during the whole travel. Observations: the radio programme “France culture” was completely masked by SRD signal.			

Case 2: SRD on Broadcast Channel	
Channel used	88.9 MHz: distant radio programme “RTL-LUX”. Observations: FM transmitter is located at Luxembourg which is approximately 54 km from Metz.
Was the reception quality of this programme acceptable, when SRD off?	Yes. Good quality “RTL-LUX” reception was recorded during the whole travel by regularly switching the SRD off.
SRD was tuned to	88.9 MHz
Was the reception quality of the signal transmitted by SRD acceptable?	Yes. Good quality SRD reception was recorded during the whole travel Observations : the radio programme “ RTL-LUX ” was completely masked by SRD signal.
Case 3: SRD on Broadcast Channel	
Channel used	89.2 MHz: local radio programme “Peltre loisir”. Observations: FM transmitter is located at Peltre which is situated approximately 4 km from TDF and 6 km from the city centre of Metz.
Was the reception quality of this programme acceptable, when SRD off?	Yes. Good quality “Peltre loisir” reception was recorded during the whole travel by regularly switching SRD off
SRD was tuned to	89.2 MHz
Was the quality of reception of the signal transmitted by SRD acceptable?	Yes. Good quality SRD reception was recorded during the whole travel in the city centre of Metz and in its vicinity by moving away from the village “Peltre” where FM transmitter is located. Observations : Poor SRD reception in the vicinity of TDF (between TDF and “Peltre”)
Case 4: SRD on Broadcast Channel	
Channel used	89.7 MHz: local radio programme “Luttange France Musique”. Observations: FM transmitter is located at Luttange which is situated approximately 20 km from Metz.
Was the reception quality of this programme acceptable, when SRD off?	Yes. Good quality “Luttange France Musique” reception was recorded during the whole travel by regularly switching SRD off.
SRD was tuned to	89.7 MHz
Was the quality of reception of the signal transmitted by SRD acceptable?	Partly yes. Good quality SRD reception was recorded during the travel in the city centre of Metz. Observations : No SRD reception in the vicinity of Metz (particularly between Metz and TDF). SRD signal was completely masked by “Luttange France Musique”.
SRD was tuned to	89.8 MHz: free radio channel located at 100 kHz from radio programme “Luttange France Musique”
Was the quality of reception of the signal transmitted by SRD acceptable?	Yes. Good quality SRD reception was recorded during the travel in the city centre of Metz. Observations : SRD signal was interfered by “Lutange France Musique” in the vicinity of “Peltre” which is situated approximately 6 km from TDF and 8 km from the city centre of Metz.

Was the reception quality of the local radio programme "Luttange France Musique" (89.7 MHz) acceptable?	No. Radio programme "Luttange France Musique" was interfered by SRD signal.

Table 3.13: One lane set-up

3.3.2.5 Analysis of dynamic in situ test results

Dynamic in situ test results show that SRD7 (50 nW) was able to ensure a good reception, in a travelling vehicle, through the FM channels "France culture" (88.7 MHz) and "RTL-LUX" (88.9 MHz). These distant stations are received with a good quality in Metz and its vicinities.

SRD7 was also able to ensure a good reception through FM channels "Peltre loisir" (89.2 MHz) and "Luttange France Musique" (89.7 MHz) used by local radios in Metz. On the other hand, SRD7 signal was either strongly interfered with or completely masked by these stations in the vicinity of Metz (particularly in open areas).

3.4 Conclusions

Laboratory measurements and in situ tests have been carried out to evaluate the impact of SRD transmitters on FM broadcasting in the band 87.5 - 108 MHz. Only two of six available SRD transmitters were extensively tested (SRD 6 - 15nW- and SRD 7 – 50nW).

The results obtained show that:

- In laboratory conditions: in the vertical plane SRD transmitter audio cable reacts as an omnidirectional antenna. In case of the use of a cigar lighter cable supply, this cable reacts as a part of SRD antenna and modifies the radiation pattern in both vertical and horizontal planes.

  In the presence of a co-channel SRD transmitter at 3 m from the FM receiver the SNR of the latter is drastically reduced. For a minimum usable FM broadcast field strength of 44 dBµV/m and an audio SNR degradation of less than 6 dB a frequency separation of at least 300 kHz is needed from the channel used by the FM receiver. The magnitude of SNR degradation depends on the SRD e.r.p.. Frequency deviation is not limited in the tested SRD transmitters.

  However it is reasonable to expect that the user of the SRD would also be in control of the Broadcast receiver and therefore mitigate the problem.

  Frequency deviation is not limited in the tested SRD transmitters, but in practice the reception of the SRD would probably be unacceptable to the user.

- At in-car conditions: if the SRD is tuned to an in service broadcast channel, then, interference may occur to adjacent vehicles depending on the FM broadcast field strength. Under these conditions, a frequency separation of 200 kHz or more is required from a broadcast station to prevent adjacent vehicle interference. Adjacent vehicles may receive the SRD if their receivers are tuned to the same frequency. The use of RDS in some vehicle receiver's may cause the receiver to move automatically away from the channel used by SRD transmitter and look for an alternative broadcast transmitter.

  In urban area, in a travelling vehicle, a 50 nW SRD transmitter is able to ensure a good reception through a channel used by a local broadcast station depending on the FM broadcast field strength received.

Finally, it should be noted that most of the observed interference was due to 50 nW SRD transmitter. On the other hand, 15 nW SRD transmitter makes the task of locating a suitable operating position within the vehicle more difficult.

Appendix 1 to Section 3: Photographs of tested SRD equipment in FM band

Figure 3.14: SRD 1

Figure 3.15: SRD 2

Figure 3.16: SRD 3

Figure 3.17: SRD 4

Figure 3.18: SRD 5

Figure 3.18: SRD6

SRD 7

Appendix 2 to Section 3: Impact On Local and Distant Radio Stations

Static test case: Two-lane road (see Figure 3.12)

SRD is placed at	**Vehicle n° 2**				
SRD tuned to (MHz)	88.1	88.3	88.5	88.7	88.7
Vehicles tuned to (MHz)	88	88	88.7	88.7	88.9
Frequency separation (MHz)	0.1	0.3	-0.2	0	-0.2
Vehicle n° 1; Interference observed?	Yes	Yes	No	Yes	Yes
Vehicle n° 2; Interference observed?	No	No	No	Yes	No
Vehicle n° 3; Interference observed?	No	No	No	No	No
Vehicle n° 4; Interference observed?	Yes	No	No	Yes	No

Table 3.14: Interferer - 15 nW SRD 6

SRD is placed at	**Vehicle n° 2**							
SRD tuned to (MHz)	88.1	88.2	88.7	88.8	88.9	88.9	89.1	89.2
Vehicles tuned to (MHz)	88	88	88.7	88.7	88.7	88.9	88.9	88.9
Frequency separation (MHz)	0.1	0.2	0	0.1	0.2	0	0.2	0.3
Vehicle n° 1; Interference observed?	Yes	No	Yes	Yes	No	Yes	No	No
Vehicle n° 2; Interference observed?	Yes	No	Yes	Yes	Yes	Yes	No	No
Vehicle n° 3; Interference observed?	Yes	No	Yes	No	No	Yes	No	No
Vehicle n° 4; Interference observed?	Yes	No	Yes	Yes	No	Yes	No	No

Table 3.15: Interferer - 50 nW SRD 7

SRD is placed at	**Vehicle n° 3**								
SRD tuned to (MHz)	89.2	89.3	89.4	89.7	89.8	89.9	99.8	99.9	100
Vehicles tuned to (MHz)	89.2	89.2	89.2	89.7	89.7	89.7	99.8	99.8	99.8
Frequency separation (MHz)	0	0.1	0.2	0	0.1	0.2	0	0.1	0.2
Vehicle n° 1; Interference observed?	Yes	No	No	Yes	No	No	No	No	No
Vehicle n° 2; Interference observed?	No	No	No	Yes	No	No	Yes	No	No
Vehicle n° 3; Interference observed?	Yes	No	No	Yes	No	No	Yes	No	No
Vehicle n° 4; Interference observed?	No	No	No	Yes	No	No	No	No	No

Table 3.16: Interferer - 50 nW SRD 7

Static test case: Single-lane road (see Figure 3.13)

SRD is placed at	**Vehicle n° 1**				
SRD tuned to (MHz)	88.1	88.3	88.5	88.7	88.7
Vehicles tuned to (MHz)	88	88	88.7	88.7	88.9
Frequency separation (MHz)	0.1	0.3	-0.2	0	-0.2
Vehicle n° 1; Interference observed?	No	No	Yes	Yes	No
Vehicle n° 2; Interference observed?	No	No	No	No	No
Vehicle n° 3; Interference observed?	No	No	No	No	No
Vehicle n° 4; Interference observed?	No	No	No	No	No

Table 3.17: Interferer - 15 nW SRD 6

SRD is placed at	**Vehicle n° 1**							
SRD tuned to (MHz)	88.1	88.2	88.7	88.8	88.9	88.9	89.1	89.2
Vehicles tuned to (MHz)	88	88	88.7	88.7	88.7	88.9	88.9	88.9
Frequency separation (MHz)	0.1	0.2	0	0.1	0.2	0	-0.2	-0.3
Vehicle n° 1; Interference observed?	No	No	Yes	Yes	No	Yes	No	Yes
Vehicle n° 2; Interference observed?	No	No	Yes	Yes	No	Yes	No	Yes
Vehicle n° 3; Interference observed?	Yes	No	Yes	No	No	No	No	Not available
Vehicle n° 4; Interference observed?	No	No	No	No	No	No	No	No

Table 3.18: Interferer - 50 nW SRD 7

SRD is placed at	**Vehicle n° 3**							
SRD tuned to (MHz)	88.1	88.2	88.7	88.8	88.9	88.9	89.1	89.2
Vehicles tuned to (MHz)	88	88	88.7	88.7	88.7	88.9	88.9	89.2
Frequency separation (MHz)	0.1	0.2	0	0.1	0.2	0	0.2	0
Vehicle n° 1; Interference observed?	Yes	No	Yes	Yes	Uncertain	Yes	No	No
Vehicle n° 2; Interference observed?	Yes	Yes	Yes	Yes	No	Yes	No	Yes
Vehicle n° 3; Interference observed?	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Vehicle n° 4; Interference observed?	Yes	No	Yes	Yes	Yes	Yes	No	No

Table 3.19: Interferer - 50 nW SRD 7

4 DETERMINATION OF THE IMPACT OF SRDS ON FM BROADCAST RECEIVERS BASED ON SEAMCAT SIMULATIONS

4.1 Scenarios

Basically three different scenarios can be defined:

1. Indoor use, e.g. built-in transmitter of TV receivers
2. Outdoor dynamic use within a car, e.g. motorway, we can have two cases:
    - 2.1 Low traffic load (speed of 120 km/h and security distance of 60 m)
    - 2.2 High traffic load (speed of 70km/h and security distance of 30 m)
3. Outdoor static use within a car, e.g. traffic jam

Scenario	**Situation**
Indoor	The victim is used within the same flat / room; no wall losses; duty cycle 100%
	The victim is used outside the same flat / room; wall losses have to be taken into account; duty cycle 100%
Motorway	low traffic load, that time the interferer passes the victim; because of the interferers could follow one after the other, the duty cycle depends on the distance of the cars and minimum protection distances based on the receiver parameter of the victim and the output power of the interferer
	high traffic load, that time the interferer passes the victim; because of the interferers could follow one after the other, the duty cycle depends on the distance of the cars and minimum protection distances based on the receiver parameter of the victim and the output power of the interferer
Traffic jam	8 interferers around the victim within a close distance; duty cycle 100%

Table 4.1: Scenarios

4.1.1 Description of the scenarios

4.1.1.1 Indoor

4.1.1.1.1 Indoor – Indoor (within the same flat)

Normally there is only one interferer used on the same frequency within a flat/room. The distance range may vary from 1m to several 10m. Because of the operator of the interferer is also responsible for the usage of the victim, this scenario can be ignored.

4.1.1.1.2 Indoor – Outside the flat

This scenario allows more than one interferer at the same time at the same frequency. On the other hand, the distance range is typically larger than 5m (room size) and, additionally wall losses of about 5-10dB have to be taken into account.

4.1.1.2 Outdoor – Outdoor

The simulation radius depends on the number of active interferers, their activity and their density:

$$R_{simu} = \sqrt{\frac{n^{active}}{\pi \times dens_{it}^{active}}}$$

4.1.1.2.1 Motorway with low traffic load

Assuming a constant velocity of 120 km/h the safety distance will be 60m. Having a lane width of 3m, each car ‘covers’ 180m^2.

The density is therefore about 5 600 cars/km^2. The number of active interferers becomes 17 (1000 m / 60m), due to the interferers on the lane closest to the victim having the most impact on the interference level.

4.1.1.2.2 Motorway with high traffic load

Assuming a constant velocity of 70 km/h the safety distance will be 30m. Having a lane width of 3m, each car ‘covers’ 90m^2.

The density is therefore about 11 120 cars/km^2. The number of active interferers becomes 34 (1000 m / 30m), due to the interferers on the lane closest to the victim having the most impact on the interference level.

4.1.1.2.3 Motorway based on the assumptions used for SRR (Short Range Radar)

The density used for this study has been assumed to be 353 cars/km^2. In order to be in line with the other parts of this document the number of active interferers is set to 34, the same as for high traffic load.

4.1.1.3 Outdoor – Outdoor (traffic jam)

For this scenario a lane width of 3 m is assumed as well as a car length of 4 m and a distance of 1 m between the cars on the same lane:

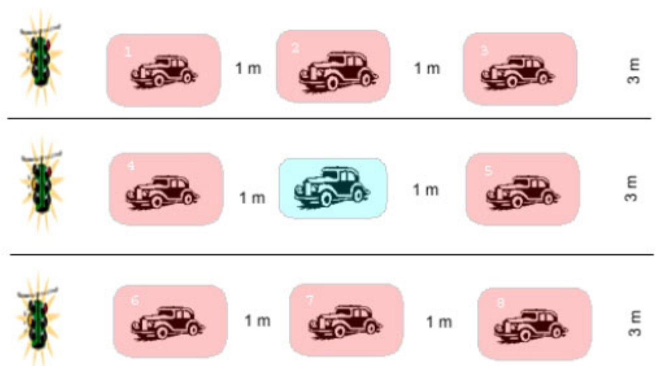


Figure 4.1: scenario ‘traffic jam’

As a randomly distribution is not given, the relative locations between the victim and the interferers are as follows:

interferer	x-position [m]	y-position [m]
#1	-5	3
#2	0	3
#3	5	3
#4	-5	0
#5	5	0
#6	-5	-3
#7	0	-3
#8	5	-3

Table 4.2: relative location for the scenario ‘traffic jam’

4.2 Simulation based on parameters of the Recommendation ITU-R BS.412-9

4.2.1 Technical parameters

4.2.1.1 FM victim features

In the SEAMCAT simulations according to the ITU-R recommendation, dRSS is the minimum field strength to be protected and sensitivity is the minimum power level at the input of a FM receiver (table3)

By definition, dRSS = C/N + F + 10*log(kTB*10^6) + 30

With F: Noise factor

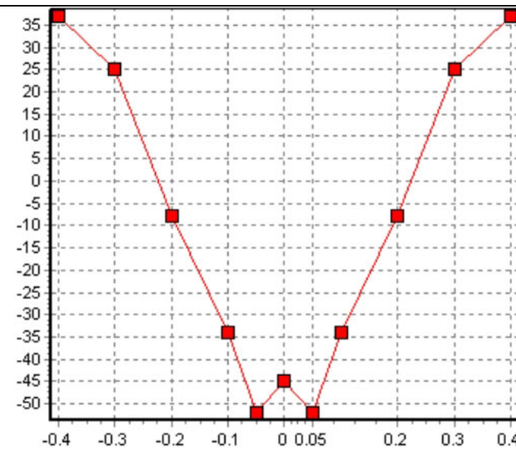
k: Boltzman constant

T: Ambient Temperature

B: Bandwidth

Values from ITU-R Recommendation BS.412-9 [3] are measured at 10m, to account for the antenna height loss (10m to 1.5m), a correction factor of 12 dB must be taken.

We obtain thus: dRSS = -74 dBm in rural (42 dBµV/m at 1.5m) and dRSS = -62 dBm in urban (54 dBµV/m at 1.5m), which is the minimum field strength to be protected derived from the values given in the Recommendation ITU-R BS.412-9 (the made man noise is integrated in these two values).

Channel spacing		200 kHz
Noise Factor 1)	F	7 dB
Boltzman constant	k	$1.38*10^{-23}$ Ws/K
Bandwidth	B	150 kHz
Ambient temperature	T	290 °K
Noise floor	P_b	-115 dBm
C/N		46 dB
Sensitivity	P_{min}	-69 dBm
Standard deviation 2)		8.3 dB
Antenna Gain	G_{iso}	0 dBi (-2.15dBd)
Used Frequency	F_c	88 MHz
Minimum equivalent field strength	E_{min}	47 dBµV/m
C/I (Δf = 0 kHz)		45 dB
C/I (Δf = 100 kHz)		34 dB
C/I (Δf = 200 kHz)		7 dB
C/I (Δf = 300 kHz)		-25 dB
Blocking response (Based on radio frequency ratios for different input powers of car receivers from ITU-R Recommendation BS.412-9 fig4).		

1) Commercial receiver
2) Standard deviation use for FM Receiver Report 945-2 [9]

Table 4.3: Victim receiver; technical parameters

4.2.1.2 SRD interferer features

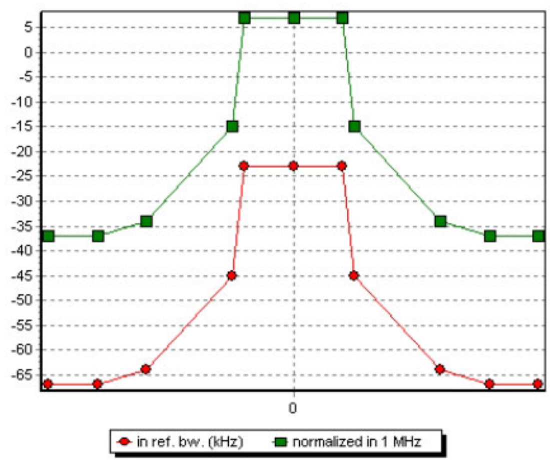
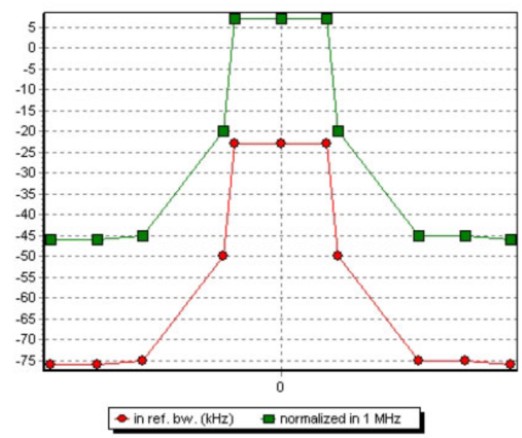
Channel spacing	200 kHz	
Bandwidth	150 kHz	
Antenna height	1.5 m	
Antenna Gain	0 dBi (-2.15dBd)	
Used Frequency	88 MHz	
Output power (e.r.p)	SRD 6	SRD 7
	15 nW	50 nW
	-48.2 dBm	-43 dBm
Transmitter mask (Based on the measurement report made in TDF Metz – see Figures 3.3 and 3.4)		

Table 4.4: SRD interferer; technical parameters

4.2.2 Parameters for the SEAMCAT simulation

4.2.2.1 Duty cycles

As described in item 1 of this document the duty cycle of the scenario 'motorway' depends:

- ✓ on the distance between cars.
- ✓ and on the minimum protection distances based on the receiver parameters of the victim and the output power of the interferer.

The minimum protection distance in free space is:

$D_{min} = 10$ ^ (($L_{min} - 20*\log_{10}(F) + 32.44$) / 20)

Where the minimum loss is deduced from a radio budget as used in the MCL method:

$L_{min} = P_{int} + G_{iso} - P_{min} + C/I$

scenario	Output Power [nW]	Distance between cars [m]	Minimum protection Distance (d_min) [m] [1)]	Duty cycle [%] [2)]
low	15	60	964	100
	50		1755	100
high	15	30	964	100
	50		1755	100

Table 4.5 : scenario 'motorway': duty cycle

1) Only given for information purpose

2) Note: the duty cycle is calculated by $duty\_cycle = \min\left(100;100 \times \frac{2 \times d_{\min}}{distance}\right)$

The duty cycle for the « traffic jam » scenarios is therefore 100%, whatever the load of the traffic (High or Low).

4.2.2.2 Numbers of active interferers and density

See also item 4.1.1.2

Scenario	# active interferers	Density (#/km²)
Low traffic load	17	5600
High traffic load	34	11200

Table 4.6: active interferers and density

4.2.3 Simulation results

Note: Offsets of -100 kHz, –200 kHz and –300 kHz have been simulated by shifting the centre frequency of the victim by steps of +100 kHz, +200 kHz and + 300 kHz respectively. Indeed it is easier to change only the frequency of the victim rather than to change e.g. 8 frequencies in the scenario 'traffic'.

Frequency offset	Scenario					
	Indoor – outdoor *)				Traffic jam*)	
	15 nW		50 nW		15 nW	50 nW
	Rural	Urban	Rural	Urban		
0 kHz	100	100	100	100	100	100
100 kHz	100	99.8	100	100	100	100
200 kHz	88	53.6	96.1	74	98.2	99.5
300 kHz	0.6	0	3.1	0	3.8	11.8

Table 4.7: simulation results probability of interference [%]

Frequency offset	Scenario motorway*)							
	Low traffic				High traffic			
	15 nW		50 nW		15 nW		50 nW	
	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
0 kHz	100	100	100	100	100	100	100	100
100 kHz	100	99.9	100	100	100	100	100	100
200 kHz	90.1	55	97	77.3	95.4	71.1	99	87.3
300 kHz	1.4	0.1	3.6	0.3	2.2	0.2	8	0.7

Table 4.8: simulation results probability of interference [%]

**) Note: for this scenario the propagation model Extended Hata (SRD) in the urban environment has been used*

4.3 Simulation based on parameters of CISPR-20 edition [10]

4.3.1 Introduction

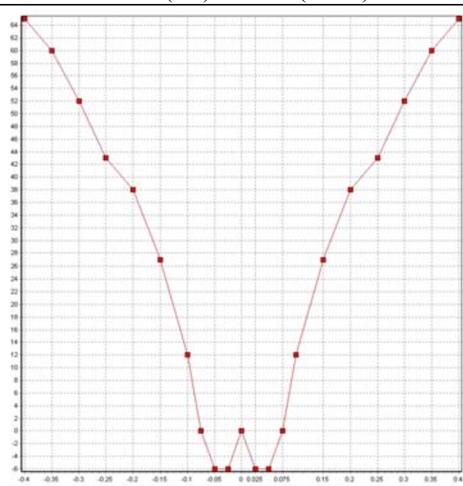
The approach of item 2 is mainly based on the planning parameters given by the ITU-R Recommendation BS.412-9 [3]. This section 4.3 is based on the requirements the broadcast car receiver has to fulfil as victim.

Even if it can be expected that the probability of interference of the scenario “indoor – outdoor” due the wall losses and the environment conditions will be less than the probabilities of interference of the other scenarios this scenario has also been simulated, but using the following assumptions:

- density of interferers: 400/km^2
- number of active interferers: 20
- duty cycle: 100%
- C/I: 40 dB (home)
- Wall loss: 8 dB

4.3.2 Technical parameters

4.3.2.1 Victim receiver

Channel spacing	200 kHz
Bandwidth	150 kHz
C/I	26 dB (car) / 40dB (home)
C(I+N)	23 dB (car) / 37 dB (home)
selectivity	
dRSS	60 dB(µV) = -47 dBm *)
Noise	-112 dBm
Antenna	Omni directional, 0 dB gain
Antenna height	1.5 m

*) <u>Note:</u>
because of the curves shown in Figure 3 of the ITU-R BS.412-9 [3] have been measured with wanted signals of –60 dBm, -50 dBm and –40 dBm respectively, one could also use as a compromise a value of –50 dBm; this would increase the minimum protection distances as well as the duty cycles of the scenarios ‘motorway’, but not significantly the simulated probability of interference using a frequency offset of 200 kHz

Table 4.9: victim receiver; technical parameters

4.3.2.2 Interference transmitter

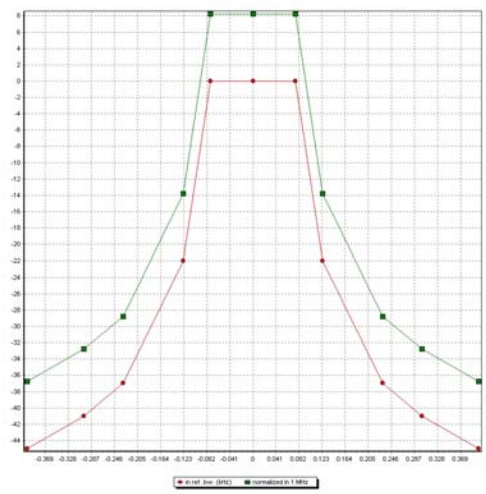
Channel spacing	200 kHz	
Modulation bandwidth	150 kHz (2 * 75 kHz stereo)	
Transmitter mask (this mask has been measured using the SRD with 50nW e.r.p.- see Figure 3.4)		
Antenna	Omni directional, 0 dB gain	
Antenna height	1.5 m	
Output power	15 nW e.r.p.	50 nW e.r.p.
	-48.2 dBm	-43 dBm

Table 4.10: interferer transmitter; technical parameters

4.3.3 Parameters for the SEAMCAT simulation

4.3.3.1 Duty cycles

The duty cycles for the scenarios 'indoor – outdoor' and 'traffic' are set to 100%.
As described in item 1 of this document the duty cycle of the scenario 'motorway' depends on the distance of the cars and the minimum protection distances based on the receiver parameter of the victim and the output power of the interferer.

scenario	Output Power [nW]	Distance [m]	Minimum protection Distance (d_min) [m]	Duty cycle [%] [1)]
Low	15	60	4.7	15.8
	50		8.6	28.7
high	15	30	4.7	31.6
	50		8.6	57.5
SRR	15	30	4.7	31.6
	50		8.6	57.5

1) Note: the duty cycle is calculated by $duty\_cycle := 100 \cdot \frac{2 \cdot d\_min}{distance}$

Table 4.11 : scenario 'motorway'; duty cycle

4.3.3.2 Number of active interferers and their density

See also item 4.1.1.2

Scenario	active	density
Low traffic load	17	5600
High traffic load	34	11200
SRR	34	353

Table 4.12: active interferers and their density

4.3.4 Simulation results

Note: because of an offset of 200 kHz is equal to a co-channel interferer of the victim used on the adjacent channel and an offset of 300 kHz is for the adjacent channel the same as an offset of 100 kHz for the channel currently simulated, only offsets of -100 kHz and –200 kHz have been simulated by moving the centre frequency of the victim by steps of +100 kHz and +200 kHz respectively, due to it is easier to change only the frequency of the victim than to change e.g. 8 frequencies in the scenario 'traffic'.

Frequency offset	Scenario									
	Indoor – outdoor *)		Traffic jam		motorway					
					Low traffic		High traffic		SRR	
	15 nW	50 nW	15 nW	50 nW	15 nW	50 nW	15 nW	50 nW	15 nW	50 nW
0 kHz	21.2	57.7	100	100	3.1	40.4	25.7	100	0.5	2.5
100 kHz	7.3	28.5	100	100	1.3	11.4	6.6	85.1	0.2	0.9
200 kHz	0. 06	0.1	0	0	0	0.01	0.03	0.1	0	0

**) Note: for this scenario the propagation model Extended Hata (SRD) in the urban environment has been used; for all other scenarios the free space propagation model has been used*

Table 4.13: simulation results probability of interference [%]

4.4 Consideration on the Probability of co-channel or partial overlap interference

Additional considerations on the Probability of interference by SRDs mounted in cars to FM receivers based on measured protection ranges.

SE24 considered a worst-case scenario resulting from traffic jam on a highway (see, the number of cars, X, inside the interference range is given by the following:

$$X = (2 * I_R / d_C) * L$$

where:

I_R is the interference range in meters;

d_C is the distance between cars in meters at full stop (traffic jam); and

L is the number of highway lanes.

Considering SE24 measurements showing that interference only occurs during co-channel or partial overlap operation, the probability of interference, P, is calculated as the following:

$$P = 1 - (1 - p_{chan})^N$$

where:

p_{chan} is the probability of co-channel interference if the SRD interferers are randomly spread over the available channels;

N is the number of active interferers inside the protection distance.

The FM band covers 20 MHz and the number of available channels at any location, N, is:

$$Number\ of\ channels = \frac{BW_{FM\ band}}{channel\ spacing} = \frac{20}{0.2} = 100$$

The number of active SRD devices, N, are:

$$N = X * D$$

where:

- *X* is the number of cars within the protection range;
- *D* is the market penetration for the SRD devices when used in cars.

Based on the assumptions, the calculated probability of interference is shown in table 1 below.

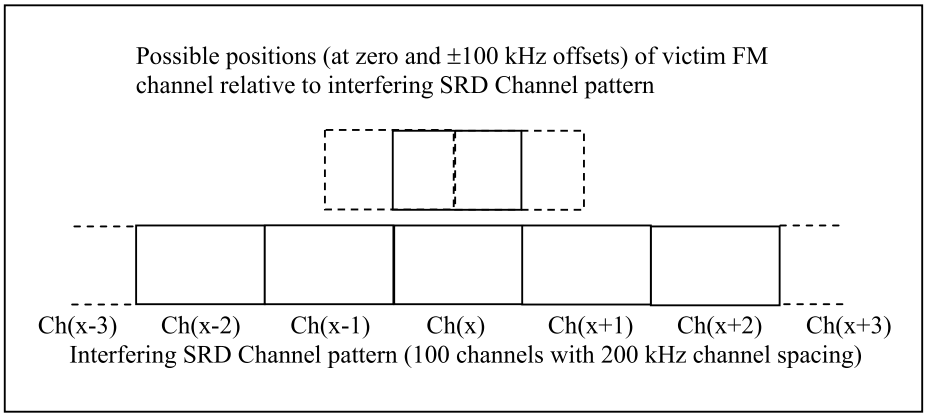


Figure 1

It is assumed that the interfering SRD uses 100 FM channels with a regular frequency spacing of 200 kHz. In that case, in a given geographical area, the victim FM channel may be centred at one of the three equiprobable frequencies at zero, -100 and +100 kHz from the interfering SRD channel centre (see Figure 1). Consequently, we can write:

$p(A_0)=p(A_{-100})=p(A_{+100})=1/3$

and

$p(A_0)+p(A_{-100})+p(A_{+100})=1$

where:

A_0: event "zero offset between the victim FM channel and interfering SRD channel"

A_{-100}: event "-100 kHz offset between the victim FM channel and interfering SRD channel"

A_{+100}: event "+100 kHz offset between the victim FM channel and interfering SRD channel"

p(A): probability of event A occurring

Consequently, p_{chan} is:

$p_{chan} = p(A_0 \cap A_{co\text{-}ch}) \cup p(A_{\pm 100} \cap A_{lo/app\text{-}ch})$

where:

$A_{co\text{-}ch}$: event "co-channel interference"

$A_{\pm 100}$: event "-100 or +100 kHz offset between the victim FM channel and interfering SRD channel"

$A_{-lo/upp\text{-}ch}$: event "lower or upper overlapping channel interference"

p_{chan}: probability of "interference" occurring if the SRD interferers are randomly spread over 100 the available FM channels

Knowing that events A_0 and $A_{co\text{-}ch}$ are dependent, as well as $A_{\pm 100}$ and $A_{lo/app\text{-}ch}$ and knowing that the compound events $A_0 \cap A_{co\text{-}ch}$ and $A_{\pm 100} \cap A_{lo/app\text{-}ch}$ are mutually exclusive, we can write:

$$p_{chan} = p(A_0\ )p(A_{co\text{-}ch}/A_0) + p(A_{\pm 100})p(A_{lo/app\text{-}ch}/A_{\pm 100})$$
$$=(1/3)x(1/100)+(2/3)x(2/100)$$
$$=(1/300)+(4/300)$$
$$=0.017$$

where:

$p(A_0)$: probability of “zero offset between the victim FM channel and interfering SRD channel” occurring

$p(A_{co\text{-}ch})$: probability of “co-channel interference” occurring

$p(A_{co\text{-}ch}/A_0)$: probability of $A_{co\text{-}ch}$ occurring, given A_0 has already occurred

$p(A_{\pm 100})$: probability of “±100 kHz offset between the victim FM channel and interfering SRD channel” occurring

$p(A_{\text{-}lo/upp\text{-}ch})$: probability of “lower or upper overlapping channel interference” occurring

$p(A_{lo/app\text{-}ch}/A_{\pm 100})$: probability of $A_{lo/app\text{-}ch}$ occurring, given $A_{\pm 100}$ has already occurred

By using the correct p_{chan} = 0.017 in the calculations described in Section 4.4, we obtain the following results:

Based on the assumptions, the calculated probability of interference is shown in table 4.14.

SRD power (nW e.r.p)	**15**	**50**
Protection distance (m)	7	15
Distance between cars (m)	5	5
Market penetration (%)	10	10
Number of active units	0.8	1.8
Number of available FM channels	100	100
Probability of event interference	0.017	0.017
Probability of interference from SRD into FM broadcasting service (%)	**1.4**	**3**

Table 4.14: Calculated probability of interference

Note: the number of active units (SRDs), N, is calculated taking into the number of cars inside the protection distance and the market penetration rate.

4.5 Conclusions

The probability of interference assessed on the basis on the MCL calculations (using 50 dBm as a dRSS) at the maximum interfering distance (> 100m) is too high because it does not consider the propagation effects due to the shielding of the car.

However, considering the protection distances based on measurements (≤15m) any probability of interference from SRDs mounted in cars is expected to be 3% in the case of SRDs operating at 50nW but only if SRDs operate with random selection of one of the channels in the whole 88 – 108 MHz frequency range.

5 OVERALL CONCLUSIONS OF THE REPORT

It was found that:

- The majority of the SRDs tested are currently available on the open market and have e.r.p. levels in the range of 9.2 to 95nW, with the power of the SRD varying over its tuning range;
- Proposed e.r.p. of 10nW and 15nW have been shown to be insufficient for acceptable reception and therefore might not ensure intended SRD functionality;
- Practical test performed with higher powered SRDs (30 – 50nW e.r.p.) demonstrated that the problem of the SRD reception would be alleviated by a power increase of this order;

- For an e.r.p. of 50nW, no interference was generated at a 200 kHz frequency offset, but interference occurred systematically in case of co-channel operation when SRD was in the vicinity of FM receiver, depending on the capture ratio between the wanted and unwanted signals.
- With e.r.p. of 50nW and interference frequencies uniformly spread over the whole 88–108 MHz band, the SEAMCAT simulations showed that probability of interference was 3%, taking into account the number of available channels and a 10% penetration rate (see section 4). Based on the presented measurement results and the practical tests carried out, it was shown that in the worst case scenario (traffic jam), SRDs at a distance of more than 10 m would not interfere with FM radio receivers even in co-channel operation. Additionally, this interference probability may be decreased further by the fact that SRD user is likely to tune away from broadcast transmission frequencies if they want to receive their signal interference free.

The studies conducted by WGSE show that the choice of power limit for these devices will need to take into account the conflicting requirements of on the one hand, the need for sufficient power for the correct operation of the SRDs and on the other hand, the need of to protect broadcasting. The studies indicate that the value chosen would be likely to be in the range 30 to 50nW e.r.p. In addition, SRDs should be required to operate with random selection of one of the frequencies in the whole 88 – 108 MHz frequency range.

List of Abbreviations

a.g.l.	Above ground level
CD	Compact Disk
D	Distance in metres
dBµV	Voltage level expressed in decibels relative to one microvolt
dBµV/m	Electric field strength expressed in decibels relative to one microvolt per metre
dBm	Power level expressed in decibels relative to one milliwatt
e.i.r.p.	equivalent Isotropically radiated power
EMI	Electromagnetic Interference
e.r.p.	effective radiated power
FCC	Federal Communications Commission
FM	Frequency Modulation
G	Gain (numeric over isotropic)
Hz	Hertz – the unit of frequency
ITE	Information Technology Equipment
kHz	Kilohertz – a frequency of one thousand Hertz
m	Metre – the basic unit of length
MHz	Megahertz – a frequency of one million Hertz
MP3	Music Player 3
nW	Nanowatt – 1x10-9 Watts
OOB	Out Of Band emission
P	Power in Watts
p.d.	Potential Difference
P.N.	test equipment plant number
PSD	Power spectral density
Q-P	Quasi-peak
RMS	Root Mean Square
RP	Radiation pattern
SNR	Signal to Noise Ratio
SRD	Short Range Device
V	Volt – the unit of electrical potential
VHF	Very High Frequency
Ω	Ohm – the unit of electrical resistance
µV	Microvolt – 1 x 10^{-6} Volts
µW	Microwatt – 1x 10^{-6} Watts

Reference Documents

[1] ETSI EN 301 357: “Cordless audio devices in the range 25MHz to 2000MHz; Consumer radio microphones and in-ear monitoring systems operating in the CEPT harmonized band 863MHz to 865MHz”

[2] Recommendation ITU-R P.370-7: “VHF AND UHF Propagation Curves for the Frequency Range from 30MHz to 1000MHz”

[3] Recommendation ITU-R BS.412-9: “Planning standards for terrestrial FM sound Broadcasting at VHF”

[4] FCC part15- Section 15.239 Operation in the band 88 - 108 MHz.

[5] ERC/Rec. 74-01E **“**Spurious Emissions”, Sesimbra 2002

[6] EN 302 018-2 “Transmission equipment for the Frequency Modulated (FM) – Part 2 : Harmonised EN under article 3.2. of the R&TTE Directive”

[7] ETSI EN 300 220-1 “Electromagnetic compatibility and radio spectrum matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25 MHz to 1000MHz frequency range with power levels ranging up to 500 mW; Part 1 : Technical characteristics and test methods”

[8] EN 55022 “Information technology equipment (ITE) – Radio disturbance characteristics – Limit and methods of measurement”

[9] Report 945-2: “Methods for the Assessment of Multiple Interference”

[10] CISPR 20: “Immunity of Sound and TV Broadcast Receivers and Associated Equipment".