# DRM+, a perfect complement to DAB/DAB+ in VHF band III
# - Technical results, planning aspects, and regulatory work -

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## INTRODUCTION

Digital Radio Mondiale™ (DRM) was originally designed by the DRM Consortium as a digital broadcasting system for the radio bands below 30 MHz and it is standardized as ETSI ES 201 980 [1]. In 2009, DRM was extended by a mode E – called 'DRM+' – to use DRM in radio bands up to 174 MHz.

Technical investigations suggest that DRM+ is a suitable candidate for the transition from analogue FM to digital broadcasting in VHF band II (87.5 - 108.0 MHz) in Europe [2]. Unfortunately, there are mainly three major problems to solve:

1. VHF band II is historically defined for the use of analogue FM sound broadcasting, and, it is – as such – extensively used in Europe;
2. the lack of agreed coordination rules for using digital broadcasting services in this frequency band;
3. the lack of standardized measurement procedures to rate both the interference and the cross modulation potential of digital broadcasting services operating in VHF band II into other radio services, esp. into the aeronautical navigation services located above 108 MHz, namely ILS and VLS.

The realistic but somewhat sad summary is simple: The deployment of DRM+ networks in VHF band II will not be possible in a mid-term.

## MOTIVATION: DEPLOYING DRM+ IN VHF BAND III

There are several reasons to investigate the potential use of DRM+ in VHF band III (174 – 230 MHz):

- in ITU-Region 1 the Final Acts of RRC-06 [3] allocates the complete VHF band III to digital broadcasting services, based on the T-DAB and DVB-T standard;
- in many European countries, e.g. Germany [4], VHF band III is intended completely for DAB coverage zones;
- RRC-06 allows for introducing further digital services, paving the formal way for introducing DRM+ in VHF band III;
- in VHF band III sufficient frequencies are available that could be used by DRM+ without harming the evolution of DAB or DVB-T;
- signal processing for DAB+ receivers (RXs) is extremely similar to the one needed for DRM+ (OFDM, MPEG4-AAC), hence, a DAB+ RX could easily be updated for DRM+;
- DAB and DRM+ complement each other in a marvellous way: On the one hand, DAB is a broadcasting system which allows the simultaneous transmission of a *multitude* of programs and services within one single multiplex [5]. It is designed to serve even large coverage areas, and, quite important, for mobile reception. On the other hand, DRM+ is well suited for providing both local and regional coverage and, deployed as SFN, even larger coverage areas for a *small number* of programs and services.

These reasons should allow for a relatively fast introduction of DRM+ in VHF band III: Deploying both systems in the same band might help to push and speed up the digitization of sound broadcasting since it allows local and regional program providers to 'go digital' *without* joining a 'big' and expensive multiplex.

## OBJECTIVES

As a first step, important technical questions related to a potential deployment of DRM+ in the VHF band III need to be addressed:

- collecting and investigating all the effects coming along with RF frequencies greater than 174 MHz, especially DRM+ Doppler performance, the latter being relevant for a good mobile reception at high speed;
- measuring the protection ratios of DAB interfered with by DRM+ and vice versa;
- setting up and conducting comprehensive field measurements to verify the protection ratios and coexistence issues;
- working out concrete planning exercises to illustrate how DRM+ could complement the DAB system family, by providing small localized program coverage for programs that have only local relevance as it is the case for many commercial but also regional public programs.

As a second step, based on the results obtained, network planning aspects are to be treated, covering the definition of suitable reception scenarios, minimum median field strength values, protection ratios, up to frequency grid spacing, i.e. everything needed to standardize and plan DRM+ in VHF band III.

## LAB MEASUREMENTS: CONCEPT & RESULTS

### Receiver prototypes

Two RX prototypes were assembled, cf. **Figure 1**and **Table 1**. The signal processing steps are identical and straight forward for both RXs: First, after RF/IF conversion, the signal is digitized using a Perseus DDC [6]. Second, after real time sample rate conversion to 192 kHz, the I/Q stream is passed to the Fraunhofer IIS DRM+ real time decoding software [7] which delivers the service streams to the respective service decoders via the RSCI/MDI interface. The only difference between both prototypes is the RF frontend used to convert RF into IF (esp. IF filter bandwidth and noise figure). If not stated otherwise, the parameters were measured at the input to the IIS DRM+ decoder.

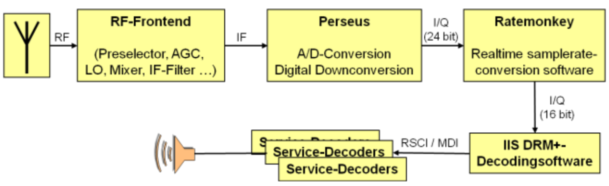


**Figure 1: Schematics of the prototypes Rx 1 and Rx 2.**

**Table 1: Overall parameters of RX prototypes.**

| RX name | Rx1 | Rx2 |
|---|---|---|
| Frontend manufacturer | Maxim | Unknown |
| Frequency bands | VHF-II/III, L | VHF-III, L |
| IF frequency [MHz] | 2.048 | 38.912 |
| IF filter bandwidth [kHz] | 133 | 1527 |
| Sensitivity 4QAM/16QAM [dBm] | -112/-106 | -117/-112 |
| Shoulder [dB] (@-40 dBm input level) | 36 | 37 |
| Noise figure [dB] | 8.3 | 3.3 |
| Phase noise [dBc/Hz] | < -80 | < -70 |

## DRM+ mobile reception performance

The hardware-in-the-loop setup used to evaluate DRM+ mobile reception performance is shown in **Figure 2**.

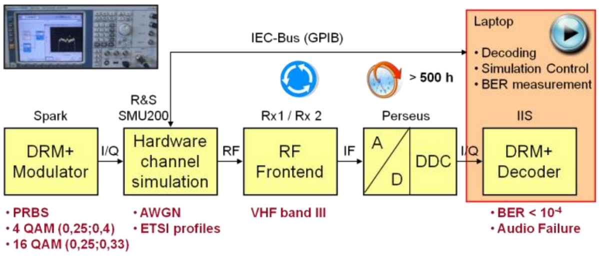


**Figure 2: Setup to evaluate mobile reception performance.**

Three types of measurements were performed:

- Signal-to-Noise-Ratio considering an AWGN only, $S/N_{AWGN}$, cf. **Table 2**;
- maximum speed $v_{max}$ considering the DRM ETSI fading profiles, $v_{max}$, cf. **Table 3**;
- Signal-to-Noise-Ratio considering the DRM ETSI fading profiles, $S/N_{Profile}$, cf. **Table 4**.

The parameters $S/N_{AWGN}$, $v_{max}$ and $S/N_{Profile}$ were determined based on an average coded BER of $10^{-4}$ as failure criterion as well as on a reference frequency of 230 MHz, i.e. at the upper fringe of VHF band III.

**Table 2: Results obtained for $S/N_{AWGN}$ @ 230 MHz[1].**

| | $S/N_{AWGN}$ [dB] | Rx 1 | Rx 2 |
|---|---|---|---|
| DRM-Mode | 4 QAM | **3.3** | **3.3** |
| | 16 QAM | **8.7** | **8.5** |

**Table 3: Results obtained for $v_{max}$.**

| | $v_{max}$ [km/h] | Rx 1 | | Rx 2 | |
|---|---|---|---|---|---|
| | | 4QAM | 16QAM | 4QAM | 16QAM |
| Profile (v [km/h]) | Urban vehicle (60 km/h) | **169** | **115** | **157** | **129** |
| | Rural (150 km/h) | **168** | **107** | **161** | **125** |
| | Hilly terrain (100 km/h) | **165** | **145** | **162** | **146** |
| | Terrain obstr. (60 km/h) | **174** | **150** | **173** | **153** |

As can be seen from **Table 3** and **Table 4**, both prototype Rx fulfil all ETSI profiles, except for ETSI rural profile for DRM+ 16QAM demanding a speed of 150 km/h. Further investigations indicate that this effect is mainly due to the (1) AGC of the Rx frontends which are not optimized for the rather small bandwidth of DRM+ as compared to DAB and, (2) the DRM+ decoding software which could be optimized further. Therefore, the authors conclude that DRM+ can meet the conditions of the ETSI profiles investigated. Please note that the hardware-in-the-loop simulations did not cover SFN profiles: A comprehensive answer if DRM+ can cope with SFN networks in VHF band III is thus still outstanding.

**Table 4: Results obtained for $S/N_{Profile}$ @ 230 MHz[2].**

| | $S/N_{Profile}$ [dB] {margin [dB]} | Rx 1 | | Rx 2 | |
|---|---|---|---|---|---|
| ETSI profile | Urban vehicle | **12.5** | **{9.2}** | **13.9** | **{10.6}** |
| | (60 km/h) | **18.8** | **{10.1}** | **18.3** | **{9.8}** |
| | Urban pedestrian | **23.0** | **{19.7}** | **23.9** | **{20.6}** |
| | (2 km/h) | **28.0** | **{19.3}** | **27.5** | **{19.0}** |
| | Rural | **14.9** | **{11.6}** | **16.6** | **{13.3}** |
| | (150 km/h) | --- | --- | --- | --- |
| | Hilly terrain | **12.0** | **{8.7}** | **12.0** | **{8.6}** |
| | (100 km/h) | **18.4** | **{9.7}** | **17.6** | **{9.1}** |
| | Terrain obstructed | **12.0** | **{8.8}** | **12.0** | **{8.6}** |
| | (60 km/h) | **17.2** | **{8.4}** | **16.9** | **{8.4}** |

## Protection ratios of DRM+ and DAB

Another important issue is to determine the respective protection ratios (PR) of a wanted signal interfered with by (i.w.b.) an unwanted signal.

The PR measurements setups are shown in

**Figure** 3 for DAB i.w.b. DRM+ and in **Figure 4** for DRM+ i.w.b. DAB. Not all DAB Rx used did allow for monitoring the estimated uncoded BER, thus, 3 minutes of 'successful' audio decoding was used as failure criterion instead.

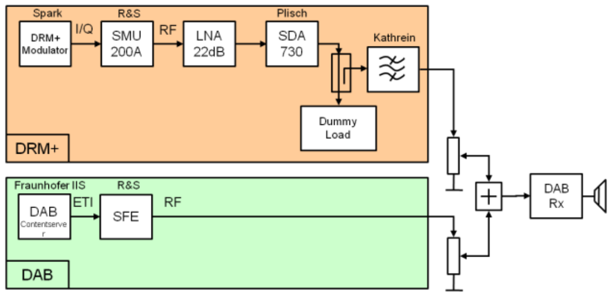


**Figure 3: Setup to measure PR of DAB i.w.b. DRM+.**

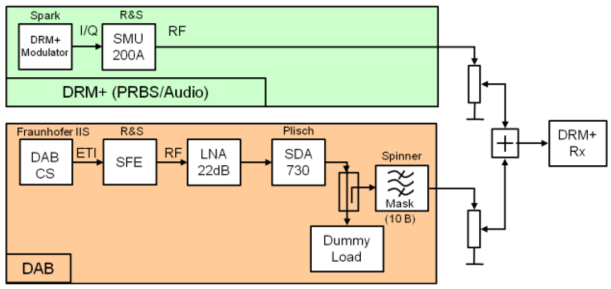


**Figure 4: Setup to measure PR of DRM+ i.w.b. DAB.**

Since up to 15 DRM+ signals could be placed within one DAB block, a very interesting question asks for the PR of DAB i.w.b. DRM+ as a function of number of DRM+ interferers. As can be seen from **Figure 5**, DAB is rather sensitive to the interferer's bandwidth. The PR yields 7 dB for one DRM+ interferer, and 10 dB is by far sufficient for more than one DRM+ interferer in the co-channel (n.b.: in the co-channel, the PR of DAB i.w.b. DAB is 10 dB, too).

[1] The items highlighted in yellow and green denote 4QAM and 16QAM performance, respectively.

[2] The figures in curly braces ('{}') give the *difference* ('margin') $S/N_{Profile}$ [dB] - $S/N_{AWGN}$ [dB].

Next, the PR of DAB i.w.b. DRM+ for the adjacent channel is investigated. In **Figure 6**, the DAB blocks as well as the assumed DRM+ channel spacing within the DAB blocks is shown. As can be seen, the PR falls down to about -40 dB, showing a slight dependency from the Rx used. For the representative consumer DAB Rx used, it drops below -45 dB.

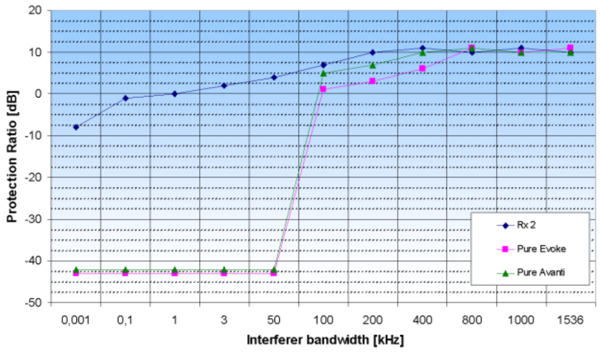


**Figure 5: PR of DAB i.w.b. DRM+ as a function of interferer bandwidth.**

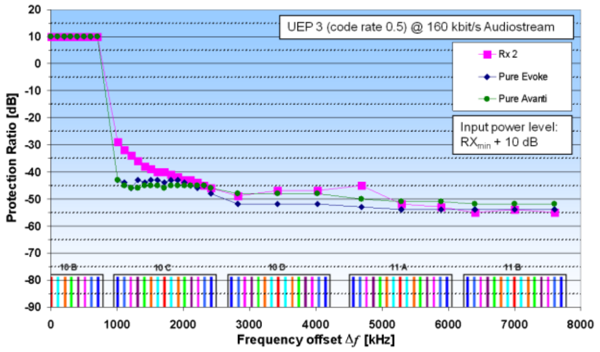


**Figure 6: PR of DAB i.w.b. DRM+.**

Finally, the reverse scenario of DRM+ i.w.b. DAB needs to be considered. From **Figure 7** it is obvious that Rx 1 performs better due to the smaller IF bandwidth. Taking Rx1 as reference, the co-channel PR for 4QAM and 16QAM differ by about 5 dB, fully in accordance to the difference in $S/N_{\mathrm{AWGN}}$, cf. **Table 2**. For the adjacent channel, a PR < -60 dB is observed.

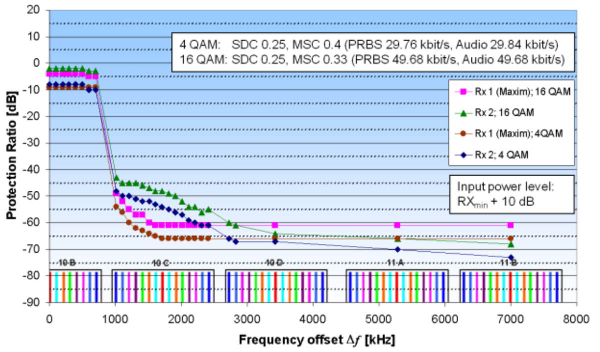


**Figure 7: PR of DRM+ i.w.b. with by DAB.**

The PR measurements were partially repeated for different absolute RF input levels for validation purposes. To summarize, the results obtained strongly propose that DRM+ can be deployed in VHF band III without harming existing DAB services [8].

For further information on the lab measurements, the reader is referred to [8].

## FIELD TRIAL: CONCEPT & RESULTS

### Transmitter concept

The field trial was based on the same transmitter (Tx) concept as the previous field tests in VHF band II.

The DAB/DAB signal was radiated in DAB block 10B from Tx 'Am Rotenberg' (Tx RB) using state-of-the-art IIS content server (CS), exciter and amplifier (Plisch, Rohde & Schwarz) with up to 300 W ERP, cf. **Table 5**. The DRM+ signal was sent out in the frequency range DAB block 10A to DAB block 10C from the site 'Am Kaiserberg' (Tx FH) with up to 180 W ERP.

**Table 5: Tx characteristics.**

| Tx name | „Am Kaiserberg" (Tx FH) FH Kaiserslautern | | „Am Rotenberg" (Tx RB) KL-Rotenberg |
|---|---|---|---|
| Loc. (PD) | 07E 46 49 / 49N 27 10 height: 260 m asl, antenna: 30 m agl | | 07E 46 19 / 49N 27 39 height: 260 m asl, antenna: 50 m agl |
| System | DRM+ | | DAB, DAB+ |
| Frequency | 211.648 MHz / 10B (10A / 10C) | | 211.648 MHz / 10B |
| Power (ERP) | 0...90 W < 05/10 | 0...180 W > 05/10 | 135…300 W |
| Antenna | Omni | | 5-elem. Yagi 6 dBi |
| Pol. | vertical | | vertical |
| Content | Audio & sync. PRBS | | Audio: Musicam (DAB), AAC+ (DAB+) |
| Equipment | Plisch ULE-Series | | R&S SLA8000, Plisch TDA 3503 |

Spark [9] or Fraunhofer IIS CS were used for DRM+ content generation, Spark's MDI client served as exciter, and power amplification was realized based on Plisch's ULE series modules. Both Tx used state-of-the-art Spinner output filters tuned to the respective frequencies. Please note that, for demonstration purposes, a 5.1 surround sound live stream was broadcasted successfully in DRM+ during the DRM+ symposium held in Kaiserslautern the 27$^{\mathrm{th}}$ of May 2010 [17].

### Results of stationary & mobile measurements

**Figure 8** gives an overview of the locations used for both stationary and mobile measurements. The stationary measurement locations are represented by yellow diamond suites, whereas the route for mobile measurements, about 65 km of length, is depicted in pink colour. The route comprises the city of Kaiserslautern, rural environments ('rolling hills'), motorways as well as light industrial and residential zones.

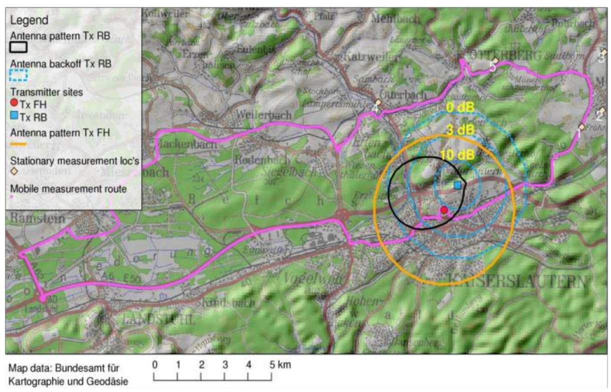


**Figure 8: Tx sites & measurement locations.**

The stationary measurements were done in 10 m height agl. First, the Rx powers $P_{DRM+}$ and $P_{DAB}$ were measured individually within their respective bandwidths. Next, the DRM+ Tx power was decreased by $TX_{Atten}$ until an average coded BER of approx. $10^{-4}$ was achieved. From these parameters, the 'field PR' of DRM+ is readily calculated as $PR_{DRM+Field} = P_{DAB} - (P_{DRM+} - TX_{Atten})$. The outcomes from these measurements are shown in **Figure 9**.

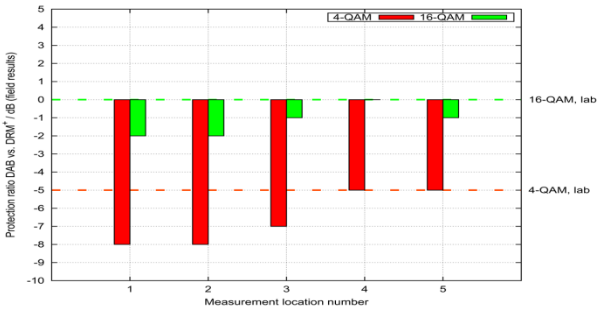


**Figure 9: PR of DRM+ i.w.b. DAB measured in the field.**

Inspecting Figure 9 suggests a confirmation of the lab results. The differences between lab and field PR's could be explained by (1) measurement uncertainty – especially in the field by about ±1 dB –, (2) the very steep gradient of BER vs. $S/N$, cf. e.g. Figure 5, [10], and, (3), the – perhaps – non-flat channel properties.

As for the mobile reception measurements, the following procedure was used to assess 'coverage': Besides other parameters, for DRM+, the instantaneous average coded BER was sampled every 0.8 $\lambda$, for DAB, the audio-sync flag and the number of CRC errors were recorded using a VAD DAB semi-professional DAB monitoring receiver [11]. For each 100x100 $m^2$ square, the BER (DRM+) and audio sync flag (DAB) CDFs were calculated as well as the associated 75% quantiles $q$. The reception was rated to be ok if $q \leq 10^{-4}$. This approach matched the subjective feeling of perceived reception quality – and thus coverage – very well for both DRM+ and DAB. The results obtained are displayed in **Table 6** and **Table 7**.

**Table 6: DRM+ coverage along the measurement route.**

| **% of 100x100 $m^2$ pixel DRM+ reception** | DRM+ Mode | | | |
|---|---|---|---|---|
| | 4QAM | | 16QAM | |
| | Fail | Ok | Fail | Ok |
| Tx FH: DRM+ (180 W) only | **3** | **97** | **35** | **65** |
| Tx FH: DRM+ (180 W) and Tx RB: DAB (135 W) | **62** | **38** | **79** | **21** |

**Table 7: DAB coverage along the measurement route.**

| **% of 100x100 $m^2$ pixel DAB reception** | Fail | Ok |
|---|---|---|
| Tx RB: DAB (135 W) only | **19** | **81** |
| Tx RB: DAB (135 W) and Tx FH: ***One*** DRM+ signal (180 W) | **28** | **72** |
| Tx RB: DAB (135 W) and Tx FH: ***Two*** DRM+ signals (180 W) | **32** | **68** |

For the sake of illustration, **Figure 10**, **Figure 11** and **Figure 12** show the DRM+ and DAB coverage obtained by applying the above described method.

A last remark regarding mobile reception: Rx 2 was installed in the IIS BMW, which is equipped with a high-end 5.1 sound system, to demonstrate mobile reception during the symposium days as show-case. Various drives were done within the coverage area of Tx FH on very different routes at very different speeds (i.e. not necessarily on the pink measurement route). Within the coverage area, reception was considered to be very stable at almost every speed by the passengers. On the motorway, 'tests' were done to see when reception breaks down due to speed. Unfortunately, in the heart of the coverage zone, speed is limited to 130 km/h on motorways, in contrast to the north-eastern coverage fringe. During the drive 'tests' done on this short piece of motorway reception did not fail up to 230 km/h. Unfortunately, a comprehensive measurement to evaluate the reason (fading, too low $S/N$) could *not* be done, but at least these non-scientific 'tests' show-case that DRM+ can be practically be received even at very high speeds.

For further information on the field test, the reader is referred to [12].

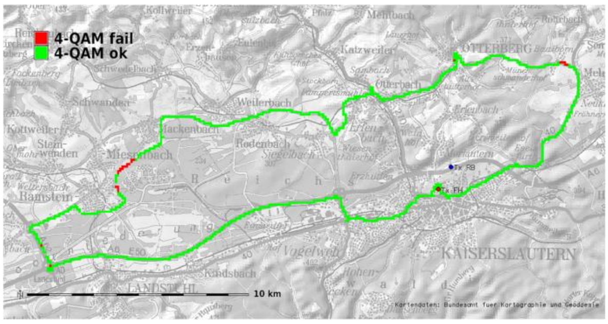


**Figure 10: DRM+ 4QAM coverage.**

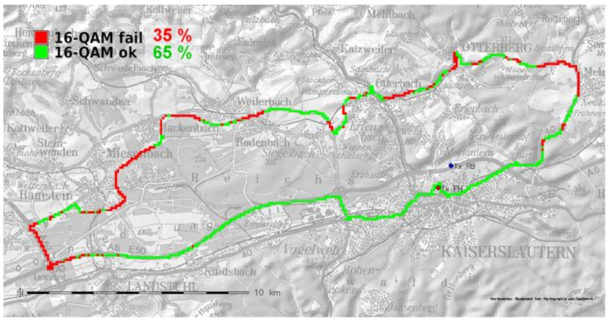


**Figure 11: DRM+ 16QAM coverage.**

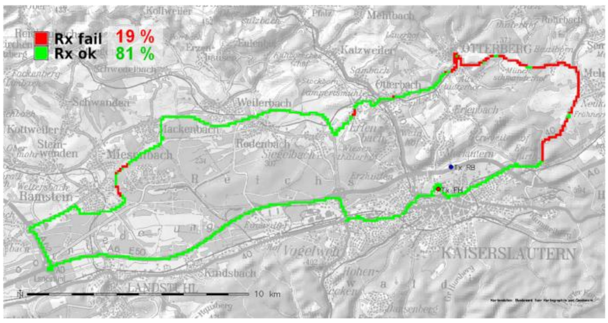


**Figure 12: DAB coverage.**

## PLANNING PARAMETERS

For DRM+ the same reception modes as for DAB [3] are defined: Fixed (FX), portable indoor (PI) and portable outdoor (PO) as well as mobile reception (MO). In addition, a handheld portable reception mode [13] with bad reception conditions and a receiver with an external antenna is defined for both indoor (PI-H) and outdoor reception (PO-H), resp.

For these reception modes, preliminary values for the minimum median field strength levels are presented in the sequel; these values have been confirmed in the field trials in Kaiserslautern and in Hannover [14]. Besides, a proposal for the PRs for DRM+ based on the results above is presented in what follows.

### Minimum median field strength level

The method for calculating the minimum median field strength level $E_{min,med}$ is provided in the Final Acts of RRC-06 [3]. The resulting levels for the different reception modes and DRM+ modes are given in **Table 8**.

**Table 8: Minimum median field strength level $E_{min,med}$ for DRM+ in VHF band III.**

| $E_{min,med}$ [dBμV/m] | | 4QAM, R=1/3 | 16QAM, R=1/2 |
|---|---|---|---|
| Reception mode | FX | **21.3** | **27.9** |
| | PI | **52.9** | **61.0** |
| | PI-H | **67.1** | **75.2** |
| | PO | **42.9** | **51.0** |
| | PO-H | **56.9** | **65.0** |
| | MO | **46.5** | **53.4** |

Comparing these values to DAB [3], see **Table 9**, reveals that DRM+ needs 13 dB for 4QAM and 5 dB for 16QAM less power to achieve coverage in portable indoor reception mode. As for mobile reception, this difference is 13.5 dB for 4QAM, and 6.5 dB for 16QAM, resp. Therefore a DRM+ transmitter needs less ERP than a DAB transmitter. But on the other hand, less programs will be broadcasted due to the narrower bandwidth of DRM+.

**Table 9: Minimum median field strength level $E_{min,med}$ for DAB.**

| Reception mode | $E_{min,med}$ [dBμV/m] |
|---|---|
| PI | 66.0 |
| MO | 60.0 |

### Protection ratios

The PRs of DRM+ i.w.b. DRM+, cf. **Table 10**, are identical with the values obtained for VHF band II.

**Table 10: PRs for DRM+ i.w.b. DRM+.**

| PR [dB] | Frequency offset [kHz] | | |
|---|---|---|---|
| | 0 | ± 100 | ± 200 |
| 4 QAM | **4** | **-16** | **-40** |
| 16 QAM | **10** | **-10** | **-34** |

The PRs of DRM+ i.w.b. DAB, cf. **Table 11**, are negative, even in the co-channel, due to the narrower bandwidth of DRM+ as compared to DAB.

**Table 11: PRs for DRM i.w.b. DAB.**

| PR [dB] | Frequency offset [kHz] | | |
|---|---|---|---|
| | 0 | ± 100 | ± 200 |
| 4 QAM | **-7** | **-36** | **-40** |
| 16 QAM | **-2** | **-18** | **-40** |

The PRs of DAB i.w.b. DRM+, cf. **Table 12**, are the same in the co-channel as in the case DAB i.w.b. DAB.

**Table 12: PRs of DAB i.w.b. DRM+.**

| PR [dB] | Frequency offset [kHz] | | |
|---|---|---|---|
| | 0 | ± 100 | ± 200 |
| T-DAB | **10** | **-40** | **-40** |

### Frequency spacing

A first approach [17] suggests to position the DRM+ centre frequencies in VHF band III starting at 174.05 MHz, stepping forward with integral multiples of 100 kHz up to 229.95 MHz (100 kHz frequency grid).

## OUTLOOK

Before the first DRM+ networks and radios can be brought into the market, several regulatory works need to be done.

The first vital work is to revise the DRM ETSI standard [1] which restricts the operation of the DRM system to all broadcasting bands below 174 MHz. This frequency is only mentioned in a description, probably rather politically motivated (in terms of non-aggression pact and to 'protect' DAB in VHF band III), and not technically. As momentous consequence, a legal and regular use of DRM+ in VHF band III is not possible. The cancellation of this disastrous frequency barrier is mandatory for the further regulatory work in CEPT and in ITU to deploy DRM+ in VHF band III (174-230 MHz).

Unfortunately, this work can only be triggered with official agreement by the DRM Consortium. But as of today, the DRM consortium fears to officially take a clear and firm stand in favour of extending DRM+ up to 230 MHz, obviously to avoid any confrontation with World DMB. Again: In the author's opinion, DRM+ is a suitable *complement* to DAB/DAB+ in many regions, and not a *substitute*. This is the bottom line to be communicated and explained carefully to the World DMB members.

The revision of the DRM standard is therefore primordial to include DRM+ in VHF band III into at least European administrative groups which actually work on the future of digital audio broadcasting:

- the ECC Working Group Frequency Management Project Team FM PT45 'Digital Broadcasting Issues' has published an 'Initial Draft ECC Report on Possibilities for Future Terrestrial Delivery of Audio Broadcasting Services' [15].
- the Radio Spectrum Policy Group (RSPG) of the EU decided that there was a need to study in more detail the future of radio broadcasting in Europe with a view to understand possible spectrum implications [16].

For the worldwide deployment of DRM+ in VHF band III, the work in the ITU Working Party 6A (WP 6A) - Terrestrial broadcasting – is most important. Two ITU recommendations are relevant:

- currently, the WP 6A works on a Revision of the Recommendation ITU-R BS.1114-6; Systems for terrestrial digital sound broadcasting to vehicular, portable and fixed receivers in the frequency range 30 – 3 000 MHz. There is a proposal of the DRM Consortium to add a Digital System G (DRM+), but, again, only up to 174 MHz.
- Another ITU recommendation has to be revised: ITU-R BS.1660-3; Technical basis for planning of terrestrial digital sound broadcasting in the VHF band. The protection ratios and the median minimum field strength levels for DRM+ all in all have to be amended.

From the point of view of the experts present at the DRM+ symposium in Kaiserslautern [17],

- implementing frequency planning consistent with RRC-06,
- building scalable and economic network infrastructures,
- integrating DRM+ in DAB+ radios by means of mainly software updates

is possible without significant difficulties for DRM+ in VHF band III.

After all the above outlined work is done, DRM+ can be brought into the market based on RRC-06 as legal European framework *after* DAB: DAB must open the market for digital radio broadcasting, and DRM+ follows as 'fitting' system, now allowing esp. the local and regional broadcasters to switch over into the digital world, too.

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## REFERENCES

[1] *Digital Radio Mondiale (DRM): System Specification*, European Telecommunications Standards Institute & European Broadcasting Union, ETSI ES 201 980 V3.1.1 (2009-08).

[2] A. Steil, J. Lehnert, F. Schad, M. Köhler, '*Leaving the dead-end street: New ways for the digitisation of the VHF sound broadcasting with DRM*', in 10th Workshop Digital Broadcasting, Fraunhofer Gesellschaft für Integrierte Schaltungen (IIS), 2009.

[3] *Final Acts of the Regional Radiocommunication Conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz (RRC-06)*, International Telecommunication Union, 2006.

[4] *Frequenznutzungsplan*, Federal Network Agency of Germany, April 2008; http://www.bundesnetzagentur.de /cae/servlet/contentblob/38448/publicationFile/2659/ Frequenznutzungsplan2008_Id17448pdf.pdf

[5] *Radio Broadcasting Systems; Digital Audio Broadcasting (DAB) to mobile, portable and fixed receivers*, European Telecommunications Standards Institute & European Broadcasting Union, ETSI EN 300 401 V1.4.1 (2006-01).

[6] http://www.microtelecom.it/perseus/

[7] http://www.iis.fraunhofer.de/bf/db/proj/drm.jsp

[8] M. Köhler, '*Messtechnische Bewertung der Nutzbarkeit von DRM+ im VHF-Band III*', Diploma Thesis, 2010, http://www.drm-radio-kl.eu

[9] http://www.drm-sender.de/

[10] Steil, A.; Schad, F.; Feilen, M.; Köhler, M.; Hedrich, E.; Kilian, G.: *Digitising VHF FM sound broadcasting with DRM+ (DRM Mode E)*. Proceedings of the IEEE Interational Symposium on Broadband Multimedia Systems and Broadcast, 13-15 May 2009, Bilbao, Spain, ISBN 978-1-244-2591-4, , http://www.drm-radio-kl.eu.

[11] DAB receiver UEB 400 DXP, http://www.vadgmbh.de/

[12] F. Schad, A. Steil, '*Abschlussbericht zum DRM+ Feldtest im VHF-Band III*', 2010, http://www.drm-radio-kl.eu (to be published).

[13] *Planning parameters for hand held reception concerning the use of DVB-H and T-DMB in Bands III, IV, V and the 1.5 GHz band*, European Broadcasting Union EBU-TECH 3317; Version 2, July 2007.

[14] http://www.ikt.uni-hannover.de/89.html

[15] *Draft Report from the 11th Meeting of WGFM PT45, 29-30 June 2010*, Copenhagen, http://www.ero.dk.

[16] http://rspg.groups.eu.int/topics/index_en.htm

[17] Public symposium 'DRM+ in VHF Band III - together with DAB+: The positive potential for Digital Broadcasting -', Kaiserslautern, 27 May 2010, http://www.drm-radio-kl.eu/symposium2010/ symposium2010en.htm

[3] Multimedia initiative of State Government (rlpinform), Ministry for the Interior and Sports, Rhineland-Palatinate, Germany.