Fachhochschule Kaiserslautern | University of Applied Sciences

LMK Landeszentrale für Medien und Kommunikation Rheinland-Pfalz

Report for 10th Workshop Digital Broadcasting September 16-17, 2009

Fraunhofer-Institute
for Digital Media Technology IDMT
D-98693 Ilmenau, Germany

Leaving the dead-end street: New ways for the digitisation of the VHF sound broadcasting with DRM+

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This contribution documents the authors' ongoing activities on DRM+. It presents recent work and results thereof and is organized as follows:

Part I 'Field trials on DRM+ coverage' is concerned with practical DRM+ coverage in VHF band II in the FM environment. Coverage measurements for both stationary and mobile reception are presented and discussed.

Part II 'First results on compatibility and coverage analyses of DRM+ single frequency networks (SFN) in the VHF band II' covers the topic of DRM+ radio network planning based on comprehensive computer-based planning exercises, including – as an absolute novelty – DRM+ SFN analyses.

Finally, **Part III 'Investigations on the deployment of DRM+ in VHF band III'** concludes the paper and provides a brief outlook on the author's possible future work on DRM+.

Leaving the dead-end street:
New ways for the digitisation of the VHF-FM sound broadcasting with DRM+

Part I: Field trials on DRM+ coverage

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I. INTRODUCTION

Digital Radio Mondiale^{TM} (DRM) is a digital broadcasting system for the broadcasting bands below 30 MHz. It has been adopted by the ITU, and is standardised as ETSI ES 201 980 [1]. The DRM consortium has recently extended this system to the broadcasting bands up to 174 MHz. 'DRM+' is included as 'Mode E' in the DRM standard and allows radio stations in 87.5 - 108.0 MHz frequency range to broadcast 'in digital'. **Tab. 1** summarises the key parameters of DRM+.

Tab. 1. Key parameters of DRM+ [1]

Parameter	Value
Net MSC data rate range	37 – 186 kbit/s
Audio coding	MPE4 AAC plus
# of channels / service	1 - 4
Symbol duration w/o guard interval	2.25 ms
Guard interval duration per symbol	0.25 ms
# of carriers per symbol	213
Subcarrier spacing	444 4/9 Hz
Transmission frame (TF) duration	100 ms
# of symbols per TF	40
# of symbols per TF's per super frame	4
Subcarrier modulation	4/16 QAM
RF system bandwidth	96 kHz

The work presented in Part I is based on [2,3,4] and closes open working items. It presents recent work as well as results thereof and deals with 'practical' DRM+ coverage as compared to 'practical' FM coverage.

II. OBJECTIVE, SETUP, AND MEASUREMENT PARADIGMS

The objectives of the field measurements are easily formulated: For DRM+,

- assess the 'real', experienced coverage by measurements – in contrast to 'planned' coverage – and
- elaborate planning approaches and paradigms.

Prior to starting the field trial, the complete DRM+ transmission chain was calibrated (for details as, e.g., receiver (RX) BER performance, RX sensitivity, RX noise figures and phase noise figures, the reader is referred to [4,5]). In a next step, as a prerequisite for any comprehensive coverage planning exercise, protection ratios FM into DRM+ were measured for different modulation schemes and reception conditions (stationary and mobile) based on two criteria: (a) coded BER, and, (b), audio failure, cf. [4,5]. The protection ratio figures were found to be nearly independent of the criterion used since the coded BER, but especially the MSC-FDR are nearly unit step functions, cf. [4, Fig. 5].

The well-tried setup used for the field measurements is discussed in detail in [2]. On the transmitter (TX) side, it consists of two independent TX: (a) a hybrid TX capable of radiating either DRM+ or conventional FM, denoted by TX FH, and, (b), a TX radiating a conventional FM signal, denoted by TX RB, cf. **Tab. 2**. TX FH generates 'useful' test signals to rate audio quality. These signals can be *intentionally* degraded by a *controllable* interference signal originating from TX RB, the 'controllable interference'.

Tab. 2. TX characteristics.

Parameter	TX FH	TX RB
Signal type	'useful'	'controllable interference'
Geo. Loc. (PD), hasl, antenna height agl	3107E4649/49N2710 260 m, 30 m	07E4619/49N2739 260 m, 30 m
License period	until 31.12.2009	until 31.12.2009
Modulation	FM or DRM+	FM
RF carrier frequency	87.6 MHz	87.6 … 88.1 MHz
Power (RMS, ERP)	0 … 35 W	0 … 35 W
Antenna	Ground Plane (ND)	Kathrein K 52 4017
Polarisation	Vertical	Vertical
Content	Test signals	Coloured noise

In the case of FM, the 'useful' test signal was made up of a 500 Hz test tone (stereo, L=R) with 0 dBr MPX and 26 kHz deviation to enable SINAD measurements. In the case of DRM+, the 'useful' test signal was made up of two services: (a) a service carrying a synchronous PRBS sequence, and, (b), a service broadcasting HE-AAC encoded audio material. In 4 (16) QAM, a SDC code rate 0.25 (0.25) and MSC code rate 0.4 (0.33) was used. The 'controllable interfering' FM signal carried two independent coloured noise signals (stereo) with 0 dBr MPX power and 75 kHz peak deviation. On the RX side, the *same* RX frontend, an ATMEL ATR4262 [6], was used for both FM and DRM+ reception. It converts the RF input signal to an IF of 10.7 MHz. Then, for FM reception, this IF is fed to the FM modulation & NF spectrum analyzer Microgen TS 9085 [7], whose NF audio out is fed to the UPV audio analyzer [8] for SINAD measurement.

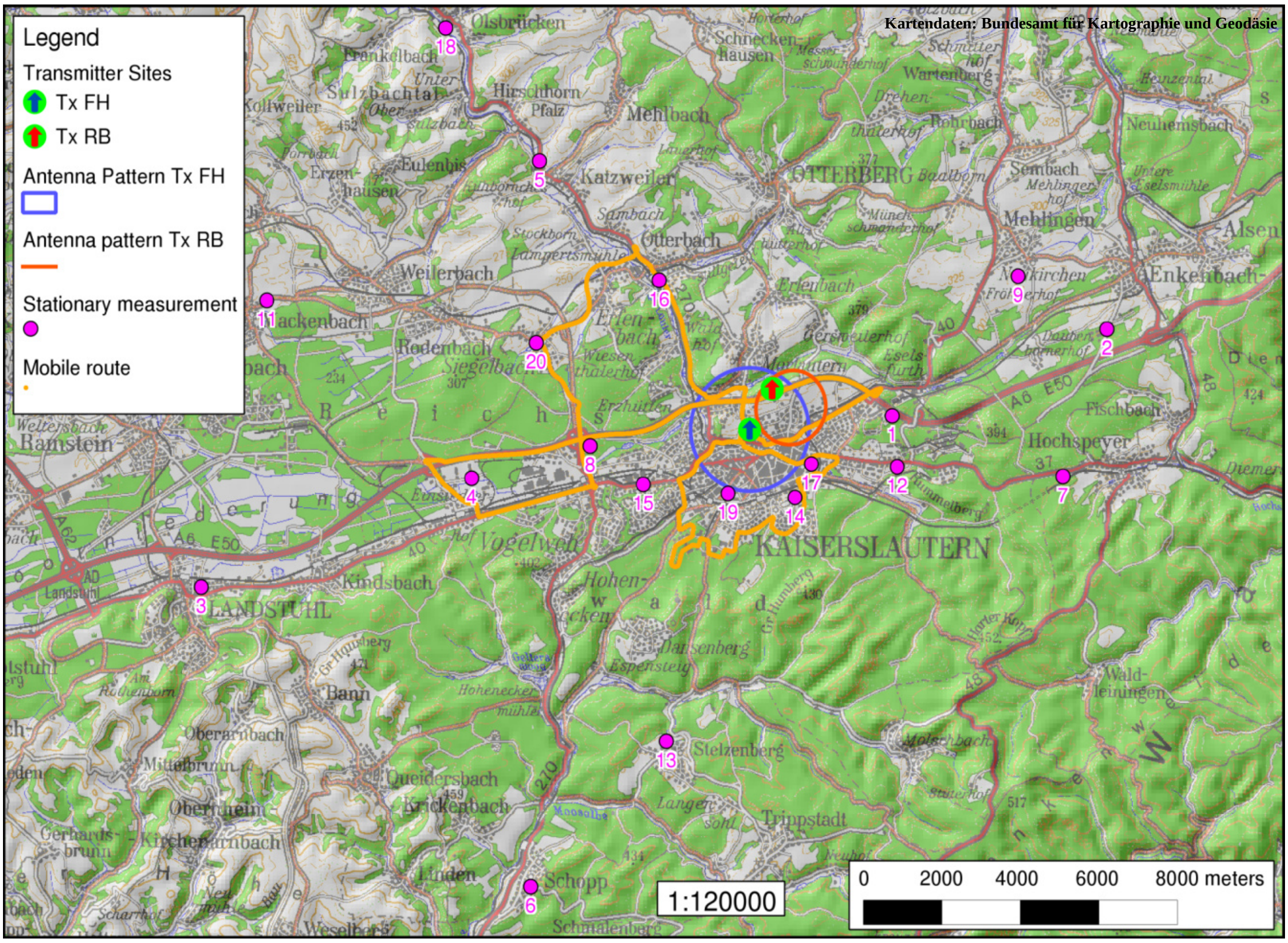

Fig. 1. TX locations, 19 points of stationary measurements, and, mobile measurement route (54 km)

In the case of DRM+ reception, the IF signal is fed to a Perseus SDR [9] which (a) samples the IF signal with a rate of 80 MHz using 14 bits of resolution, and, (b), down converts it to the complex baseband (IQ domain) whilst decimating to a rate of 250 kS/s. The IQ samples are streamed with 24 bit of resolution via USB to a PC running a real time polyphase resampler. At it's output, the sample rate is 192 kS/s as required by the subsequent FHG IIS software realtime DRM+ decoder. Finally, this decoder outputs the received MSC streams via the RSCI-protocol to the audio decoder and other applications, enabling e.g. to record the current coded BER [4].

At the RX location, the RF input signal is assumed to be made up of three uncorrelated parts: the useful FM/DRM+ signal (TX FH), the controllable interfering FM signal (TX RB) with frequency offset Δf and the inevitable background noise, accounting for both co-channel interferers as well as other components. Their respective in-band RMS powers, measured in a bandwidth of ±60 kHz around the center frequency of useful signal, are denoted as P_U, $P_{CI}(\Delta f)$, and P_N, respectively. From these measures, the SNR_{RF} at the RX's input can be derived as

$$\mathrm{SNR}_{\mathrm{RF}} = \frac{P_{\mathrm{U}}}{P_{\mathrm{CI}}(\Delta f) + P_{\mathrm{N}}}\,. \tag{1}$$

In (1), the absolute value of frequency offset Δf takes on the values [0; 100; 200] kHz in the field measurements. Varying the power of TX RB from 0 W (i.e. $P_{CI}(\Delta f)$ = 0W) to 35 W (i.e. $P_{CI}(\Delta f) = P_{CI,max}(\Delta f)$), bounds the RF input dynamics (and, thus, in the case of FM, the achievable audio dynamics):

$$\frac{P_{\mathrm{U}}}{P_{\mathrm{N}}} \le \mathrm{SNR}_{\mathrm{RF}} \le \frac{P_{\mathrm{U}}}{P_{\mathrm{CI,max}}(\Delta f) + P_{\mathrm{N}}} \tag{2}$$

The objective measures to assess and to compare demodulated audio quality are SINAD (FM) and coded BER (DRM+). Like in [2,3,4], the approved principle of *comparing* measured FM and DRM+ audio quality figures for a given receiving location is adopted. SINAD was chosen for FM since, (a), SINAD has proven to be highly correlated to two other FM audio quality measures (psophometrically weighted (S/N) [10] and the Audemat quality classes [4]), and, (b), SINAD can easily be measured in both stationary and mobile reception scenarios. The broadcasted DRM+ services allowed, besides measuring coded BER, to listen to the decoded audio material and to subjectively rate the perceived audio quality[1]. All measured RF and audio quality parameters are recorded along with their geographical reference.

[1] Unfortunately, the audio decoder used did not provide adequate status information to define appropriate *objective* audio quality rating figures. Preliminary listening tests showed that the chosen coded BER of 10^{-4} is a quite good criterion to decide whether or not audio decoding is possible or not.

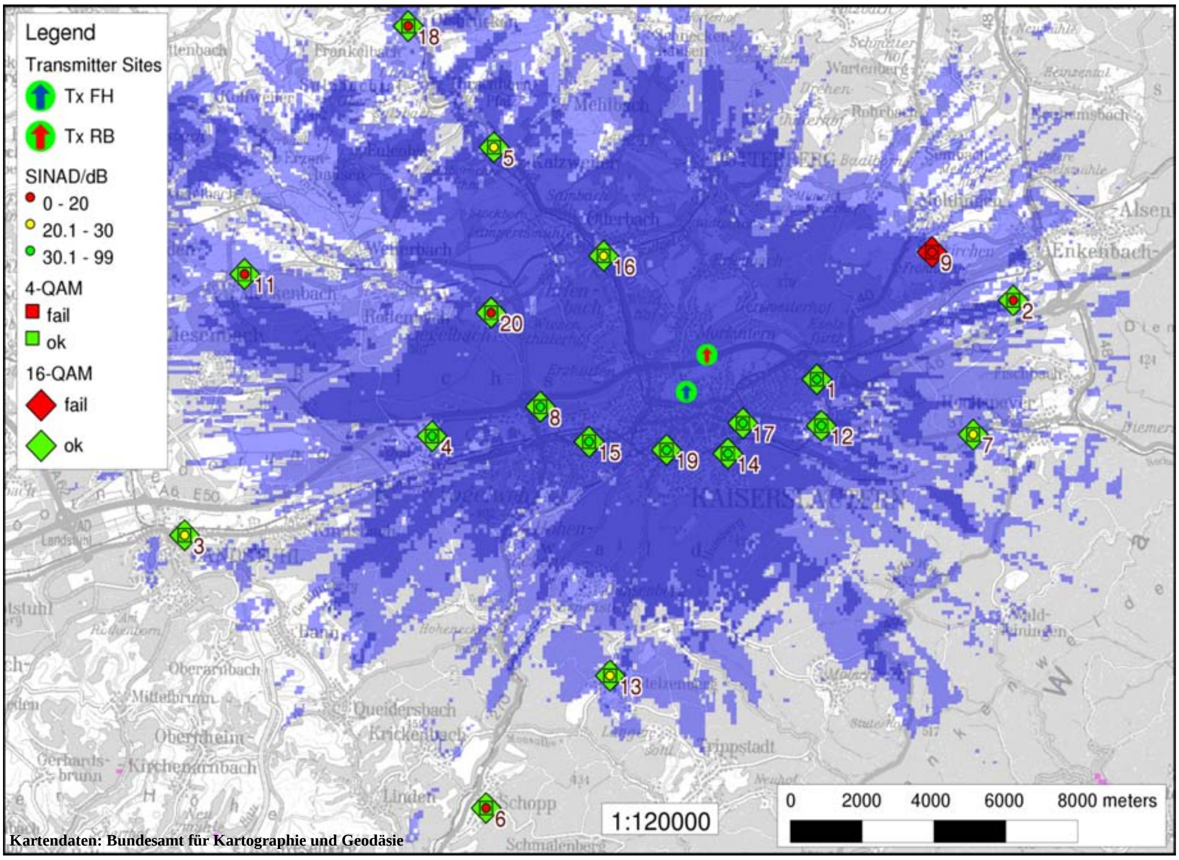

Fig. 2. Predicted vs. measured coverage for DRM+ with TX RB is switched off. Predicted coverage: 4 QAM light blue, 16 QAM dark blue. Assignment of measured coverage see Tab. 3.

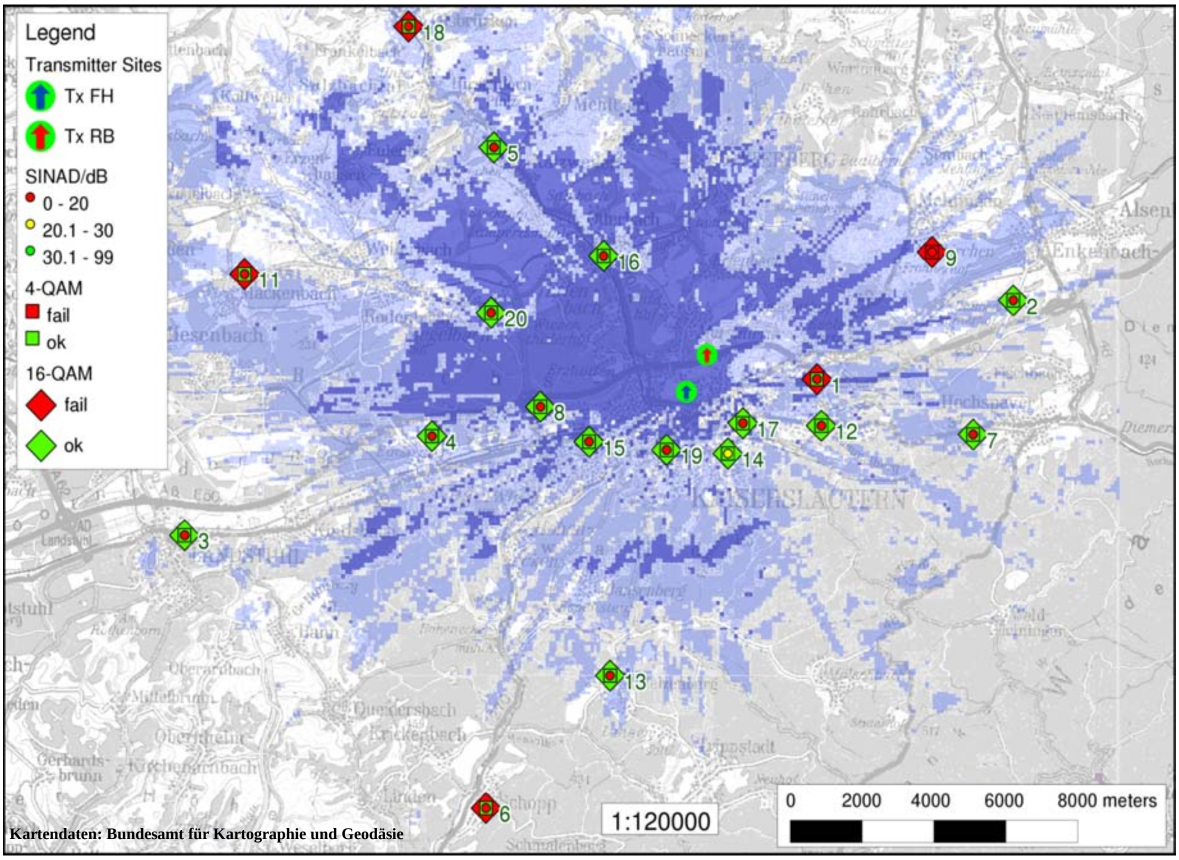

Fig. 3. Predicted vs. measured coverage for DRM+ with TX RB operating at 35 W in the first neighbouring channel (87.7 MHz). Predicted coverage: 4 QAM light blue, 16 QAM dark blue. Assignment of measured coverage see Tab. 3.

To define a RX location to be ‘covered’ or ‘not covered’, a quite simple ‘stop-light’ classification based on audio quality was used, cf. **Tab. 3**.

Tab. 3. Mapping audio quality to coverage assertion.

FM SINAD / dB	**DRM+** Coded BER	**Coverage assertion**	**Colour representation**
(-∞ ... 20]	> 10^{-4}	**No**	**Red**
(20 ... 30]	----	**Not really**	**Yellow**
30 ... ∞)	<= 10^{-4}	**Yes**	**Green**

Two words to the wise: (a) in Tab. 3, the SINAD interval (20 ... 30] corresponds to a *hardly tolerable* audio quality, that is, this location is *marginally* (‘not really’) covered, i.e. audio quality is bad. In contrast, DRM+ shows the typical behaviour of digital transmissions: Either it works perfectly or not; (b), the protection ratio curves used for standard FM planning are based on a psophometric (S/N) of 50 dB [10]. This figure translates – for ‘real’ MPX signals – to roughly 38 dB SINAD. Thus, setting the SINAD margin for coverage assertion to 30 dB is indeed not in line with the planning rules [11], but it subjectively better relates experienced coverage to perceived audio quality.

To conclude this section, the TX locations, the 19 points of stationary measurements, cf. Sec. III, as well as the route for mobile measurements, cf. Sec. IV, are shown in Fig. 1.

III. STATIONARY MEASUREMENTS

19 locations have been chosen for stationary measurements as representative test points, cf. Fig. 1, based on, (a), a sequel of orienteering measurement runs, and, (b), on DRM+ coverage planning exercises based on FRANSY [12] for both 4 QAM and 16 QAM stationary reception in 10 m height above ground level (agl) with a directional antenna oriented towards TX FH. Examples of predicted DRM+ coverage areas are shown in **Fig. 2** and **Fig. 3.** Note that the map sections in Fig. 2 and Fig. 3 only display the area predicted to be ‘covered’ (light blue (4 QAM), dark blue (16 QAM)). The rest of the map sections are the areas predicted to be ‘interfered’, i.e. those areas in which – on the one hand – P_U is sufficiently high, but, – on the other hand – P_N is so strong that the needed SNR_{RF} according to (1) for proper DRM+ decoding is not reached for *interference* reasons. Areas in which P_U does not surmount the DRM+ RX sensitivity lie *outside* the map sections. This means that all DRM+ RX scenarios lie either within the predicted *interference limited* area or within the predicted *covered* area.

All stationary measurements were carried out using a directional antenna in 10 m height agl, oriented towards TX FH. This situation is by far not the typical receiving situation, but it is in line with the valid procedures to plan and measure today’s FM coverage, and is the basis for the DRM+ coverage predictions shown in Fig. 2 and Fig. 3. For each location, the RF and audio parameters as described in section II were recorded for different frequency offsets Δf.

For the sake of illustration, the evaluation of two interesting scenarios is discussed in the sequel: The comparison of *predicted* DRM+ coverage vs. the *measured* coverage (Fig. 2) and DRM+ coverage impairment by TX RB operating in the first neighbouring channel at 87.7 MHz with full power (Fig. 3). For the sake of comparison, the measured FM ‘coverage’ as defined in Tab. 3 is given, too. In Fig. 2 and Fig. 3, the following symbolism is used: The symbol is composed of three interlocked symbols, ◇, □, and, ○, corresponding to 16 QAM, 4 QAM, and, FM, respectively. The colour of the symbols determine the coverage assignment according to Tab. 3. For example, the symbol denotes ‘16 QAM not covered, 4 QAM covered, FM not really covered’.

Inspecting Fig. 2 suggests that the predicted DRM+ coverage matches the measured DRM+ coverage quite well. Furthermore, 4 QAM has a larger coverage as compared to 16 QAM. This effect stems from the different SNR_{RF} according to (1) needed for 4 QAM and 16 QAM, namely roughly 5 dB and 13 dB, respectively [4]. Comparing the DRM+ coverage to FM coverage reveals that DRM+ has a - by far - greater coverage area (both 4 QAM and 16 QAM). Again, this effect stems from the fact that DRM+ gets along with a substantially lower SNR_{RF} according to (1) as compared to FM. On the other hand, perceived FM audio degrades more gracefully as compared to DRM+ audio quality. To complement the impression that DRM+ has a good coverage potential, the ‘absolute coverage reserve’ of DRM+ as compared to FM was determined in some locations as follows: First, the TX power of TX FH was lowered until the 20 dB SINAD was reached, and the corresponding RX power P_{SINAD} was recorded. Then, switching the modulation of TX FH to DRM+, the TX power was further lowered until a BER equal to 10^{-4} was reached, and, again, the corresponding RX power P_{BER} was taken. The dB difference $P_{SINAD} - P_{BER}$ can readily be interpreted as ‘absolute coverage reserve’ for the stationary reception. In all cases, this ‘absolute coverage reserve’ turned out to be at least 20 dB in favour of DRM+. As a consequence, DRM+ offers the potential of trading TX power vs. coverage reliability which could help to ensure proper and stable DRM+ indoor reception.

Next, inspecting Fig. 3 suggests that, as in the case of Fig. 2, the predicted and the measured coverage seem to coincide quite well. In contrast to DRM+, the FM coverage completely breaks down, cf. Fig. 3. This is due to the FM interferer, TX RB, operating at full power in the first neighbouring channel, thus completely ‘quieting’ the useful FM signal originating from TX FH. In other words: DRM+ is by far more robust to 1st adjacent channel interference than FM, fully in the line with the protection ratios measured.

To round off this section, two further results from the stationary measurements shall briefly be expressed. First, looking at the case where TX RB operates at full power in the co-channel, i.e. both TX FH and TX RB radiate at 87.6 MHz, then, DRM+ coverage as well FM coverage break down more or less completely. This is to be expected since in (1), $P_{CI} >> P_N$ holds: The SNR_{RF} according to (1) is simply too poor. Next, the case in which TX RB is operated in the 2nd adjacent channel is considered. The results obtained for this scenario propose that both DRM+ and FM coverage are not substantially impaired as compared to Fig. 2, which, again, especially holds for DRM+. In any location, the 2nd adjacent channel interferer TX RB could *not* alter the coverage assignments for DRM+ given in Fig. 2!

IV. MOBILE MEASUREMENTS

As mentioned before, DRM+ coverage as compared to FM coverage for mobile reception was the second receiving scenario under investigation. The measurements described hereafter were carried out with a measuring van owned by the Fachhochschule Kaiserslautern. The van is equipped with an system allowing to trigger measurements based on either time or distance. The measuring route of about 54 km length, cf. Fig. 1, was also chosen to represent the RX conditions met in the coverage area of TX FH for DRM+ reception. The route comprises a highway section as well as inner city parts incl. traffic lights and passes as many stationary test locations as possible. The speed of the van varied from 0 km/h to 120 km/h, depending on traffic situation. A $\lambda/4$ dipole mounted on the roof of the van was used as RX antenna. As for the stationary case, mobile measurements for different frequency offsets Δf along the route were taken for both FM and DRM+. The measurement system, triggered every 0.8λ of travelled distance to ensure uncorrelated samples, collects and stores RF and audio parameters as described in section II along with its GPS-based geographical reference, so that these can be analysed and cartographically displayed with any appropriate GIS software.

As an instructive example of measurement data analyses editing, mobile coverage for the same frequency combinations as used in Fig. 2 and Fig. 3 are presented in the sequel. Using Grass [13] and Quantum GIS [14], the recorded measurement data was rasterised to 100x100 m^2 pixels based on quartiles as follows: For FM, the coverage assignment according to Tab. 3 was done relying on the 50% SINAD quartile within the pixel. For DRM+, the assignment was based on the 75% BER quartile since this quartile subjectively matches the experienced audio failures in the best way.

Fig. 4 and **Fig. 5** show the measured mobile coverage for FM (Fig. 4) and DRM+ (Fig. 5) with TX RB switched off. In Fig. 4, the SINAD assignment from Tab. 3 was adopted, whereas in Fig. 5, the yellow colour indicates pixel in which only 4 QAM, but no 16 QAM coverage was observed. The converse case, i.e. a pixel being considered to be covered by 16 QAM but not by 4 QAM did not occur. Now, inspecting Fig. 4 and Fig. 5 supports the findings drawn from discussing Fig. 2, that is, DRM+ coverage is substantially greater as compared to FM coverage. The coverage situation as proposed by Fig. 5 matches the subjective DRM+ coverage impression very well: Various test drives in the city area with HE-AAC or 5.1 surround (MPEG surround sound, [15]) encoded audio material, broadcast in 4 QAM or 16 QAM mode, show that the city can be considered as being ‘covered’ by DRM+.

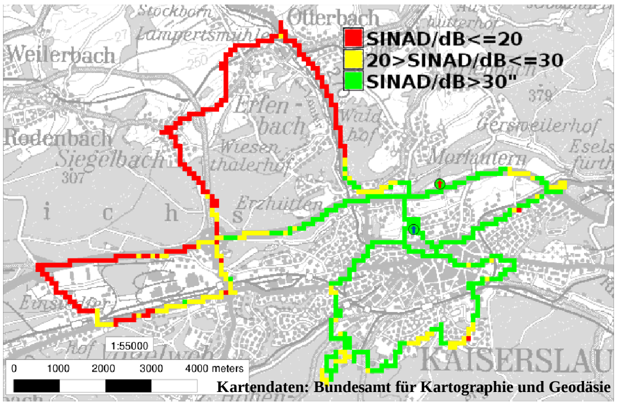

Fig. 4. Measured mobile coverage for FM with TX RB switched off. Assignment of measured coverage see Tab. 3.

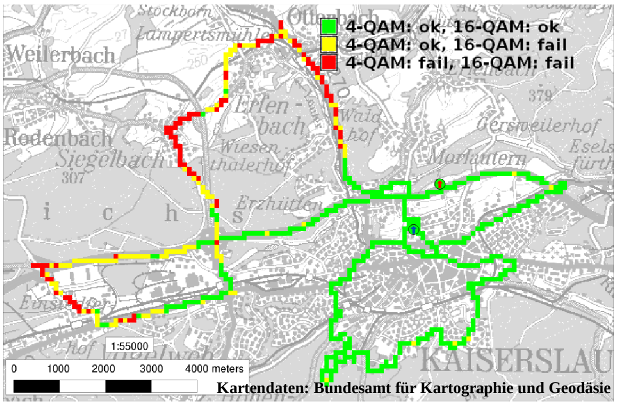

Fig. 5. Measured mobile coverage for DRM+ with TX RB switched off. Assignment of measured coverage see legend.

Fig. 6 and **Fig. 7** show the measured mobile coverage for FM (Fig. 6) and DRM+ (Fig. 7) with TX RB operating at full power in the 1st adjacent channel. The coverage assignment is the same as in Fig. 4 and Fig. 5. Looking at Fig. 6 and Fig. 7 also supports the findings drawn from the stationary measurements, cf. the presentation of Fig. 3. The conclusion drawn in Sec. III that DRM+ is much more robust to 1st adjacent channel interference as compared to FM is emphasized impressively by comparing Fig. 6 and Fig. 7.

To complete the presentation of mobile coverage measurement results in this section, two further results shall be given briefly. First, looking at the case where TX RB operates at full power in the co-channel, i.e. both TX FH and TX RB radiate at 87.6 MHz, then, DRM+ coverage as well FM coverage break down more or less completely for same reasons as given in Sec. III. This is to be expected since in (1), $P_{CI} >> P_N$ holds. Furthermore, the result that both DRM+ and FM coverage are not substantially impaired by 2nd adjacent channel interference is fully endorsed by the measured data.

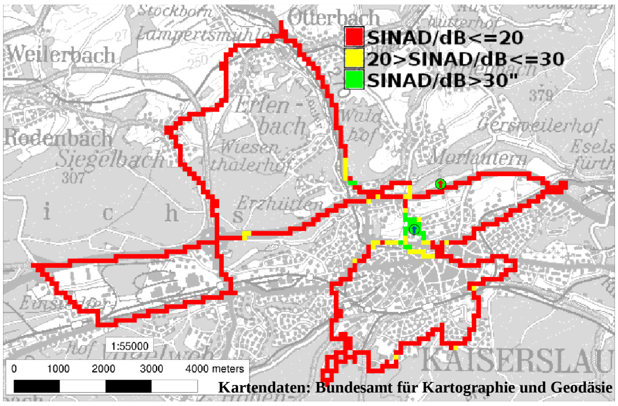

Fig. 6. Measured mobile coverage for FM with TX RB operating at 35 W in the first neighbouring channel (87.7 MHz). Assignment of measured coverage see Tab. 3.

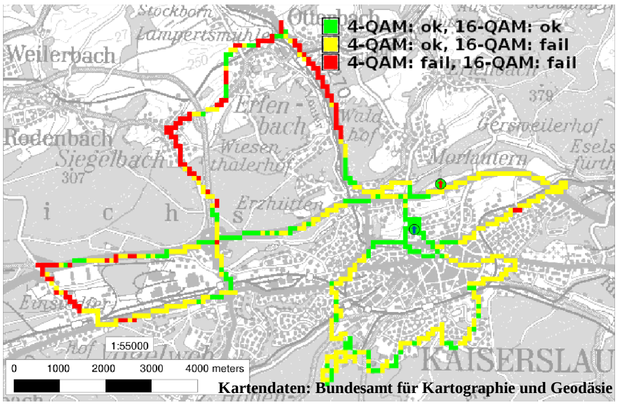

Fig. 7. Measured mobile coverage for DRM+ with TX RB operating at 35 W in the first neighbouring channel (87.7 MHz). Assignment of measured coverage see legend.

V. CONCLUSIONS

Part I of this paper presents and discusses the first analyses of data recorded within the scope of a DRM+ field trial which focussed on 'real', experienced DRM+ coverage. For the sake of comparison, FM coverage is evaluated, too.

The first analyses proposes a substantial coverage potential of DRM+ as compared to FM for both stationary and mobile reception. A more complete and more detailed analyses, e.g. statistical evaluation of SNR_{RF} vs. BER or MER, will be published in [5] later in this year.

ACKNOWLEDGEMENTS

The authors would like to thank the following companies/institutions/authorities/... for their valuable material and/or technical support: Federal Network Agency (BNetzA) of Germany, Robert Bosch GmbH, Deutsche Flugsicherung GmbH, Südwestrundfunk (SWR), Dolby Germany GmbH, ARD.ZDF medienakademie, LfM Nordrhein-Westfalen, LfK Baden-Württemberg, Radio RPR, BMW, Media Broadcast GmbH, PURE digital, NP Technologies Inc., Institute for Communications Technology at the University of Hannover, ATMEL Germany and SSB-Electronics. Note that the enumeration does not reflect any whatsoever weight.

Special thanks goes to Rohde & Schwarz Vertriebs GmbH and to the Central Office for IT and Multimedia[2]

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Leaving the dead-end street:
New ways for the digitisation of the VHF sound broadcasting with DRM+

Part II
First results on compatibility and coverage analyses of DRM+ single frequency networks (SFN) in the VHF band II

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INTRODUCTION

The technical challenge for a starting and migration period from analogue to digital sound broadcasting is to deploy new DRM+ TX stations into the actually congested VHF FM band without interference impairments to the existing FM environment. Moreover, the coverage of DRM+ TX stations should be at least equal or even better as compared to FM TX stations, and, especially for portable and mobile reception, an extra coverage reserve for stable reception is mandatory for acceptance.

Based on computer-aided frequency planning models, first conclusive evidence on whether or not DRM+ TX stations with adequate or even larger coverage areas can be planned into the VHF FM band are obtained.

This paper presents the results of planning exercises on compatibility and coverage analyses. The objective of this paper is to elaborate a technical approach which allows inserting DRM+ TX stations into the European VHF-FM band whilst completely relying on the legal radio regulations and coordination procedures.

For frequency analysis, the frequency and network planning software FRANSY [1] was used. Based on transmitter site databases, terrain databases, and wave propagation models, the coverage of a broadcasting system and its interference impact on other TX stations can be calculated. A specialised version of FRANSY was compiled for the German State Media Authority of Rhineland-Palatinate (Landeszentrale für Medien und Kommunikation - LMK), allowing the determination of compatibility in a mixed analogue-digital scenario with adapted protection ratio curves.

As an absolute novelty, the planning exercises presented in this paper show the Single Frequency Networks (SFN) potential of DRM+. The SFN planning was done with FRANSY, too, fully taking into account the protection of existing FM TX stations. The objective of this SFN analysis is to prove that FM frequency resources can be released (while coverage is at least preserved or perhaps enlarged). Thus, at locations where no frequency is available, frequencies get available, or, frequencies can be liberated for other purposes.

PRINCIPLES OF BROADCAST ANALYSES

Parameters for broadcast network planning

Frequency planning for broadcast networks to determine, (a), the coverage area of a broadcasted, wanted signal under interference impairment, and, (b), the compatibility with other networks is based on:

- *minimum equivalent field strength* of the desired system at the receiver input (E_{minRX}) required to enable the receiver to correctly decode the wanted signal,
- *correction values of the reception mode* for the targeted situation where the reception is guaranteed with predefined probabilities, e.g. fixed, portable indoor, portable outdoor, mobile, with different receiving situations and time/location probabilities,
- *minimum median equivalent field strength* for the network planning (E_{med}), which differs from the defined reception mode and the minimum equivalent field strength at the receiver input,
- *protection ratio* (PR [dB]) between wanted signal and interference signal, which defines how strong an interfering signal as compared to the wanted signal may be without degrading the quality of the wanted signal,
- *usable field strength* (E_u) as the sum of all interference field strengths of all relevant interfering TX stations at the receiving location, each of them added including their respective protection ratio. A location is adequately covered if the field strength of the wanted signal is bigger than the usable field strength and bigger than the minimum median equivalent field strength, too.

Reception modes

Investigations in terrestrial digital sound broadcasting systems take into account four reception scenarios, which are in line with the planning recommendations for T-DAB-networks [2] and reflect today's use of radio, namely:

- *FR = fixed reception:* Reference for the network planning, even it is not a realistic scenario to describe the main behaviour of listeners. Receiver with antenna plug connected to a directional antenna in a 10 m height,

- *PIR = portable indoor reception:* Receiver with stationary power supply and a build-in (folded)-antenna or with plug for an external antenna. The location of the receiver is fixed,
- *POR = portable outdoor reception:* Receiver with battery supply and a build-in antenna, can be used as a receiver everywhere,
- *MR = mobile reception:* Car reception with car antenna, also at high speed.

All four reception scenarios should be included in a future planning guideline for DRM+ since the portable and the mobile reception represent the main use for terrestrial sound broadcasting.

MODEL VALUES FOR THE ANALYES

Reception mode

The DRM+ network analyses presented in the following only refers to fixed reception[1], This allows directly comparing with FM coverage since the latter is only defined for the fixed reception[3].

DRM+ mode

DRM+ is described in the ETSI standard with 16-QAM and 4-QAM modulation and different code rates for the MSC. For the following analyses the following modes for DRM+ were used (cf. Part I):

- 4-QAM and R=2/5 (protection level 1),
- 16-QAM and R=1/2 (protection level 2).

Protection ratio for DRM+

The necessary planning values for the DRM+ analyses (minimum reception field strength and protection ratio) are based on the laboratory and field measurements results conducted by the University of Applied Sciences of Kaiserslautern in 2008 (interfering effects of DRM+ on FM signals) [4] and in 2009 (interfering effects of FM on DRM+ signals, DRM+ coverage) [5].

The protection ratios for FM and DRM+ for steady and tropospheric interferences are summarized in **Tab. 1** and **Tab. 2.**

Tab. 1. Protection ratios for steady interference

Steady interference (50 % time and 50 % location)					
Frequency offset [kHz] *Protection ratio [dB] for*	0	100	200	300	400
DRM+ (16-QAM) interfered with by DRM+	14	-7	-32	-40	-40
DRM+ (4-QAM) interfered with by DRM+	6	-14	-40	-40	-40
DRM+ (16-QAM) interfered with by FM (stereo)	20	-4	-40	-40	-40
DRM+ (4-QAM) interfered with by FM (stereo)	11	-13	-40	-40	-40
FM (stereo) interfered with by DRM+	50	38	-7	-40	-40

Tab. 2. Protection ratios for tropospheric interference

Tropospheric interference (1 % time and 50 % location)[2]					
Frequency offset [kHz] *Protection ratio [dB] for*	0	100	200	300	400
DRM+ (16-QAM) interfered with by DRM+	6	-14	-32	-40	-40
DRM+ (4-QAM) interfered with by DRM+	-2	-22	-40	-40	-40
DRM+ (16-QAM) interfered with by FM (stereo)	12	-12	-40	-40	-40
DRM+ (4-QAM) interfered with by FM (stereo)	3	-21	-40	-40	-40
FM (stereo) interfered with by DRM+	50	38	-7	-40	-40

Minimum median equivalent field strength for the DRM+ network planning

The calculation of the minimum median equivalent field strength is based on values of the minimum field strength at the receiver input as measured during the laboratory and field tests performed by the University of Applied Sciences of Kaiserslautern in 2009 [6].The calculations are based on the parameters for the field strength prediction in accordance with ITU-Rec. P.1546-1 [7] with defined reception conditions (location percentage of 50%, 10 m antenna height for the fixed reception) and on the assumptions for the field strength performance of a DRM+ signal as described in a diploma thesis of the Technical University Kaiserslautern [8] (this corresponds also to the definition for T-DAB in the RRC-06 [9]). The minimum median equivalent field strength for DRM+ fixed reception was computed with:

- 13 dBμV/m for 16-QAM and R=1/2,
- 5 dBμV/m for 4-QAM and R=2/5.

Note that these very low values are only useful for a noise limited coverage area to define the borderline coverage. These values will never be reached in an interference limited network environment as it is known as the actual situation in the VHF Band II. Coverage will always be limited by the usable field strength which is always much higher than the minimum median equivalent field strength. In the migration period, DRM+ coverage suffers from the high level of the usable field strength produced by many FM TX stations. Later on, in a pure digital DRM+ environment, the usable field strength drops and the DRM+ coverage will rise.

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1 The planning values for the reception modes of the portable and mobile reception could be computed and analyzed with the available test results, however, this goes beyond the scope of this paper.

2 The network planning is based on the protection ratio for tropospheric interference. The value varies in the co-channel and first adjacent channel of the base interference. The difference of 6 dB was taken from the FM planning values.

METHOD AND SCENARIO FOR FREQUENCY ANALYSES

Method of analysis

In FRANSY the *transmission characteristics* were specified for each tested TX station. Accurately adjusting the relevant protection ratio curves for FM and DRM+ was an essential issue to properly reflect the measured results.

An *interference analysis* identified the FM TX stations being potentially concerned by, (a), a conversion of the tested TX station from FM to DRM+ or by, (b), the planning of a new DRM+ TX station by increasing the usable field strength at, (a), the location of the concerned TX station or, (b), at the 54 dB interference outline.

A *compatibility analysis* determined which constraints on the effective radiated power (ERP) are necessary to protect the existing FM TX stations. Basis of this analysis is the so called 'Administrative proceeding of potentially concernment' of the German Federal Network Agency (Bundesnetzagentur - BNetzA) [10].

For each examined TX station a *coverage analysis* was accomplished. This coverage analysis refers to DRM+ in fixed reception to enable the comparison with FM.

Scenario for network planning

As a suitable example of a network planning within the VHF FM band the 2nd commercial FM network in the German state Rhineland-Palatinate (*bigFM-NET*[3]) was consulted out of the Geneva Plan 1984 (GE84) [11] with 6 high-power basic-network TX stations '*basic TX*' (cf. **Fig. 1** and **Tab. 3**).

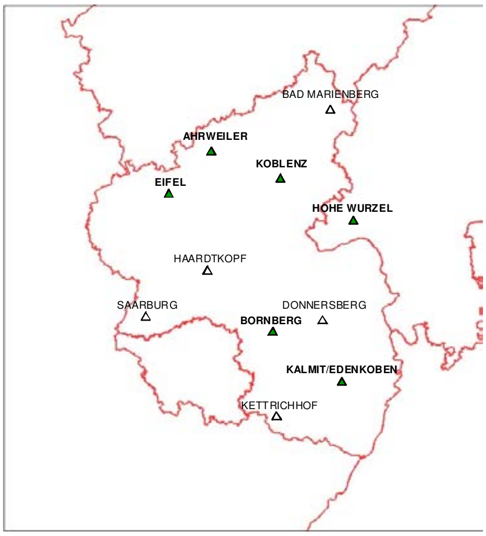

Fig. 1. TXs of the *bigFM-NET*

This configuration has a specific charm lying in the fact that frequency resources could not be planned in Geneva 1984 (GE84) for all high-power basic transmitter sites. Therefore, a state-wide FM coverage can not be ensured, which should, however, be possible with DRM+. The low power TX stations of the *bigFM-NET* with a power up to 1 KW which were planned in Geneva 1984 or later were not considered.

[3] Currently the bigFM sound programme is been broadcasted, and therefore in the following, this network is called *bigFM-NET*

Tab. 3. Transmission characteristics of the FM basic TXs of the bigFM-NET

TX station	Frequency	FM ERP	Radiation pattern
Ahrweiler	104.9 MHz	30 kW / 44.8 dBW	D
Bornberg	107.6 MHz	25 kW / 44 dBW	D
Eifel	106.6 MHz	20 kW / 43 dBW	ND
Hohe Wurzel	104.5 MHz	20 kW / 43 dBW	D
Kalmit/ Edenkoben	106.7 MHz	25 kW / 44 dBW	D
Koblenz	104.0 MHz	40 kW / 46 dBW	D
Haardtkopf	missing		
Saarburg	missing		
Donnersberg	missing		
Bad Marienberg	missing		
Kettrichhof	missing		

CONCEPT AND RESULTS OF THE ANALYSES

FM coverage

As a reference for DRM+ investigations the FM coverage of all 6 basic TXs of the *bigFM-NET* with the transmission characteristics of as defined GE84 was determined (without aeronautical radio constraints), cf. **Fig. 2.**

Inspecting Fig 2 reveals substantial coverage gaps due to missing frequency resources at the remaining 5 basic TXs (Bad Marienberg, Haardtkopf, Saarburg, Donnersberg, Kettrichhof).

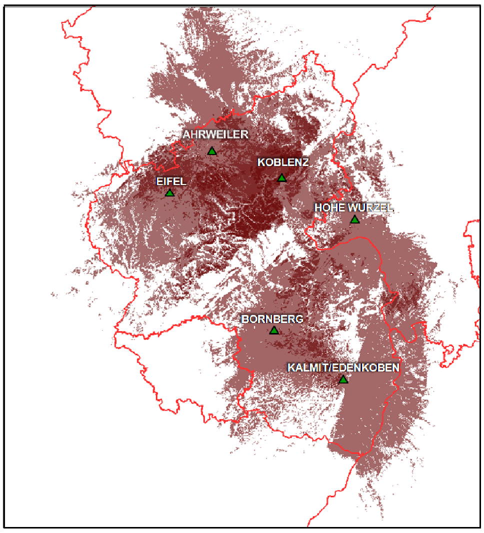

Fig. 2. FM overall coverage of the *bigFM-NET*

Direct conversion from FM to DRM+

As comparison to the overall FM coverage the coverage of the basic TXs after a hard switch-over from FM to DRM+ with 16-QAM and 4-QAM was determined.

In a compatibility analysis for the protection of the existing FM environment, for each TX station, the sectoral power constraints necessary for converting to DRM+ were calculated. Assuming that the aerial remains unchanged, the indentions of different sectors (i.e. antenna pattern constraints) are translated into reducing the ERP by the same amount (i.e. an ERP constraint). The constraints are identical for 16-QAM and 4-QAM (cf. **Tab. 4**).

Tab. 4: Transmission characteristics of the basic TXs after direct conversion to DRM+

TX station	Frequency	ERP (DRM+)	ERP difference to FM
Ahrweiler	104.9 MHz	12 kW / 40.8 dBW	-4 dB
Bornberg	107.6 MHz	8.9 kW / 39.5 dBW	-4.5 dB
Eifel	106.6 MHz	6.3 kW / 38 dBW	-5 dB
Hohe Wurzel	104.5 MHz	7.1 kW / 38.5 dBW	-4.5 dB
Kalmit/ Edenkoben	106.7 MHz	8.9 kW / 39.5 dBW	-4.5 dB
Koblenz	104.0 MHz	14 kW / 41.5 dBW	-4.5 dB

The DRM+ state-wide coverage is guaranteed already with 16-QAM. With 4-QAM the coverage reliability and the coverage into the neighbouring communication areas is improved, cf. **Fig. 3**. The results propose the conclusion that even after a further reduction of the DRM+ ERP by 10 dB the country can be still a covered completely. [12].

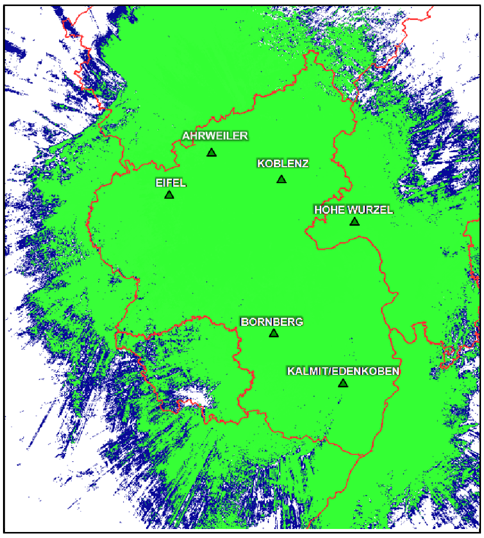

Fig. 3. Overall coverage of DRM+[4]

[4] In all figures with DRM+ coverage the coverage area with 16-QAM is represented in green, the coverage area which is additionally achievable with 4-QAM is shown in blue.

DRM+ single frequency network (SFN)

Direct conversion from FM to DRM+ whilst keeping the frequency at the TX station has only one benefit: The reduction of the ERP.

During the migration period from analogue to digital sound broadcasting the liberation of frequency resources for other networks with consideration of the protection of existing FM networks as well as of forming single frequency networks (SFN) for the improvement of the frequency economics and coverage reliability is of primordial interest.

In this paper, for the first time, SFNs were designed with FRANSY. Doing so differs significantly from analysing a single TX station.

It is feasible in the compatibility analysis by a suitable before/afterwards consideration. The following assumptions were met for the SFN model planning for a DRM+ SFN for *bigFM-NET*:

- The basic TXs without GE84 plan frequency are to be merged into a fitting regional SFN.
- For Rhineland-Palatinate, 4 regional SFN are formed. The master TX station of this region gives the SFN frequency, cf. **Fig. 4,** for the SFN 'PFALZ' two variants were computed.
- In each SFN, the central basic TX with a GE84 plan frequency will be the master TX station for the SFN. The other basic TXs use this frequency, if one basic TX has still a GE84 plan frequency; it becomes free for other purposes.
- The low power TX stations of the *bigFM-NET* with an EPR up to 1 KW, which were planned in GE84 or later, were not taken into account since gap fillers for the SFN can be planned afterwards.
- As a starting point for the SFN compatibility analysis, the ERPs in accordance with GE84 (without aeronautical radio constraints) at the TX stations with a non directional radiation pattern are adopted.
- All FM TX stations concerned by the SFN planning remain unchanged and are protected.
- For the coverage analysis, the constraints on aerial patterns stemming from the compatibility analysis, being partially not realizable, were rounded. In the case of a subsequent levelling of the sectoral indentions on 0 dB realistic antenna constructions are realizable.

The compatibility analysis yields plausible SFN configurations and ERP features, represented in **Tab. 5.**

The compatibility analysis confirmed the assumption that the SFN master TX stations suffer from obvious ERP losses as compared to their ERP with FM, since - by forming of the SFN - not only one TX station but up to three TX stations contribute to the interference product on this frequency. This sum interference product should not become larger than the interfering effect of the original Geneva plan FM TX station.

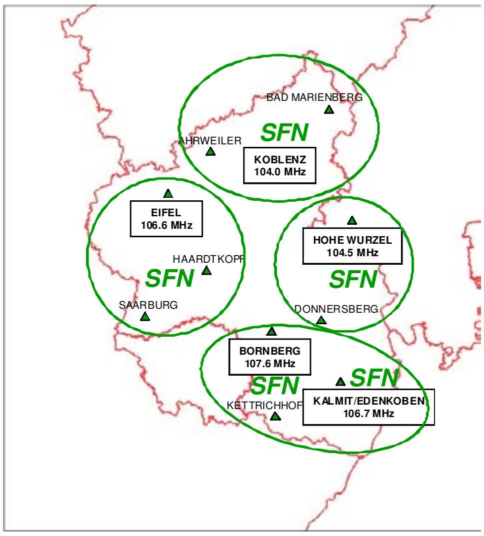

Fig. 4. SFN concept

As a result the frequency resources for DRM+ can be used at all basic TXs, and the FM frequencies at the locations Ahrweiler (104.9 MHz) as well as Bornberg (107.6 MHz) and/or Kalmit/Edenkoben (106.7 MHz) can be used for other purposes.

Tab. 5. Transmission characteristics of the basic TXs in the DRM+ SFN

SFN	Location	sectorial DRM+-ERP constraints	average DRM+-ERP over all sectors
SFN KOBLENZ - 104.0 MHz			
	Koblenz	10 dB … 16 dB	2 kW
	Ahrweiler (104.9 MHz becomes idle)	7 dB … 24 dB	1.1 kW
	Bad Marienberg	1 dB … 17 dB	2.3 kW
SFN EIFEL - 106.6 MHz			
	Eifel	10 dB … 15 dB	1.1 kW
	Haardtkopf (new location)	12 dB … 30 dB	1.3 kW
	Saarburg (new location)	5 dB … 50 dB	0.2 kW
SFN RHEINHESSEN - 104.5 MHz			
	Hohe Wurzel	7 dB … 19 dB	1.3 kW
	Donnersberg (new location)	18 dB … 37 dB	0.3 kW
SFN PFALZ1 - 106.7 MHz			
	Kalmit/Edenkoben	12 dB … 15 dB	1.2 kW
	Bornberg (107.6 MHz becomes idle)	7 dB … 23 dB	1.2 kW
	Kettrichhof (new location)	0 dB … 15 dB	1.2 kW
SFN PFALZ2 - 107.6 MHz			
	Bornberg	10 dB … 16 dB	1.3 kW
	Kalmit/Edenkoben (106.7 MHz becomes idle)	10 dB … 45 dB	0.5 kW
	Kettrichhof (new location)	0 dB … 23 dB	0.4 kW

From the coverage analyses for the individual DRM+ SFN a complete coverage in the SFN regions is achieved, cf. **Fig. 5 to 9.**

From the representation of the overall coverage of all regional SFN (cf. **Fig. 10**) it can be concluded that a complete coverage of the state Rhineland-Palatinate can be achieved. The coverage is almost as large as in the case of the pure FM DRM+ conversion (cf. **Fig. 3**), but, on the other hand, the multiple coverage in the coverage area is substantially larger - and therefore, also the coverage reliability.

Fig. 11 shows the areas in which several basic TX at the same time contribute coverage and therefore the increase of the network gain and the coverage reliability. In addition, the electromagnetic compatibility with the environment is substantially better due to the significant reduction of transmitting power.

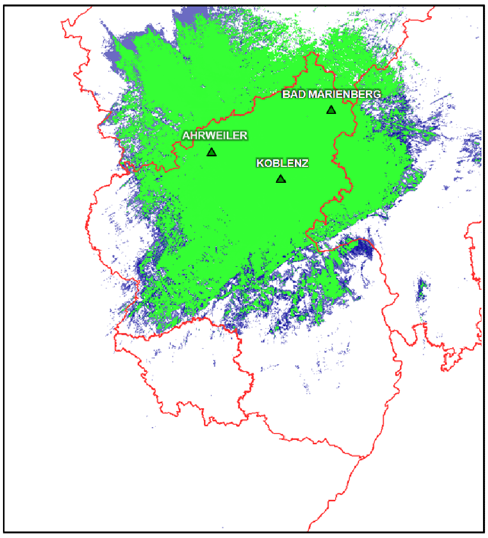

Fig. 5: DRM+ coverage of SFN KOBLENZ

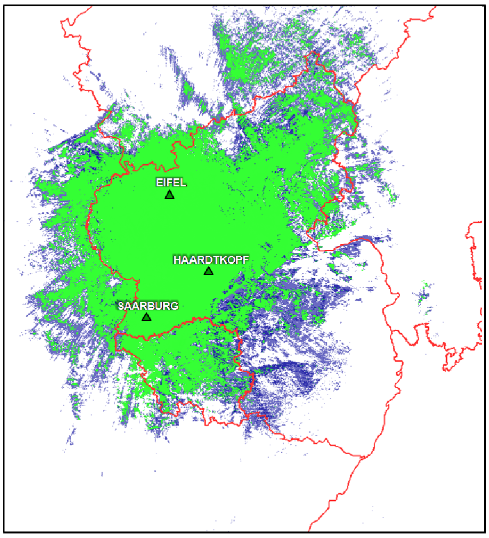

Fig. 6: DRM+ coverage of SFN EIFEL

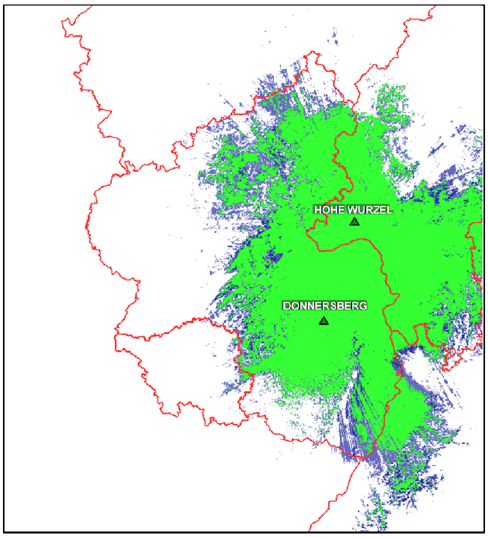

Fig. 7: DRM+ coverage of SFN RHEINHESSEN

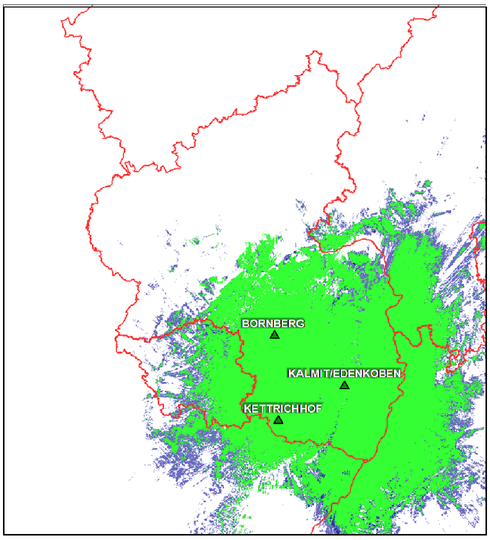

Fig. 8: DRM+ coverage of SFN PFALZ1

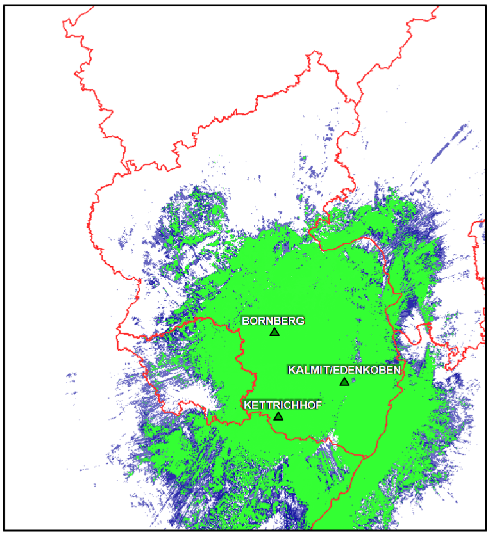

Fig. 9: DRM+ coverage of SFN PFALZ2

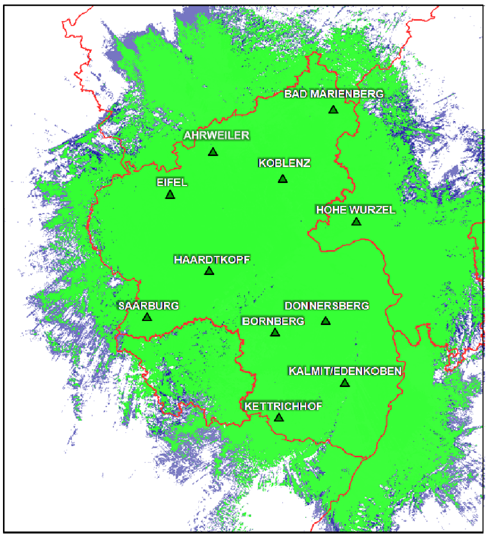

Fig. 10: DRM+ coverage (all SFNs, variant PFALZ1)

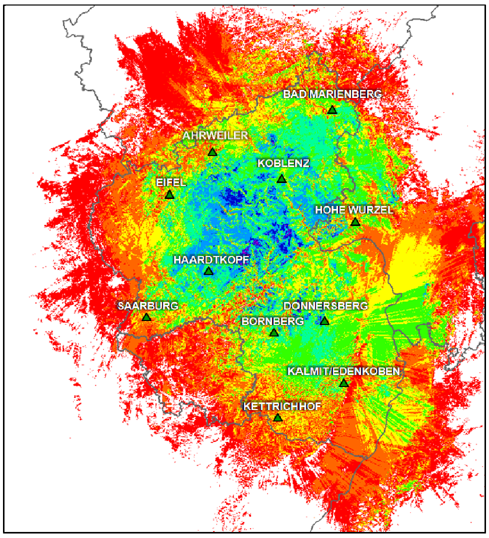

Fig. 11: Multiple coverage of all DRM+ SFNs with 16-QAM (variant PFALZ1)[5]

SUMMARY

The planning exercises presented in this paper prove – as a basic principle - that a DRM+ SFNs can be introduced in the actual VHF FM band in a compatible way. As compared to FM, DRM+ SFNs exhibit high coverage reliability even at lower TX powers. Furthermore, frequencies can be liberated, which then become available for other purposes. All these benefits of DRM+ SFNs facilitate the soft analogue to digital switch-over.

In a next step further TX locations could be optimized into the SFN in order to achieve, e.g., improved mobile and portable coverage in the larger cities, and, to allow further reduction of transmitting power with TX locations lying in the main coverage areas.

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[5] Colour scale: Coverage by 1 TX (red), 2 TX (orange), 3 TX (yellow), 4 TX (green) 5 TX (cyan), 6 TX (light blue), 7 TX (dark blue), 8 and more TX (purple).

REFFERENCES

[1] http://www.irt.de/de/produkte/programm-verbreitung/fransy.html

[2] 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)

[3] ITU-R BS.412-9: Planning standards for terrestrial FM sound broadcasting at VHF

[4] Report of the field trial of DRM+ in Kaiserslautern 2008 on http://drm-radio-kl.eu/berichte_vortraege.htm

[5] Field trial of DRM+ in Kaiserslautern 2009, University of Applied Sciences of Kaiserslautern. To be published on http://drm-radio-kl.eu/berichte_vortraege.htm

[6] Report for the 10th Workshop Digital Broadcasting 2009, September 16-17 2009, Ilmenau 'Leaving the dead-end street: New ways for the digitisation of the VHF sound broadcasting with DRM+ - Part I - DRM+ Field Trial 2009: Concept, Setup, and First Results'

[7] Recommendation ITU-R P.1546-1 Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz

[8] Report of a diploma thesis of the Technical University Kaiserslautern „technisch-wissenschaftlichen Vergleich der Verträglichkeit von UKW-FM mit HD-Radio™ und mit DRM+ under http://www.drm-radio-kl.eu/berichte_vortraege.htm

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[10] http://www.bundesnetzagentur.de/media/archive/958.pdf

[11] Final Acts of the Regional Administrative Conference for the Planning of VHF Sound Broadcasting (Region 1 and Part of Region 3) Geneva, 1984

[12] J. Lehnert, Leaving the dead-end street: New ways for the digitisation of the VHF-FM sound broadcasting with DRM+, Part II: First results on compatibility planning of DRM+ and HD-Radio™ in the VHF band, 9th Workshop Digital Broadcasting, Erlangen, September 18-19, 2008

Leaving the dead-end street: New ways for the digitisation of the VHF sound broadcasting with DRM+

Part III: Outlook: Investigations on the deployment of DRM+ in VHF band III

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INVESTIGATIONS ON THE DEPLOYMENT OF DRM+ IN VHF BAND III

Part I and Part II of this paper prove that **DRM+** is a suitable candidate for the digitization of **VHF band II**, especially the FM band – from a technical point of view.

Important technical aspects are that

- DRM+ compatibility with the existing FM systems can be achieved,
- DRM+ coverage is at least as good as FM coverage (depending on the percentage of original FM TX power spend for DRM+),
- DRM+ coverage reliability can be traded vs. TX power,
- frequencies can be liberated by carefully setting up DRM+ SFN networks, thus allowing a more efficient spectrum use.

These statements still hold even though DRM+ suffers from typical effects encountered in small-band OFDM systems where, e.g,

- the coherence bandwidth can get substantially higher as compared to the transmission bandwidth, resulting in deep signal fades,
- the amplitude of the RF signal is varying very fast (high crest factor) with a rather broad, Gaussian like cumulative distribution, resulting in a higher interference potential in the vicinity of the carrier frequency to conventional FM receivers as compared to FM RF signals.

All these effects are addressed and can technically be solved to further improve DRM+ performance in the future. Therefore, from a pure technical perspective, DRM+ is now ready for introduction in VHF band II!

A question which begs to be asked is a quite simple one: Could DRM+ also be used in **VHF band III (174 - 230 MHz)** as an ideal complement to the Digital Audio Broadcasting ETSI-system-family (DAB/DAB+/DMB) [1]? If yes, what are – from a technical point of view – the conditions and the constraints, the advantages and the drawbacks? The idea has it's own charm since in VHF band III only digital broadcasting systems on DAB basis are deployed, thus, compatibility is to be achieved only within OFDM-type systems.

Both systems can 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. 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 or regional coverage and, deployed as SFN, even large coverage areas for a ***small number of programs and services*** (4 programs and services at maximum). Deploying both systems in the same band might help to push and speed up the digitisation of sound broadcasting since it allows local and regional program providers to 'go digital' *without* joining a 'big' and expensive multiplex. Note that the DAB approach does not provide this unique selling proposition for local and regional coverage!

Besides technical issues, the following short list is quite relevant to market and regulatory issues:

- VHF-Band III (174 – 230 MHz) is uniquely assigned to *digital* sound broadcasting.
- The original intention of entirely filling band III with DAB will not become reality: today, it is obvious that only a portion of band III will be used by DAB. Stations with clear regional and/or local focus could therefore be planned as DRM+ stations in appropriate free DAB blocks, cf. **Fig. 1** and **Fig. 2**.
- The non solved *legal* and still pending compatibility testing procedures between digital systems in band II and the aeronautical services – which today prevent DRM+ from being introduced in band II in the near future – are of minor concern in band III, except for the upper part, i.e. for frequencies > 223 MHz.
- Since in VHF band III, only digital systems are deployed, coordination issues are much easier to solve than those encountered if, in band II, a mixed analogue-digital scenario becomes reality. This applies

especially to international coordination and agreements on protecting existing FM services.

- Since the DAB family and DRM+ have a great technical deal in common, i.e. MPG4-AAC, OFDM modulation, …, building cost efficient digital RX should be possible.

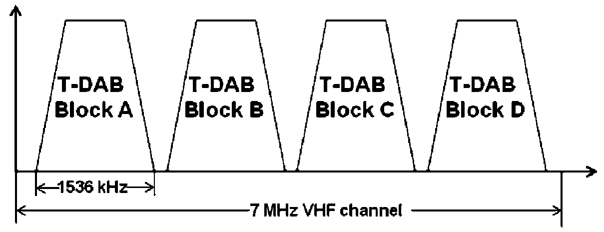

Fig. 1. T-DAB frequency blocks in VHF Band III

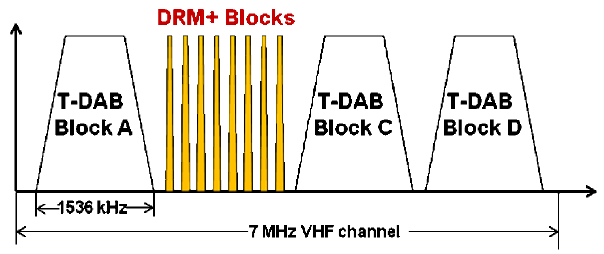

Fig. 2 DRM+ frequency blocks in a free range added to T-DAB frequency blocks in VHF Band III

The authors intend to start working on this question by

- collecting and investigating all the effects coming along with the higher frequencies, e.g. DRM+ Doppler performance,
- measuring the protection ratios of the DAB-System [2] into DRM+ and vice versa,
- setting up and conducting comprehensive field measurements to verify the protection ratios,
- working out planning exercises to show how DRM+ could complement the DAB system-family, e.g. for providing small localised program coverage, i.e. programs that have only local relevance as it is the case for many commercial but also regional public programs in Germany.

REFFERENCES

[1] http://www.etsi.org/WebSite/Technologies/DAB.aspx

[2] ETSI EN 300 401, Digital Audio Broadcasting (DAB) to mobile, portable and fixed receivers