EBU

OPERATING EUROVISION AND EURORADIO

TECH 3357

CASE STUDIES ON THE IMPLEMENTATION OF DRM+ IN BAND II

Geneva

January 2013

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Case Studies on the Implementation of DRM+ in Band II

EBU Committee	*First Issued*	*Revised*	*Re-issued*
TC	2013		

Keywords: Digital Radio Mondiale, DRM+, Digital Radio Broadcasting, Band II.

1. Introduction

DRM+ is a digital audio broadcasting system developed from the original DRM system by extending the operating frequency range to radio bands above 30 MHz. In particular the extension allows the implementation of DRM in the FM band as it has been specifically designed to be compatible with FM transmissions. As such it fits within the FM spectrum masks. The system has been standardised in ETSI ES 201 980 V3.2.1 [1] while planning parameters and criteria are defined in Recommendation ITU-R BS.1660-6 [2].

DRM+ offers the following benefits:

- Better protection from interference, which will be efficient in an all DRM+ environment
- It allows the transmission of multiple audio programmes in a single FM channel.
- It enables an extensive range of multimedia and data services
- It has the capability to offer high quality audio using data rates up to 186 kbit/s (AAC)
- Improved power budget over FM, allowing lower transmitted powers for equivalent coverage
- SFN capability allowing efficient spectrum use

Within the SM-EDP EBU group, planning studies have been performed which consider several aspects of the DRM+ system and its implementation. These desk-top based studies investigated the potential to introduce new DRM+ transmissions into Band II by assessing the likely coverage of the new transmissions and their impact on existing FM services. As FM currently makes extensive use of Band II, any new DRM+ transmissions would be required to comply with the GE84 FM frequency plan [3], which the studies took into account.

The relevant parameters and criteria for carrying out the DRM+ studies are summarized in **Annex A**, *'Planning parameters and assumptions for DRM+ in Band II for use in EBU planning study'*. The annex outlines working procedures for the studies on the implementation of DRM+ in Band II and sets out planning parameters such as Protection Ratios and maximum interference signal levels.

A new DRM+ service can be introduced within the existing FM environment in two main ways. They are:

a) Replacing an existing FM transmission with DRM+

This first option entails the conversion of an existing FM transmitter to DRM+. In doing this it may be necessary to modify the characteristics of the DRM+ transmission to maintain compatibility with other services in the network, particularly FM. As DRM+ is more resilient to interference and can be adequately received at a lower level than FM, it may also be desirable to reduce the transmitted power of the DRM+ service if the FM coverage is to be replicated.

In this respect three planning studies were carried out, one for Sweden (Stockholm) [**Annex B**] and two for Germany (Frankfurt) [**Annexes D & E**]. Furthermore a field trial took place in the UK (Edinburgh) [**Annex G**] which was undertaken according to this scenario.

b) Adding a new DRM+ transmission on a new frequency

This option is to introduce a new DRM+ transmission into the existing FM environment, which would require a new frequency. To achieve this, an existing transmission site could be used with a new frequency or a new site could be set up at a completely new location. One study has been carried out for this option, using the example of Frankfurt, Germany [**Annex C**].

Further to the studies mentioned above, the impairment of FM broadcast reception by in-Band OFDM signals [**Annex F**] through the cross-modulation effect has been documented.

The methodology and results of the studies are summarized below; detailed information on the studies is provided in **Annexes A - G**.

2. Planning Criteria and Methods Used in the Studies

The general DRM+ planning parameters that were applied in the EBU studies are in accordance with Recommendation ITU-R BS.1660-6 [2]. When introducing DRM+ into the existing FM environment it is important to identify planning assumptions and parameters suitable for both involved systems. **Annex A** details the working procedures used and sets out criteria and parameters (such as Protection Ratios and Maximum Interference Signal levels) assumed in the planning studies.

The planning procedures used in the studies are in accordance with the GE84 Agreement [3] and ITU-R BS 412-9 [4], respectively. However in the context of DRM+ some procedures and parameters have to be adapted to DRM+. Where this has been necessary, such as the Protection ratios for FM interfered with by DRM+, the appropriate recommendation has been used.

Compatibility Analysis - Procedure

The compatibility of the new DRM+ transmission with the existing FM services has to be checked. According to the GE84 Agreement the introduction of a new service should not increase the usable field strength more than 0.5 dB.

The compatibility analysis was carried out based on the protection ratios of FM interfered with by DRM+ is given in Table 1 (reproduced from Table 56 in [2] and also in Tables A2 and B3):

Table 1: Protection ratios FM interfered with by DRM+ used for compatibility analysis

Frequency offset	[kHz]	0	±100	±200	±300	±400	±500	±1000
PR	[dB]	49	30	3	-8	-11	-13	-21

Coverage Calculation

As a next step the achievable coverage of the new DRM+ transmitter was calculated. This was done for a few representative DRM+ modes (e.g. 4-QAM 1/3 or 16-QAM 1/2) and for various reception modes (e.g. mobile, portable indoor and portable indoor handheld reception). It is important to get an idea of the achievable coverage area for the DRM+ service, particularly if an FM transmitter is to be replaced; then a comparison to the previous FM coverage is required.

Cross modulation Effect

DRM+ introduces another potential source of interference to FM reception that does not occur in FM-only networks. This new interference is referred to as the cross modulation effect and is summarized in **Annex F**. The impact of this effect is solely reliant on the level of the interfering signal, whereby its impact remains – irrespective of the wanted signal level. Conventional protection ratios are therefore insufficient to account for this effect as it is necessary to consider the absolute level of the interfering DRM+ signal, rather than the conventional ratio between the wanted and interfering signals. The implication is that increasing the wanted level does not overcome the interference, as would normally be the case.

As measurements show, the impact of the cross-modulation effect is relevant for frequency offsets between the wanted FM transmitter and interfering DRM+ transmitter from 200 kHz to 4 MHz. Should an offset between a particular FM transmission and a DRM+ signal fall within this range the level of the interfering DRM+ signal within the FM service area must be kept below the corresponding levels set out in Table 2 (reproduced from **Annex A**). If the relevant level is exceeded, the FM service would be degraded by cross-modulation.

Table 2: Maximum interfering signal levels

Frequency offset	[MHz]	0.2 - 1	2	3	4
Maximum interfering signal level	[dBm]	-31	-24	-16	-9

3. Replacing an FM transmitter with DRM+

Several studies have been carried out concerning this matter: three desktop based studies included in **Annexes B**, **D** and **E**, and the field trial of **Annex G**.

3.1 Methodology

The methodology of the three desktop investigations is more or less identical. Firstly, the compatibility of the new DRM+ transmitter with the existing FM services was checked. Based on these results the effective radiated power and antenna patterns of the new DRM+ transmitter was modified until conformity was obtained.

The next step was the calculation of the achievable DRM+ service area. Following that the impact of the cross-modulation effect on the existing FM service was assessed for two of the three studies.

3.2 Edinburgh Trial

Additional to the desktop studies, a DRM+ field trial (**Annex G**) took place in Edinburgh. In the trial the DRM+ signal was transmitted from a well established, heavily used station that hosts many services including: digital television, FM radio, DAB and a variety of ancillary mobile communications. The transmission frequency of the trial was 107.0 MHz, a disused FM assignment, implying that the DRM+ transmission effectively replaced an FM signal. As such the frequency assignment of the trial formed part of the national FM channel raster, in which the FM service from Durris on 106.8 MHz was the only nearby adjacent channel transmission with significant power.

The trial made use of the existing infrastructure on site, requiring the DRM+ service to be combined into the same antenna system as other operational FM services. The antenna system had mixed polarization and was nominally omnidirectional at 182 m above sea level. The ERP of the DRM+ signal was set to 1 kW whereas the original FM service operated at 10 kW ERP.

Predictions of the DRM+ and original FM service were made so that they could be compared and coverage measurements were carried out for mobile DRM+ reception in 4-QAM and 16-QAM modes.

3.3 Results

The studies have shown that the conversion of an FM transmitter to DRM+ would be possible, provided that the power of the new DRM+ transmission is decreased and/or the antenna pattern is restricted to protect existing services. In some cases it would be necessary to restrict a DRM+ transmission over the equivalent FM service by some 20 dB in certain directions. Such an onerous requirement arises in some cases because of the large differences in protection ratios at various frequency separations; for example at 400 kHz spacing the FM to FM protection ratio is -20 dB whereas the FM interfered with by DRM+ protection ratio is -11 dB. At wider frequency separations the difference is even larger. Since the DRM+ transmitter characteristics would be configured based on compatibility with the existing FM environment, the FM services would not be affected by interference from the new DRM+ transmitter beyond the 0.5 dB increase according to the GE84 Agreement.

One obvious factor influencing the compatibility of a new DRM+ transmitter is the nuisance situation of the existing FM environment. In an FM network characterized by low usable field strengths, a DRM+ transmission would generally require large restrictions to ensure compatibility with FM. Conversely, noticeable smaller restrictions would be required for DRM+ transmitters that would operate in an FM network with a high usable field strength. Therefore the conversion to DRM+ is less critical in an FM environment characterized by high usable field strengths (i.e. high interference environment) than in a FM environment with low usable field strength (i.e. low interference environment).

Despite these onerous protection requirements, predictions of the DRM+ coverage has shown that good mobile, portable indoor and portable indoor handheld reception would be feasible. Even though the power of the DRM+ transmitter would likely have to be decreased compared to the FM transmitter, the coverage would be at least comparable with fixed FM reception.

The field trial in UK has shown that it is possible to combine a DRM+ service into an existing antenna system with current FM services that are on air without causing any adverse effects to the existing services.

Measurements taken in the trial confirmed that very good DRM+ coverage is achievable in dense urban areas like Edinburgh, especially by adopting the rugged 4-QAM mode. Coverage was also found to be satisfactory in rural areas where only occasional impairments were found due to terrain shielding; in these locations the FM was similarly degraded. Comparisons of the predicted and measured coverage show a very strong correlation.

Another important effect on compatibility with the FM environment must also be considered: the impact of cross-modulation on the existing FM service. This effect is essentially independent of the present level of usable field strength. The intensity of the cross-modulation effect depends basically on the signal level of the new DRM+ transmitter and the frequency offset between DRM+ and FM service. If the new DRM+ transmitter produces a field strength exceeding the levels set out in Table 2 within the FM coverage area, the FM service may be affected by cross-modulation. This situation would be often found in a densely occupied FM spectrum. The desktop based case studies have shown that sizeable parts of existing FM service areas in the vicinity of the DRM+ transmitter may be affected by cross-modulation.

In the Edinburgh DRM+ trial (**Annex F**), even though the received power level of the DRM+ signal would be predicted to cause cross-modulation interference in some areas, the effects were not reported. However, as the Edinburgh trial was a practical ‘real world’ trial in which the DRM+ signal was transmitted within the existing live FM network it was not possible to carry out detailed measurements of the cross-modulation effect to establish its presence and magnitude, should it have existed. Bearing in mind this restriction, the effect was actively sought out, with the result that no audible impairments to FM services in the area were found. This experience indicates that in practice the cross-modulation effect may not be as objectionable as laboratory based tests may predict.

4. Finding interleaved frequencies in Band II for new DRM+ transmissions

One study has been undertaken concerning the introduction of a DRM+ transmitter into the FM environment as an additional frequency from an existing transmitter site (**Annex C**).

4.1 Methodology

The methodology of the desktop investigation was the following:

First of all a frequency search was conducted to find the optimal frequency for the chosen transmitter site. For this purpose the lowest usable field strength was used as the crucial factor.

The compatibility of the new DRM+ transmitter with the existing FM services was then checked. Based on these results the antenna pattern of the new DRM+ transmitter was determined.

Following this the calculation of the achievable DRM+ service area was carried out.

Finally the impact of the cross-modulation effect on the existing FM service was analyzed.

4.2 Results

For the investigated case the new DRM+ transmitter was a low power station with an effective radiated power of 20 dBW. For this low power station an implementation within the existing FM environment was found to be possible, provided that the DRM+ antenna pattern was restricted. For the analyzed transmitter restrictions up to 17 dB would be needed. Since the DRM+ transmitter characteristics are configured based on compatibility with the existing FM environment, the FM services would not be unduly affected by interference from the new DRM+ transmitter.

The calculation of the DRM+ coverage areas has shown that mobile, portable indoor and handheld indoor reception would be possible and they would all be about the same size. This is due to the fact that the service areas are mainly limited by interference within the fully occupied FM environment. Compared to the coverage area of an equivalent FM transmitter (identical power and transmitter characteristics) the DRM+ coverage is improved.

As described above, the FM environment would not be unduly affected by interference from the new DRM+ transmitter. However, one problem remains; the susceptibility of FM tuners to cross-modulation. If the new DRM+ transmitter is located within or near the coverage area of an FM transmitter the maximum interfering signal levels in Table 2 could be exceeded and FM receivers may then suffer from cross-modulation. This situation would often be found in a fully occupied FM spectrum. The investigated case has shown quite clearly that a sizeable part of the existing FM service area in the vicinity of the DRM+ transmitter may be affected by cross-modulation.

Should the DRM+ transmitter site be located in a sparsely populated area such as on a mountain or in a field this effect may have limited impact on the FM coverage.

5. Conclusions

Desktop studies have shown that it would be possible to replace a single FM transmitter by a DRM+ station or to introduce a new low power DRM+ transmission into the FM environment without unduly increasing the usable field strength of the existing FM services. Regarding the compatibility analysis the conversion to DRM+ is less critical in an FM environment characterized by high usable field strengths (i.e. high interference environment) than in a FM environment with low usable field strength (i.e. low interference environment).

The studies also showed that in practical cases, the conversion of an FM transmission to DRM+

would be possible. In doing so, however, significant power restrictions may be required to protect existing FM services. Because of the higher robustness of DRM+ this does not imply a reduction of the DRM+ coverage area compared with the coverage of the original FM transmitter.

The field trial in the UK achieved excellent DRM+ coverage with good audio quality for most of the tested areas. Coverage of the lower power DRM+ transmitter was also confirmed to replicate the FM coverage.

The theoretical studies nevertheless suggest that FM services may be affected by cross-modulation from a new DRM+ transmitter. The intensity of the cross-modulation effect basically depends on the DRM+ signal level and the frequency separation between the DRM+ and FM services. No effects of cross-modulation interference were, however, reported in the Edinburgh DRM+ trial. The experience suggests that in practice the cross-modulation effect may not be as objectionable as laboratory based tests may indicate.

6. Possible further work and studies

The study concerning the introduction of an additional DRM+ transmitter into the FM environment was only carried out for one particular instance and may not be indicative of other cases. Further studies in this regard would therefore be helpful. Beyond that, there have been no studies with regard to DRM+ transmitter sites at completely new locations. This could be of interest since it may be possible to locate the DRM+ transmitter in a sparsely populated or remote area where the cross modulation effect has no impact.

Further investigations regarding the cross-modulation effect are necessary; in particular, the verification of the effect in practical field trials.

7. References

[1] **ETSI ES 201 980 V3.2.1** Digital Radio Mondiale (DRM); System Specification , ETSI, 06/2012

[2] **Rec. ITU-R BS.1660-6** Technical basis for planning of terrestrial digital sound broadcasting in the VHF band, ITU R, 08/2012

[3] **GE84** Final Acts of the Regional Administrative Conference for the Planning of VHF Sound Broadcasting, Geneva, 1984

[4] **Rec. ITU-R BS. 412-9** Planning standards for terrestrial FM sound broadcasting at VHF, ITU-R, 12/1998

Annex A: Planning parameters and assumptions for DRM+ in Band II for use in a planning study

A1. Introduction

This annex contains planning assumptions and parameters that were used in a planning exercise that investigated the feasibility of introducing DRM+ in Band II without interfering with existing (FM) allocations. Two different scenarios were investigated:

1. The replacement of an existing FM transmitter by a DRM+ transmitter; questions are:
    - What are the characteristics of a possible DRM+ transmitter (ERP) that has the same interference potential as the existing FM transmitter?
    - What coverage of the DRM+ service can then be achieved?

2. The introduction of new DRM+ transmitters into the existing GE84 frequency plan for Band II; questions are then:
    - What DRM+ transmitter characteristics (ERP and antenna height) can be used?
    - What coverage of the DRM+ service can be achieved?

In terms of work procedures there is little difference between analysing the two different scenarios as the questions to be answered for the two scenarios are also almost identical.

The first question covers the compatibility with existing services in Band II and the GE84 frequency plan in particular. The second question, what kind of service area can be achieved; is an introduction of DRM+ feasible in terms of achieved service area?

Initial discussions within the SM-EDP group focussed on the second case, the introduction of new DRM+ transmitters.

A2. General Planning assumptions

In order to complete a planning study, there is a need to define planning parameters as well as to define the conditions for carrying out the study.

The following planning assumptions are used:

- Use of the GE84 FM plan and the Master International Frequency Register (MIFR) as a basis
- Planning parameters should be in agreement with the GE84 plan this means, for example:
    - Use of the former ITU-R Rec. 370 that was used in the creation of the GE84 plan. Use of ITU-R Rec. 1546 may also be an alternative.
    - Use of directional receiving antennas.
    - Receiving antenna height at 10 m.
- Use of the FM planning parameters defined in ITU-R BS.412-9 [A1].

Even if the above well defined planning parameters are used there may, at some stage, be a need

[*] **Document source**: Mats Ek, Progira Radio Communication. Original document reference: ECS-EDP 108 Rev 3.

to use modified or relaxed planning criteria. This could be, for example:

- Use of omnidirectional receiving antennas for FM
  From previous FM planning/replanning studies it has been concluded that use of omnidirectional receiving antennas will make it even more difficult to introduce new services in Band II. The reason is that more interference is "invited" and usable field strength will accordingly increase.

Other possible modified planning parameters could be:

- Calculations done at 1.5 m receiving antenna height, as was done in the case of the Dutch "Zero Base" replanning. This will also result in a different value for the minimum usable field strength (Emin) for the FM service.
- Use of relaxed protection ratios according to KPN FM-receiver measurements.
- Use of terrain based field strength prediction models instead of Recommendation ITU-R P.370 such as, for example, Recommendation ITU-R P.1812.
- Modified interference calculations for example only consider the strongest or dominant interferers in each pixel.
- Relaxation of the 1% time interference criteria to, for example, 5% or even 10% of time
- Interference summation method; today SMM (Simplified Multiplication Method) is mainly used, but PSM (Power Sum Method) could also potentially be used.

It may, however, be difficult and time consuming to get acceptance for modified planning parameters both on a regulatory level as well as within the broadcasting community. For this reason it does not seem realistic to deviate from the planning parameters in the GE84 frequency plan and those given in ITU-R BS.412-9 [A1].

A3. Outline of working procedures for the planning study

The following procedure describes the case of the introduction of new DRM services, (scenario 2). The procedure for replacing or converting an existing FM transmitter (scenario 1) to DRM+ can be seen as a subset of this since it only relates to one particular site and to one particular frequency.

The planning study can be made in the following way:

1. Identification of a suitable area (or areas) for carrying out the study. Criteria for selection of area(s) could be:
   - Availability of good and reliable FM transmitter data.
   - The area is commercially interesting for further sound broadcasting services.
   - Spectrum in the area is already extensively used by FM services.

2. It would be preferable to make the planning studies in several different geographical locations in Europe, with varying spectrum usage conditions. At this preliminary stage the following three areas are proposed:
   - Frankfurt
   - London
   - Stockholm

3. Calculation of possible ERP from potential DRM+ transmitting sites, without increasing the usable field strength of existing (FM) services.

- ◦ Input is protection ratios for DRM+ into FM, (and of course FM into FM)
- ◦ Take account of maximum interfering signal levels due to susceptibility of FM tuners to cross-modulation (for frequency offsets between 200 kHz and 4 MHz)
- ◦ Calculations are made for each frequency (87.5 - 108 MHz)
- ◦ Calculations are made for a number of positions in the selected planning areas. The positions are associated to sites where existing FM services are transmitted.
- ◦ Transmitting antenna height is set to the actual antenna height for the site under consideration.
- ◦ Coverage area of existing FM services are calculated for the desired frequencies
- ◦ Introduction of the new DRM service should not increase Usable field strength (Ufs) more than say 0.5 dB, which is the increase which should normally be acceptable according to the GE84 Agreement [A2]
- ◦ Maximum allowed ERP in each direction (resolution for example 10°) is stored for each position and for each frequency
- ◦ The possible ERP (in each direction) is presented for the “best” frequencies at potential DRM+ site positions.

4. Calculation of coverage area for a few suitable potential DRM+ sites (on acceptable frequencies) from point 3, above.

- ◦ Protection Ratios for FM into DRM+ are required
- ◦ Coverage criteria for DRM+ according to ITU-R BS.1660-6 [A4]
- ◦ Coverage presented for a few representative DRM+ modes
- ◦ Coverage presented the selected DRM+ modes and the following three reception conditions:
  - Mobile car reception
  - Portable indoor
  - Portable handheld, indoor
- ◦ Additionally Coverage area for the following cases may also be of interest
  - Fixed reception
  - Portable outdoor
  - Portable handheld, outdoor

A4. Suggestions for planning parameters for DRM+

A4.1 General

In order to complete the planning study there is a need to define planning parameters for DRM+ services. These planning parameters in general consist of several parts, such as protection ratios, coverage definitions and other planning parameters. Planning parameters for DRM+ are in general found in ITU-R BS.1660-6 [A4]. The planning parameters given in this document can in most cases be used directly.

A4.2 Protection criteria

A4.2.1 Protection ratios

Two sets of protection ratios will need to be defined for the purpose of the studies: DRM+ interfering with by FM and vice versa. Protection ratios are presented in ITU-R BS.1660-6 [A4], which includes the latest findings concerning this issue. However, all studies previously carried out by the EBU SM-EDP group are based on protection ratio values given in a preliminary version of the technical supplement to ECC Report 141 [A3] as shown in Table A1. Compared to these former values, the protection ratios in [A4] are limited to frequency offsets in the range of ±200 kHz. More recent field measurement results [A7] provide evidence that there is no relevant interference for frequency offsets ≥ ±300 kHz. Therefore protection ratios for those larger frequency offsets have not been taken into account in Recommendation ITU-R BS.1660-6 [A4].

Table A1: Protection Ratio values in the technical supplement to ECC Report 141 [A3]

Frequency offset	[kHz]	0	±100	±200	±300	±400
DRM+ (16-QAM, R=1/2) interfered with by FM (stereo)	[dB]	18	-9	-49	-68	-69
DRM+ (4-QAM, R=1/3) interfered with by FM (stereo)	[dB]	11	-13	-54	-76	-77

Protection ratios for FM interfered with by DRM+ are also given in [A4]. These values are shown in Table A2. For comparison the protection ratios for FM interfered with by FM (±75 kHz, stereophonic) as given in [A1] are also presented in the table. These values are also needed for an entire evaluation of the existing interference situation.

Table A2: Protection ratios for FM interfered with by DRM+ and FM interfered with by FM

Frequency offset	[kHz]	0	±100	±200	±300	±400	±500	±1000
Basic protection ratio for FM (stereo) interfered with by DRM+	PR_{basic} [dB]	49	30	3	-8	-11	-13	-21
Protection ratio for FM interfered with by FM (steady interference)	*PR* [dB]	45	33	7	-7	-20	-	-
Protection ratio for FM interfered with by FM (tropospheric interference)	*PR* [dB]	37	25	7	-7	-20	-	-

The measurements in [A5] have shown protection ratios for FM interfered with by DRM+ from 400 kHz onwards, which are considerably higher than for FM interfered with by FM. Therefore, frequency offsets up to 1 MHz should be considered. The values for 600 kHz to 900 kHz can be interpolated from the given values of 500 kHz and 1 MHz.

A4.2.2 Maximum interfering signal levels

Measurements of protection ratios for FM interfered with by DRM+ for FM tuners [A6] have shown that for frequency offsets higher than 200 kHz the maximum acceptable signal level is almost independent of the wanted FM level due to a cross-modulation effect.

In [A6] the following maximum interfering signal levels are given:

Table A3: Maximum interfering signal levels for FM interfered with by DRM+

Frequency offset	[MHz]	0.2 - 1	2	3	4
Maximum interfering signal level	[dBm]	-31	-24	-16	-9

These figures, when plotted give the graph in Figure A1

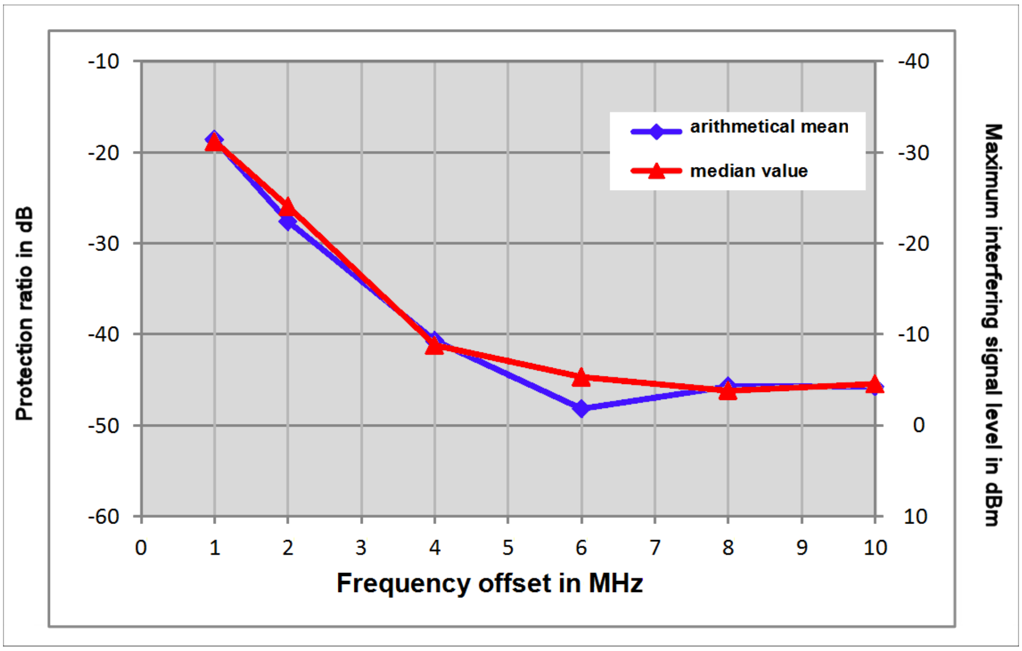


Figure A1: Maximum interfering signal level

Only frequency offsets up to 4 MHz are considered according to the current FM specification which defines protection ratios lower than -40 dB as not relevant (protection ratio FM interfered with by DRM+ equals -40 dB at a frequency offset of 4 MHz)

A4.3 DRM+ Modes

It is proposed that only following DRM+ modes should be considered:

- 4-QAM R= 1/3
- 16-QAM R= 1/2

A4.4 Coverage criteria and other required planning DRM+ planning parameters

Planning parameters for DRM+ needed in order to complete the planning study are given in [A4]. (Only in cases where EBU EDP has an opinion deviating from [A4] will there be a need to specify and justify this).

A5. References

[A1]	**Recommendation ITU-R BS.412-9**	Planning standards for terrestrial FM sound broadcasting at VHF
[A2]	**GE04**	Final Acts of the Regional Administrative Conference for the Planning of VHF Sound Broadcasting (Region 1 and Part of Region 3), Geneva 1984
[A3]	**Technical supplement to ECC Report 141**	Future Possibilities for the Digitalisation of Band II (87.5 - 108 MHz), 04/2012
[A4]	**Recommendation ITU-R BS.1660-6**	Technical Basis for planning of terrestrial digital sound broadcasting in the VHF band, 08/2012
[A5]	**FM45(11) 243**	Interference potential of OFDM based digital broadcasting systems
[A6]	**Schramm, Raul**	Messung der Verträglichkeit von DRM+ Signalen bei Empfang von FM-Stereo im UKW-Frequenzband
[A7]	**FM45(10) 223**	Protection Ratios for FM interfered with by digital broadcasting signals, FH Kaiserslautern, LMK, 12/2010

Annex B: Planning study to replace a High Power FM transmitter with a DRM+ transmitter (Sweden)

B1. Summary

This study looks into the possibilities of replacing a high power FM transmitter with a DRM+ transmitter on the same frequency. The FM transmitter at Stockholm/Nacka on 92.4 MHz has been used as an example. By reducing the ERP of the DRM+ transmitter by up to 12 dB the compatibility with surrounding FM stations on co- and adjacent frequencies is maintained. The resulting coverage of the DRM+ transmitter is comparable to the FM coverage, assuming the GE84 FM planning parameters are used for FM. This is a result of the fact that DRM+ is capable of handling a lot of interference from FM. The co-channel PR is 18 dB for 16-QAM R = 1/2 and only 11 dB for 16-QAM R = 1/3.

The main obstacle for such a conversion seems to be existing FM transmitters within the coverage area of the DRM+ transmitter in the frequency range ±1 MHz. The reason is that DRM+ interference extends up to ±1 MHz compared to ±400 kHz in the FM case. FM transmissions in this frequency range may result in restriction in the ERP of the DRM+ transmitters.

It can also be concluded that the FM transmitter sites in Sweden often use a common infrastructure, which helps in this case.

This study has not taken into account possible cross modulation effects. Cross modulation is caused by the fact that the FM receiver is sensitive to the amplitude modulation in the OFDM (DRM+) signal.

B2. Introduction

In this study we will study the possibilities to replace an FM transmitter with a DRM+ transmitter in Band II, and the possible coverage area resulting from such a conversion.

The following cases are studied:

- Compatibility study when replacing an FM transmitter with a DRM+ transmitter
- Definition of allowed ERP
- Calculation of DRM+ Coverage area

This is done for two cases a “smaller” FM transmitter with an ERP of 1 kW and a main transmitter using 300 m antenna height and an ERP of 100 kW.

Both transmitters are located in the Stockholm area. And in order to make the compatibility calculations, transmitter data for Sweden and relevant neighbouring countries have been used.

B3. Input data and procedure

Planning parameters for DRM+ and its compatibility with FM are in agreement with EDP 108 Rev3. It has however not been possible to evaluate the cross modulation effect from DRM+ into FM.

The following calculation steps are carried out:

[*] **Document source**: Mats Ek, Progira Radio Communication. Original document reference: SM-EDP 189.

1. Calculation of coverage contour for existing FM transmitter
2. Determination of maximum possible ERP of DRM+
3. Calculation of coverage contour for DRM+ for the case of portable reception
4. Detailed coverage area for the DRM+ transmitter for different DRM+ modes.

The FM transmitter data used is operational transmitter in Sweden, Finland, Estonia and Latvia. However the main limitation comes of course from the FM transmitters in Sweden, and to some extent transmitters in Finland.

The FM transmitter at 92.4 MHz in Stockholm was chosen. It is transmitting programme 1 (P1) from the Swedish Radio (public service). FM transmitter data is as follows:

Site:	Stockholm/Nacka
ERP:	60 kW
Antenna height:	192 m
Polarization:	Horizontal

The reason for this choice of transmitter is that it is a main transmitter and it is located in an area where the spectrum is more or less completely occupied and where it would not be possible to find frequencies for new FM services.

B4. Results of calculations

B4.1 The FM coverage Area

In the first step the interference limited coverage contour for the FM transmitter is determined. It is shown below.

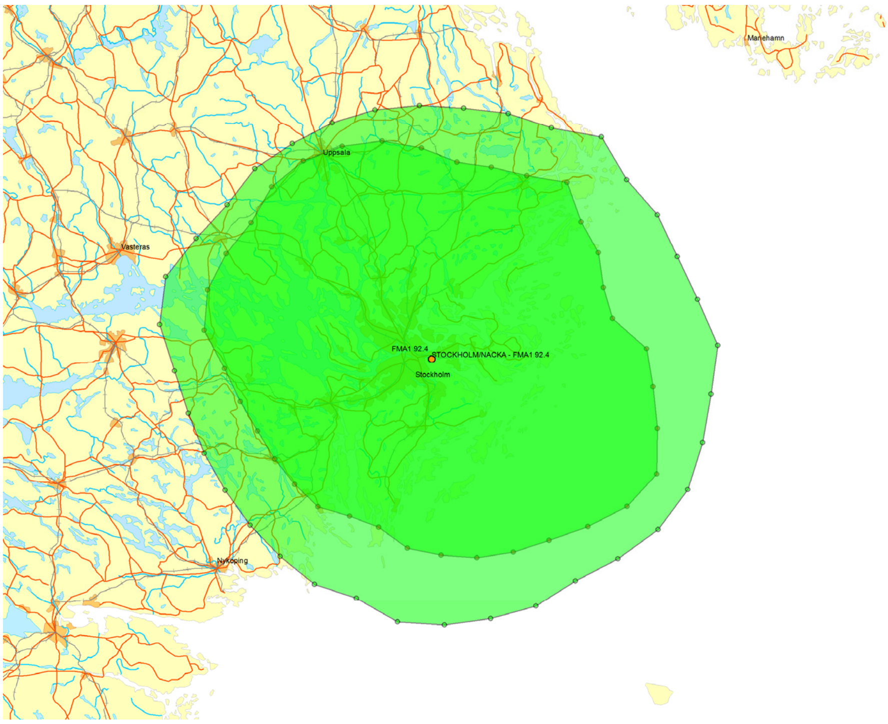


Figure B1: Noise and interference limited coverage for the FM transmitter at Stockholm/Nacka at 92.4 MHz.

The GE84 planning parameters are used to determine the interference limited coverage area. It seems to represent a fairly normal interference limitation with usable field strengths in the range from 58 - 64 dBuV/m. Coverage radius varies from about 55 - 70 km.

Looking at the main interferers (at the site) to the FM transmitter gives the following result:

Name	Country	Freq MHz	ERP dBW	POL	Nuisance Signal	Nuisance FS dBuV/m	Nuisance Type	iFS dBuV/m	PR dB	Corr. dB	Rx ant. disc. dB
KISA-FMA192.5	S	92.5	44.80	H	FM	57.23	Tropospheric	36.00	25.0	0.0	-3.8
HÖRBY-FMA1	S	92.4	47.80	H	FM	47.15	Tropospheric	12.47	37.0	0.0	-2.3
FILIPSTAD-FMA1	S	92.4	24.00	V	FM	43.62	Tropospheric	16.62	37.0	0.0	-10.0
KRAMFORS-FMA1	S	92.4	30.80	H	FM	41.83	Tropospheric	16.83	37.0	0.0	-12.0
TURKU-A-FMA1	FIN	92.6	47.80	H	FM	39.42	Tropospheric	44.42	7.0	0.0	-12.0
MORA/ELD-FMA1	S	92.2	47.80	H	FM	36.16	Tropospheric	41.16	7.0	0.0	-12.0
SÖDERHAMN-FMA1	S	92.5	24.00	H	FM	36.02	Tropospheric	23.02	25.0	0.0	-12.0

It can be seen that the main interferers are main transmitters quite far away (up to 400 km distant). Most of these transmissions are horizontally polarized. When replacing the FM transmitter with DRM+, vertical polarization can be considered for use, but this would however only offer a "cosmetic" advantage. The reason is that even if the FM planning criteria given in GE84 is based upon the use of directional, horizontally polarized receiving antennas, the vast majority of the FM receivers use omnidirectional antennas with little or no polarization discrimination.

Using terrain data the FM coverage area looks like this. Population coverage is about 1970000. The terrain based coverage seems to fit the interference contour quite well.

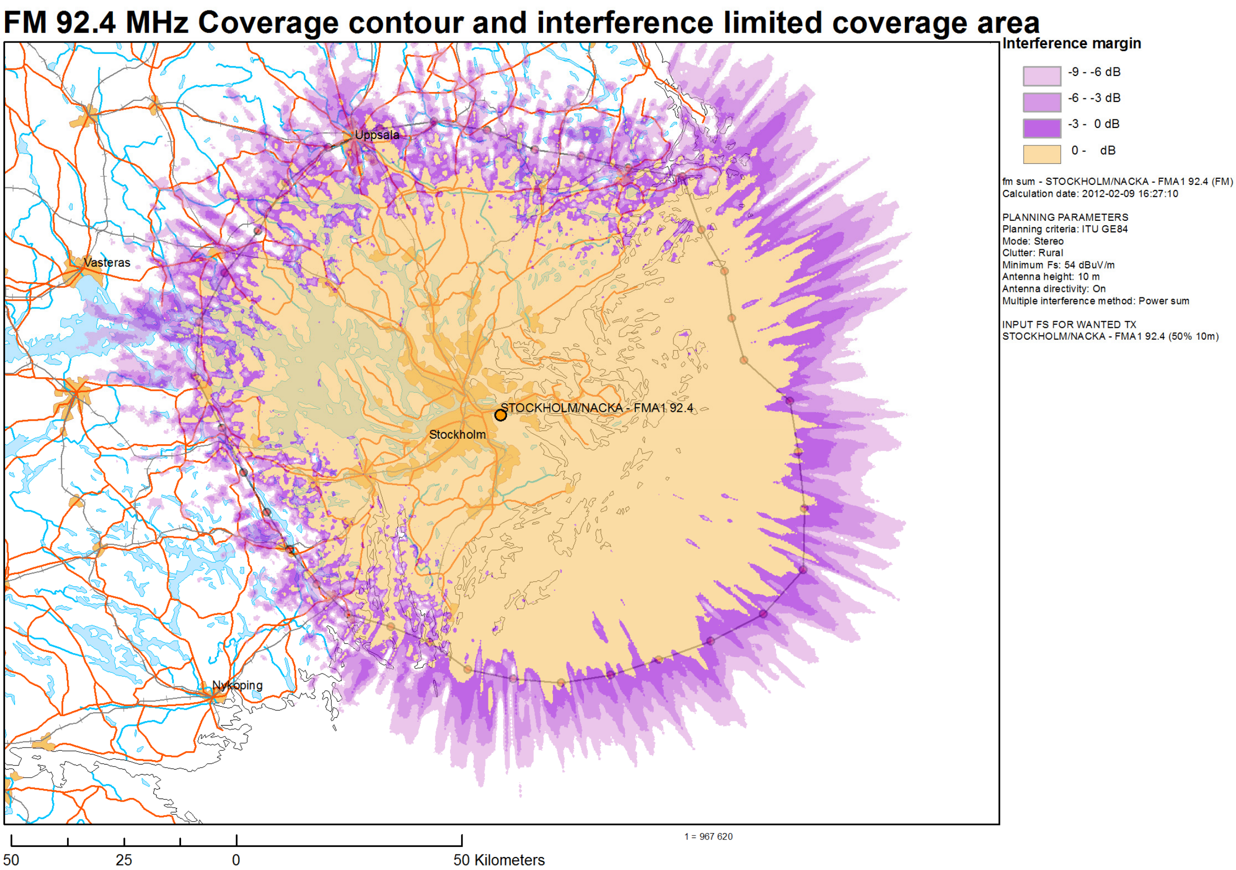


Figure B2: Terrain based interference limited coverage and interference contour. The agreement between the two coverage areas is quite good.

B4.2 Replacing the FM transmitter with a DRM+ transmitter

The next step will be to replace FM transmitter with a DRM+ transmitter. When doing so, the ERP of the DRM+ transmitter can be discussed. Since the co-channel PR for FM interfered with by DRM+ is 49 dB and the co-channel PR protection ratios FM into FM is 37 and 45 dB for the tropospheric and the steady case, respectively, there generally seems to be a need to reduce the power by 12 dB in order to not increase the interference in this case. However since the total aggregated interference levels of the possible victims is not known, a lower ERP reduction may be possible, at least when considering the frequency range ±400 kHz.

However since the DRM+ transmitter may cause interference up to ±1 MHz into FM there will be other victims, which makes it necessary to reduce the ERP of the DRM+ transmitter further.

Table B1: Protection ratios for FM interfered with by DRM+, used for compatibility analysis

Frequency offset	[kHz]	0	±100	±200	±300	±400	±500	±1000
PR	[dB]	49	33	7	-7	-11	-13	-21

Note The values in this table were provisional at the time of this study. The final values that were subsequently agreed and that appear in [2] and in Table 1 & Table A2 differ somewhat, but in the context of this report make little difference in the conclusions that are drawn.

Initially we will assume that we want to have an ERP for the DRM+ of 12 kW. This means a reduction of the ERP of 7 dB relative to the FM transmitter.

We will now see how much power we can radiate using DRM+ on the same frequency without increasing the usable field strength more than 0.5 dB for the affected transmitters. 0.5 dB Is a normal value, used in planning.

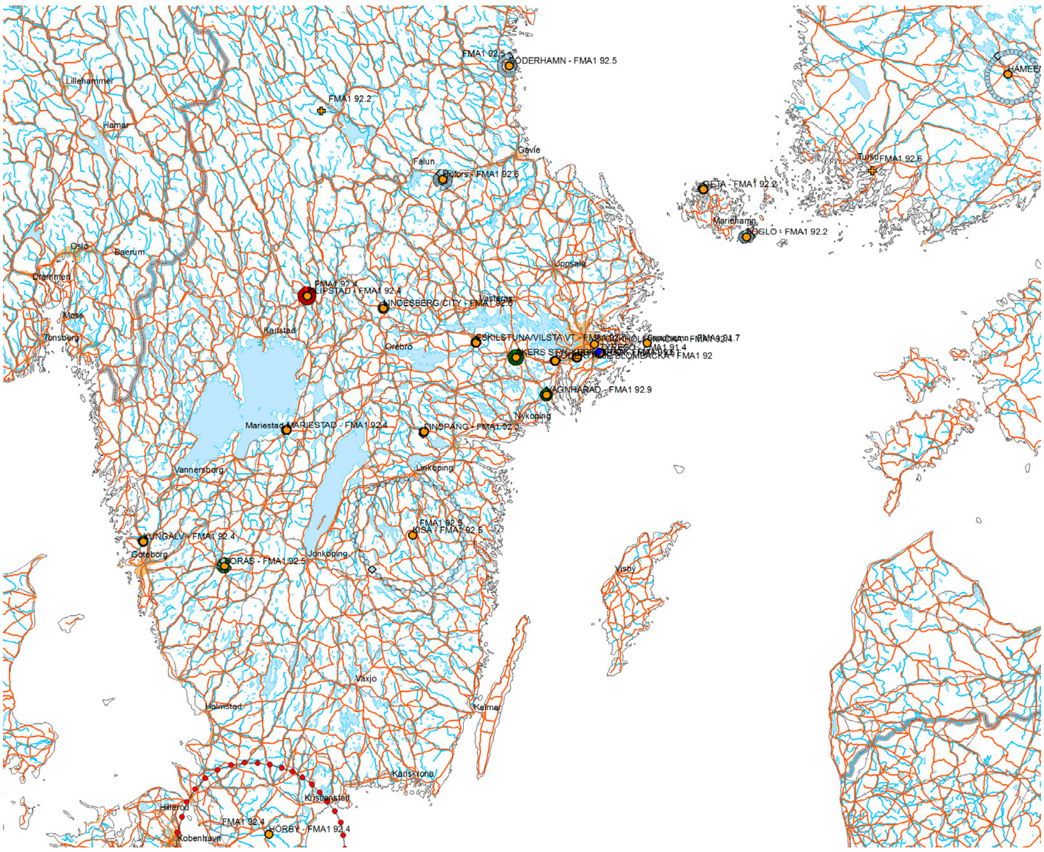


Figure B2: The victim transmitters found when converting from FM into DRM+.

Note that most of the victims are the same as in the FM case, but there are a few new victims present inside the ±1 MHz frequency range.

The affected transmitters differ slightly from the ones found when looking at the FM transmitter. In particular there are a number of small transmitters inside the coverage area of the DRM+ transmitter. They are:

- Botkyrka 91.6 MHz
- Tyresö 91.4 MHz
- Sodertälje 92.0 MHz

The restriction caused by these transmitters is less than the other co- channel FM transmitters, however, so they do not result in any additional reductions in the possible ERP.

The main restriction remains more or less the same as in the FM to FM case; it is the co-channel FM transmitter in Filipstad at 92.4 MHz.

Since the protection ratio increases from 37 dB (FM into FM) to 49 dB (DRM+ into FM), we can expect a reduction in the ERP of about 12 dB, relative to the FM transmitter, caused by this increased nuisance field strength, at least in some directions. We have already reduced the power by 7 dB so an additional 4 - 5 dB reduction should be needed. This can be seen in Table B2 and Figure B4.

B4.3 Antenna diagram of DRM+ transmitter

The result shows that there is a need to reduce the ERP in some directions. Relative to the Assumed maximum ERP of 12 kW the following reductions are needed in order to keep the increase of usable field strength below 0.5 dB. In this case it is presented as an antenna diagram. Maximum Reduction needed is 4.5 dB. It is also clear that in some directions it is also possible to increase the ERP of the DRM+ transmitter (relative to 12 kW). These possibilities are not investigated further here.

Table B2: Antenna Reductions needed for 12 kW ERP DRM+ transmitter

Azimuth	Reduction	Azimuth	Reduction
0 (360)	-4.1	180	0
10	-4.1	190	0
20	-1.9	200	-3.4
30	0	210	-3.4
40	0	220	-3.3
50	0	230	-2.5
60	0	240	0
70	0	250	-3.6
80	0	260	-3.6
90	0	270	0
100	0	280	-4.5
110	0	290	-4.5
120	0	300	0
130	-1.7	310	0
140	-3.4	320	0
150	-4.2	330	0
160	-4.2	340	0
170	-3.2	350	-4.1

Graphically the antenna diagram looks like this:

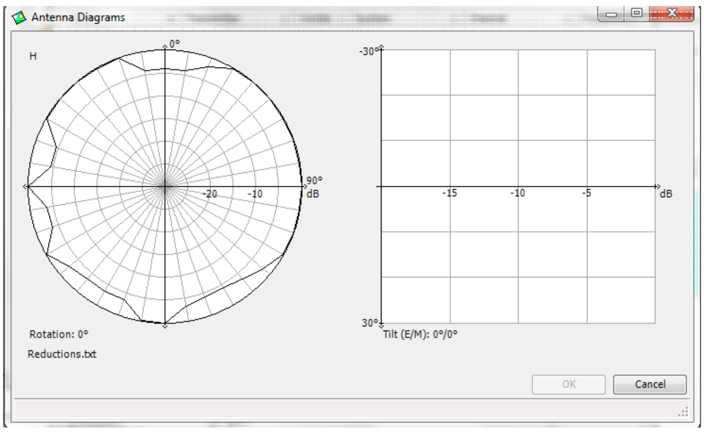


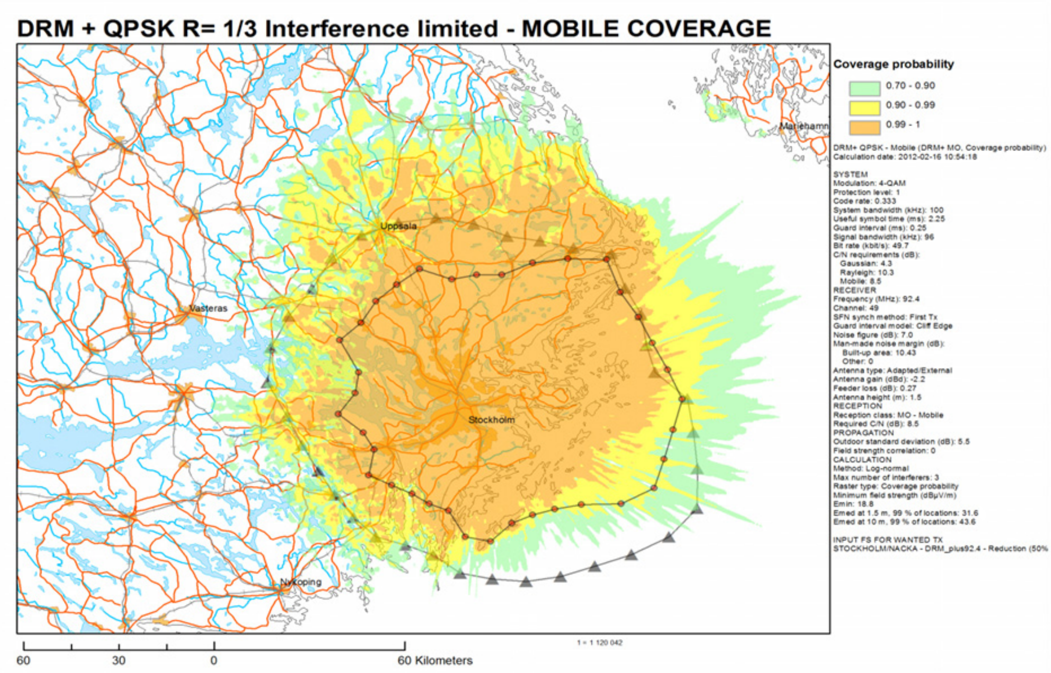
Figure B4: Antenna reductions need in order to not increase interference more than 0.5 dB.

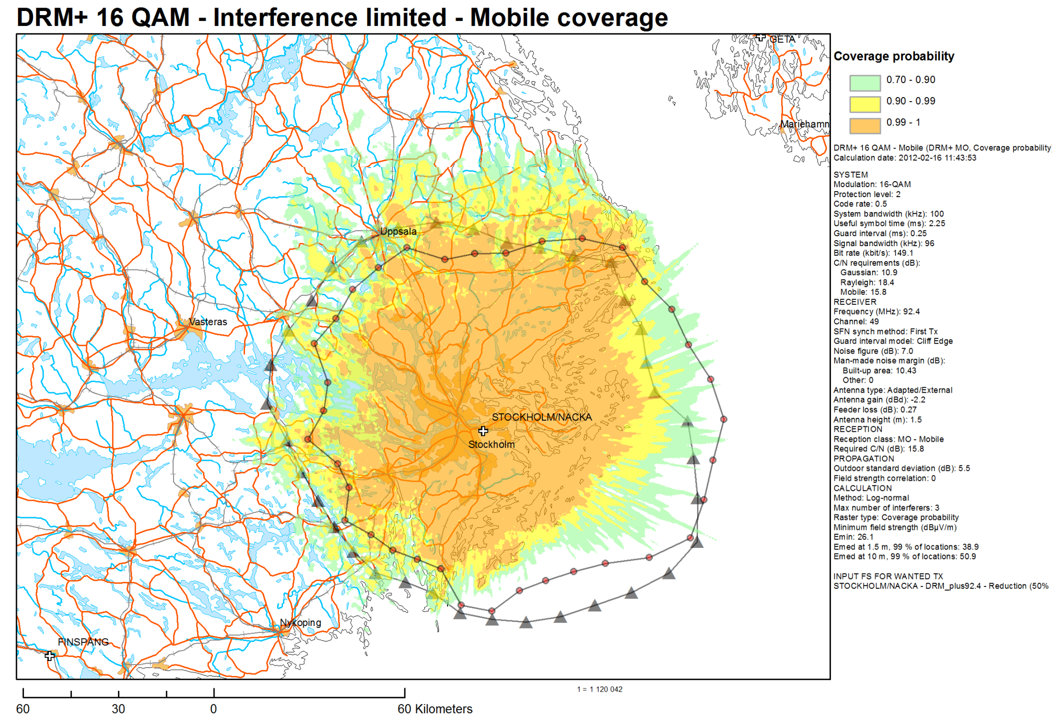
B4.4 Coverage of DRM+ Transmitter

Using the DRM+ transmitter parameter given by the compatibility analysis, the coverage contour and the terrain based coverage can be estimated for the transmitter. This is done for two DRM + modes, QPSK 1/3 and 16-QAM 2/3 for mobile, portable indoor and handheld indoor reception cases. It should perhaps be noted that the portable outdoor coverage is very similar to mobile coverage.

As a reference, the coverage contour of the FM transmitters (indicated by triangles) is given in the following plots.

B4.4.1 Mobile DRM +coverage

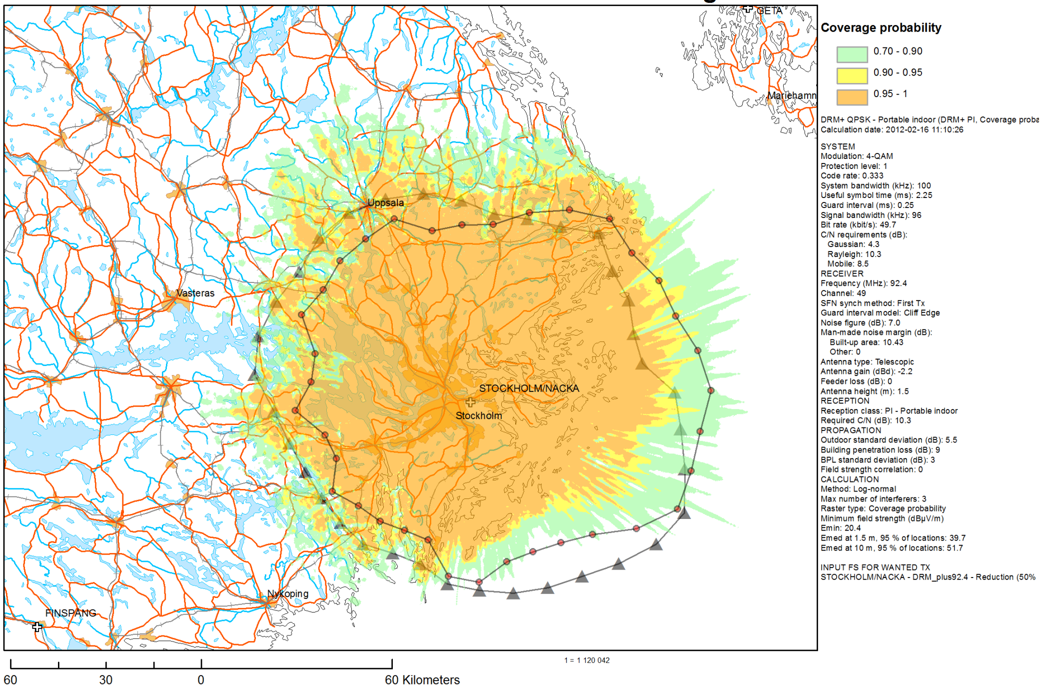




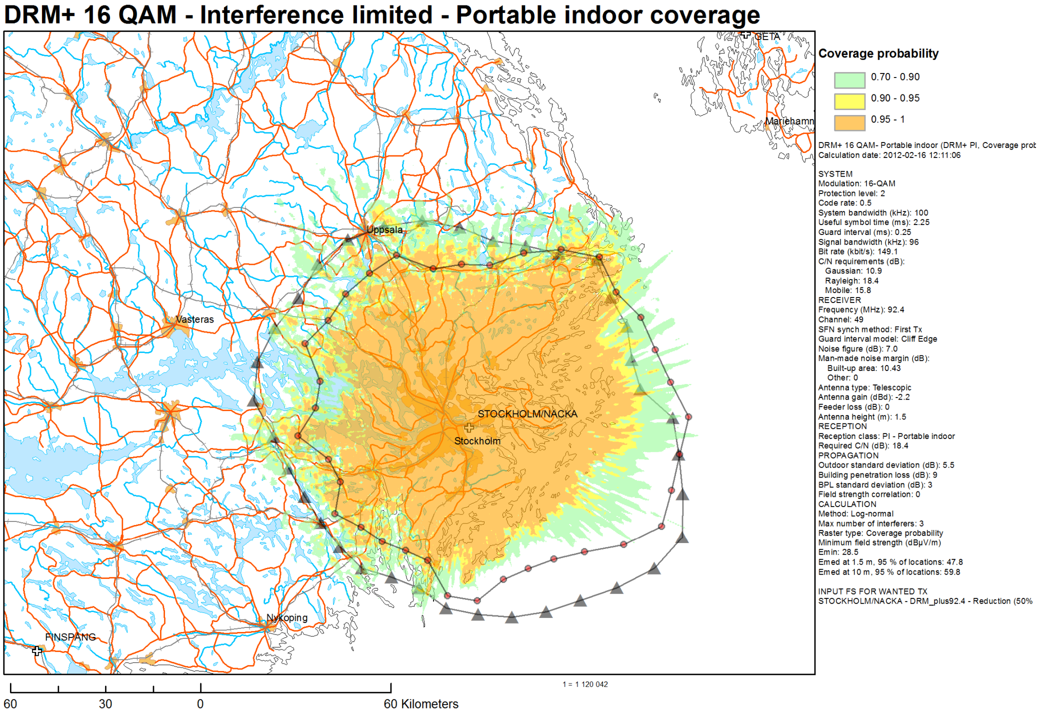
Figures B5 & B6: Coverage contour and pixel based coverage for DRM+ Transmitter QPSK 1/3 and 16-QAM Mobile reception. Population Coverage is 2.020 and 1.936 millions, resp.

B4.4.2 Portable indoor coverage

DRM+ QPSK Interference limited - Portable indoor coverage



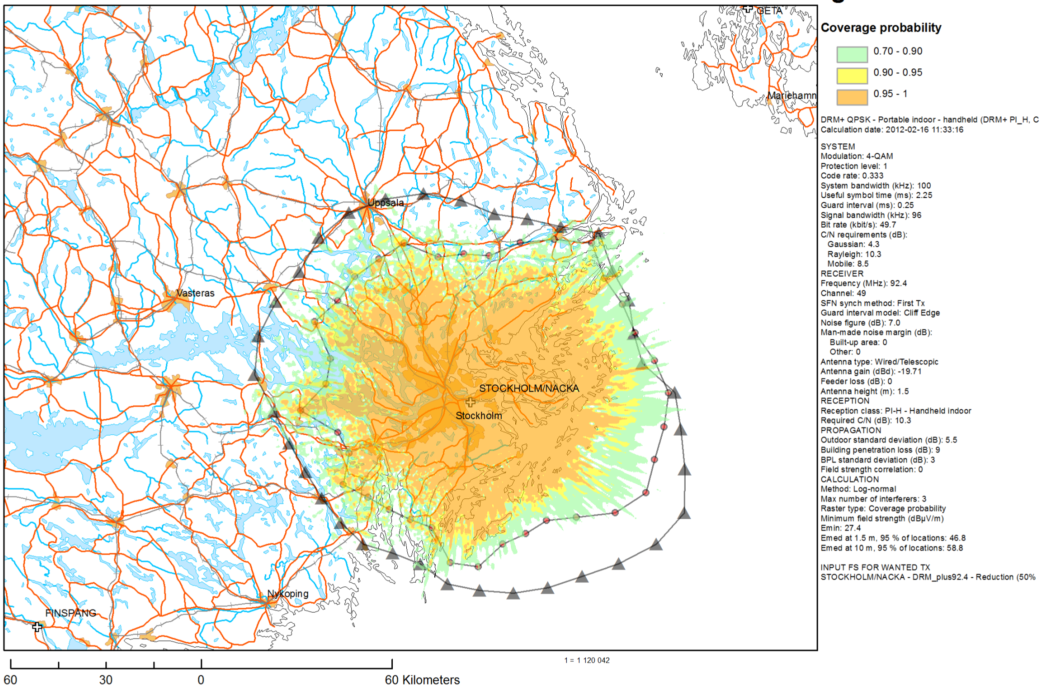
DRM+ 16 QAM - Interference limited - Portable indoor coverage



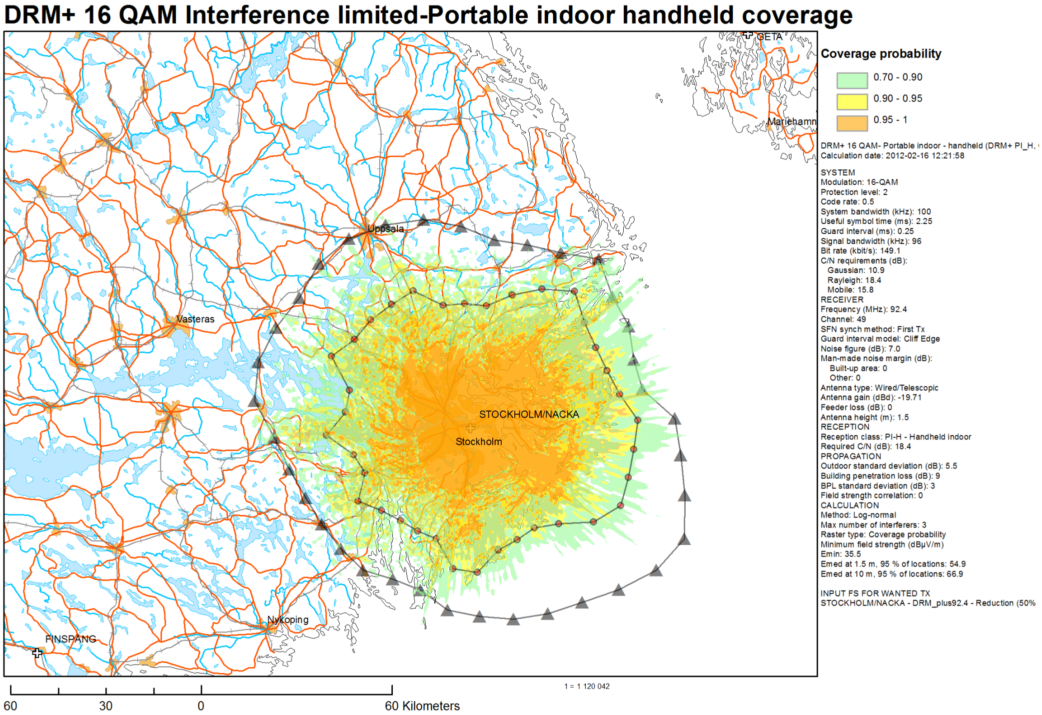
Figures B7 & B8: Coverage contour and pixel based coverage for DRM+ Transmitter QPSK 1/3 and 16-QAM Portable Indoor Coverage. Population Coverage is 1.980 and 1.861 millions, resp.

B4.4.2 Portable indoor handheld coverage

DRM+ QPSK - Interference limited - Portable indoor handheld coverage



DRM+ 16 QAM Interference limited-Portable indoor handheld coverage



Figures B9 & B10: Coverage contour and pixel based coverage for DRM+ Transmitter QPSK 1/3 and 16-QAM Portable Indoor Coverage handheld. Population Coverage is 1.843 and 1.634 millions, resp.

B4.5 Further analysis

One question to be answered is if the ERP reduction in this example is generally representative. One further example is tested in order to give an indication. It is the 60 kW ERP transmitter at 96.2 MHz at the same site which is converted to DRM+. Again an initial ERP reduction of -7 dB is assumed for the DRM+ transmitter.

This time the further ERP reductions needed are in the order of 21 dB (on top of the -7 dB) in some directions! This means that the coverage area will be very limited in this case. The following antenna reductions are found:

Azimuth	Reduction
0 (360)	-19.2
10	-16.1
20	0
30	0
40	0
50	0
60	0
70	-4.4
80	-4.4
90	0
100	0
110	0
120	0
130	0
140	0
150	0
160	0
170	0

Azimuth	Reduction
180	0
190	0
200	0
210	0
220	0
230	-16.9
240	-16.9
250	-13.1
260	-6.1
270	-15.6
280	-15.6
290	-17.9
300	-17.9
310	-19.1
320	-19.1
330	-19.1
340	-10.3
350	-11.4

Further analysis show that there is a small FM transmitter with an ERP of 150 W at 95.3 MHz using vertical polarization in downtown Stockholm. The frequency difference is 900 kHz. The protection ratio (DRM+ into FM) should be about -20 dB according to Table B1. The two coverage areas overlap.

The situation in the previous case, where the conversion from FM to DRM+ was successful, was actually not too different. The main difference was that the total nuisance field strength was higher in the first case for the victim transmissions. The consequence of this was that it was possible to convert the FM transmitter to DRM+, since the additional contribution from DRM+ was small. While in the second case the nuisance field strength was quite low resulting in a high contribution from the DRM+ transmitter. Although of course not generally proven there seems to be a bit of a paradox here. More interference, tighter frequency plan, may make it easier to convert FM transmissions into DRM+!

The result means that it may not be possible to replace an FM transmitter by DRM+ if there is another non co-located FM transmitter with overlapping coverage area within ±(400 kHz - 1 MHz) from the DRM+ frequency, using a frequency which is quite “good” in terms of nuisance field. Restrictions in the ERP may be severe. The solution in this case would be to co-locate the two transmitters!

Annex C: Planning study for DRM+ in Band II (Germany) – Part 1

The purpose of the study is to investigate the possibility of introducing a DRM+ transmitter into the FM environment in Band II. The two main options are those of introducing a new DRM+ transmitter into the existing frequency plan or of replacing an existing FM transmitter by DRM+, which is addressed in this annex *with the special condition that an existing transmitter site is used*.

The study was carried out by using a transmitter site in Frankfurt (FfM Funkhaus) which is located in Hessen/Germany (see Figure C1).

Figure C1: Location of the FfM Funkhaus transmitter site

The optimal frequency in Frankfurt was detected by means of a frequency scan. For this geographical location the lowest usable field strength is achieved with a frequency of 88.6 MHz. This frequency was therefore taken as a planning basis for the new DRM+ transmitter in the study.

New DRM+ transmitter: FfM Funkhaus 88.6 MHz (max. effective antenna height: 90m)

For the new DRM+ transmitter non directed antenna radiation patterns are assumed with an effective radiated power of 20 dBW.

First of all the compatibility of the new DRM+ transmitter with the existing FM services has to be checked. According to the GE84 agreement [C1], the introduction of a new service should not increase the usable field strength more than 0.5 dB. A compatibility analysis was carried out, based on the protection ratios FM interfered with by DRM+ given in “Planning Parameters for DRM Mode E (‘DRM+’)” [C2].

For protection ratios FM interfered with FM the table in ITU-R BS.412-9 [C3] was extended by a constant value of -40 dB from 400 kHz onwards (as given in Annex 2 of [C3]).

Based on the results of the compatibility analysis the antenna radiation patterns of the DRM+ transmitter has been modified (see Figure C2). For this study the radiation patterns are used only for a theoretical case, without consideration of any practical feasibility.

* Document source: Kerstin Pfaffinger, IRT Munich, 7 September 2012.

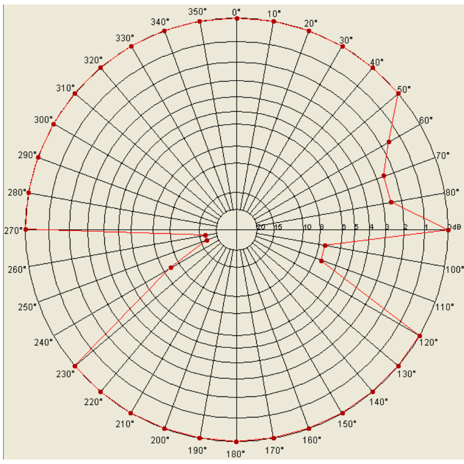


Figure C2: Radiation patterns of the new DRM+ transmitter

In spite of the modified antenna patterns there are three remaining compatibility problems: the new DRM+ transmitter is located within the interference contour of three existing FM transmitters:

1) Pfaffenberg 88.4 MHz
2) Grosser Feldberg Taunus 89.3 MHz
3) Frankfurt Funkhaus 87.9 MHz

The position of the DRM+ transmitter within the interference contours is shown in Figure C3. The first interference contour (for FM transmitter Pfaffenberg 88.4 MHz) indicates an increase of the usable field strength by more than 0.5 dB at three adjacent test points. The coverage losses for the FM service might possibly be accepted due to their location at the edge of the coverage area.

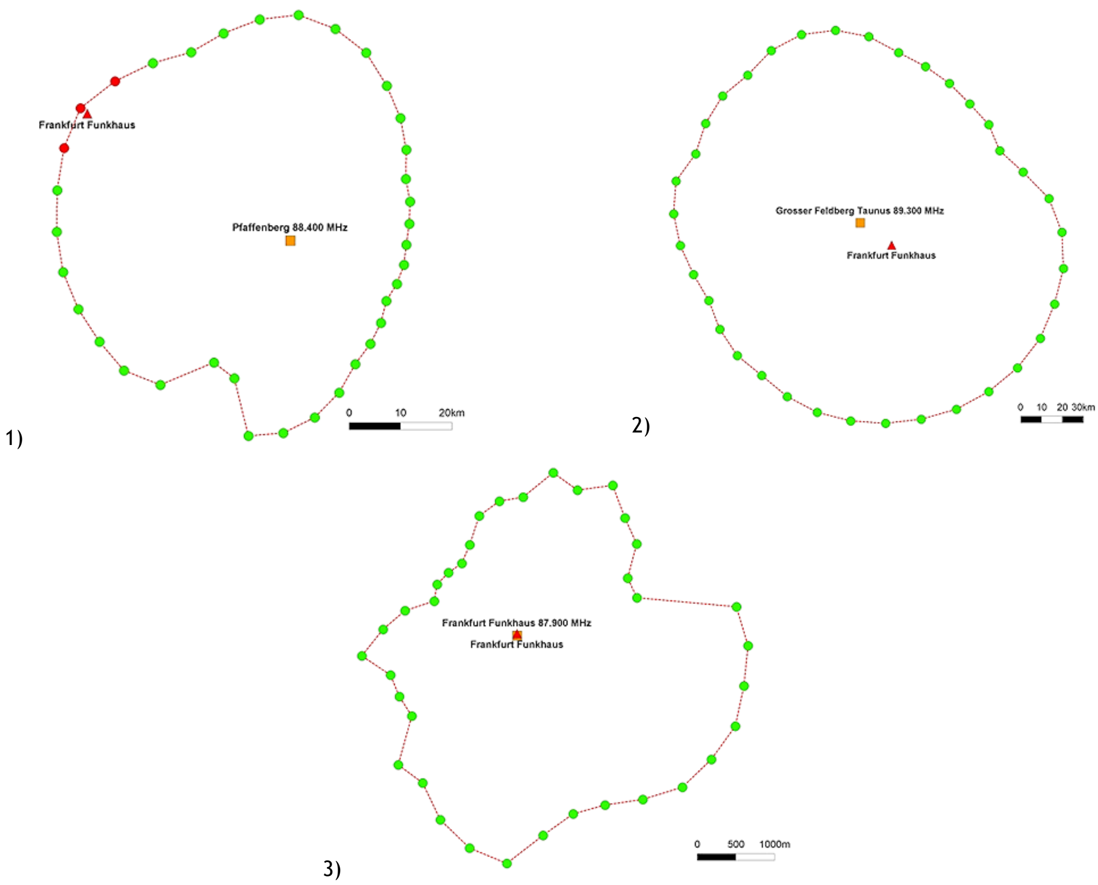


Figure C3: DRM+ transmitter and FM interference contours

Beyond that the position of the DRM+ transmitter within the interference contours is an indication for a need to take into account cross-modulation effects. If a DRM+ transmitter is located inside the coverage area of an FM transmitter, the FM service may be affected by cross-modulation effects. This topic will be dealt with in **Annex F**.

After configuring the basic transmitter characteristics of the DRM+ transmitter site on the basis of compatibility with the existing FM environment, the next step is the calculation of the achievable DRM+ service area.

The coverage area of the new DRM+ transmitter for the mobile case is shown in Figure C4. Figure C5 gives the coverage area for the portable indoor reception and Figure C6 for the portable indoor handheld reception. Planning parameters have been used according to the document "Planning Parameters for DRM Mode E ('DRM+')" [C2] from the German DRM Platform. The protection ratios DRM+ interfered with by FM are taken from **Annex A**.

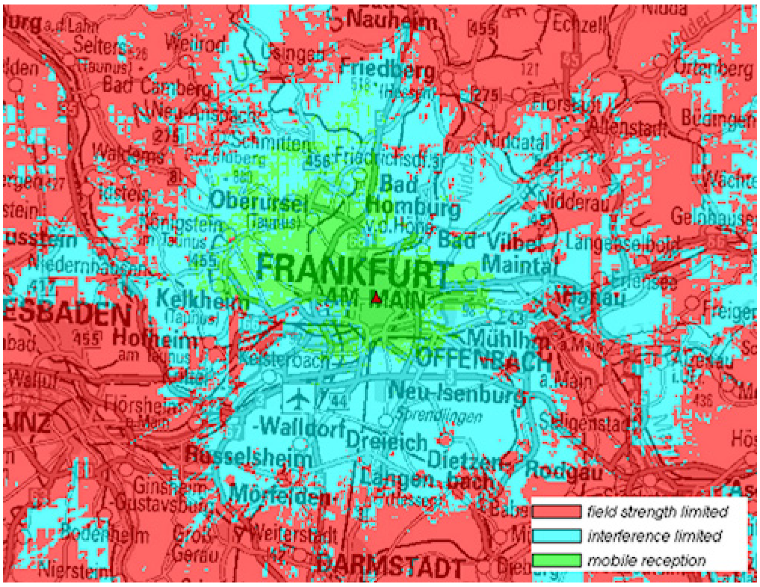


Figure C4: DRM+ mobile reception (4-QAM 1/3)

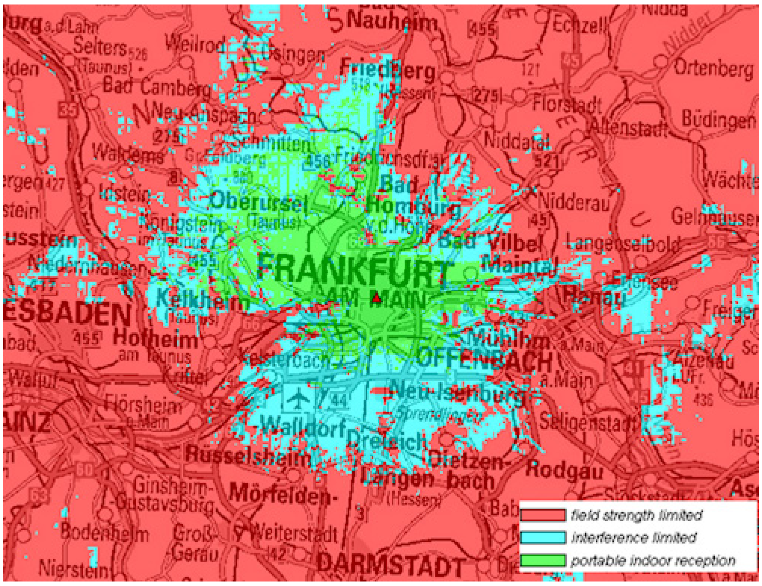


Figure C5: DRM+ portable indoor reception (4-QAM 1/3)

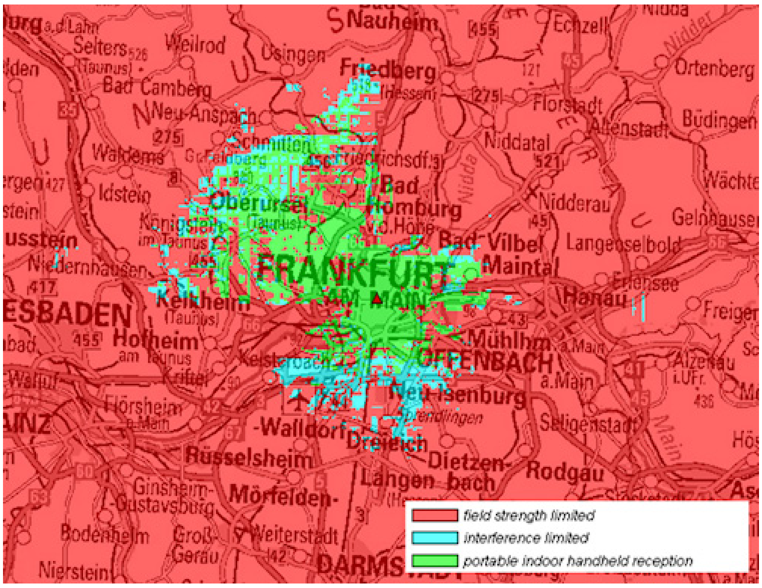


Figure C6: DRM+ portable indoor handheld reception (4-QAM 1/3)

It is obvious that the service areas of all three reception modes are about the same size due to the fact that the service areas are mainly limited by interference. However, compared to the coverage area of an equivalent FM transmitter (identical power and transmitter characteristics), the DRM+ coverage is measurably improved. Figure C7 shows the comparison DRM+ mobile reception versus FM fixed reception for the transmitter site FfM Funkhaus 88.6 MHz.

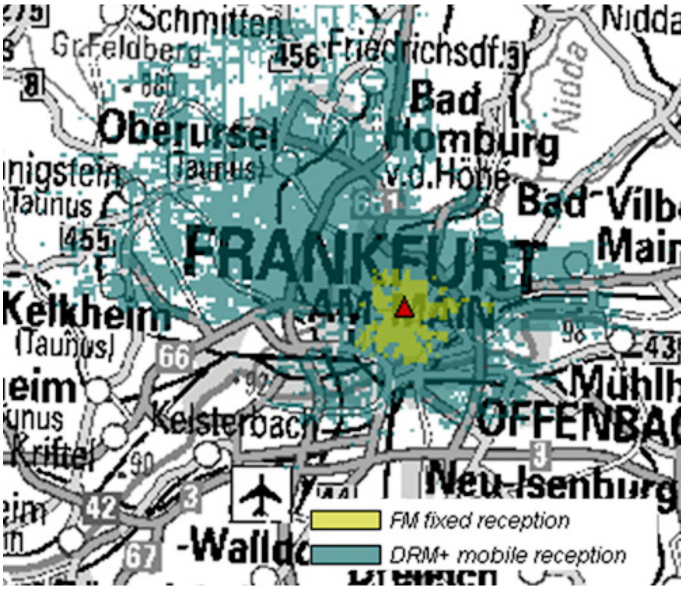


Figure C7: DRM+ mobile (4-QAM 1/3) versus FM fixed reception

Since the DRM+ transmitter characteristics are configured based on compatibility with the existing FM environment, the FM service should not be affected notably by interference from the new DRM+ transmitter. However, one remaining problem is the susceptibility of FM tuners to cross-modulation. If the new DRM+ transmitter is located within the coverage area of an FM transmitter and the maximum interfering signal levels given in **Annex A** are exceeded, the FM service is affected by cross-modulation effects. As already mentioned before, the new DRM+ transmitter is located within the interference contour of three existing FM transmitters (see Figure C3). For these FM service areas the impairment of the coverage should be checked. The frequency offsets are in the range of 0.2 MHz to 1 MHz, leading to a maximum interfering signal level of -31 dBm.

The coverage loss caused by cross-modulation is indicated in Figures C8 to C11. For a better view of the effect, Figure C10 zooms in on the relevant area of Figure C9. In the areas where the maximum interfering signal level is exceeded, the FM service is interfered by the DRM+ transmitter (purple coloured zone). It is quite obvious that an appreciable part of Frankfurt city is affected by this cross-modulation effect.

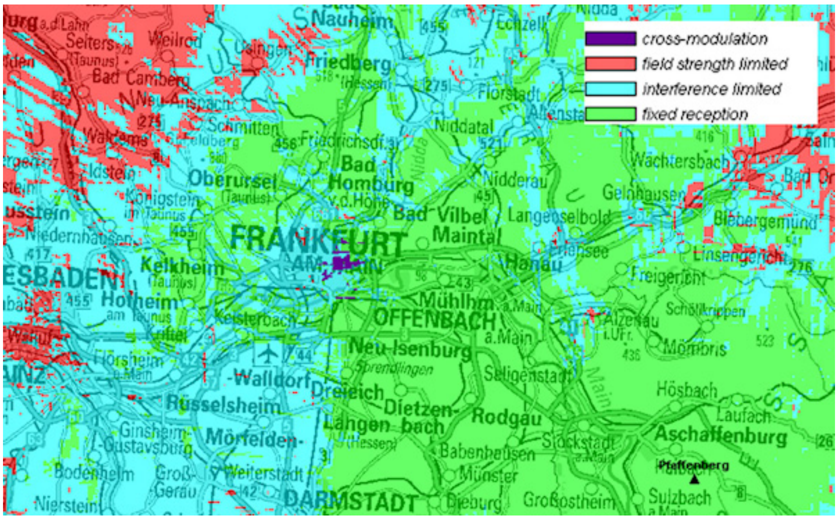


Figure C8: Cross-modulation within FM service area Pfaffenberg 88.4 MHz

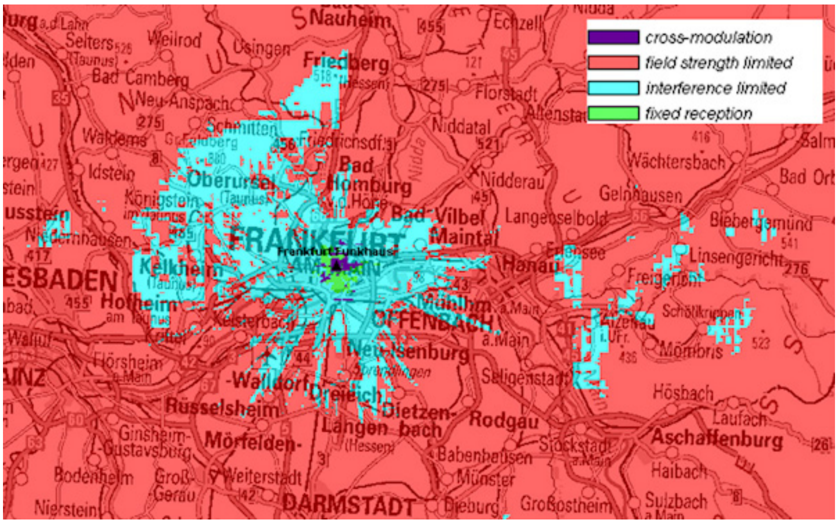


Figure C9: Cross-modulation within FM service area FfM Funkhaus 87.9 MHz

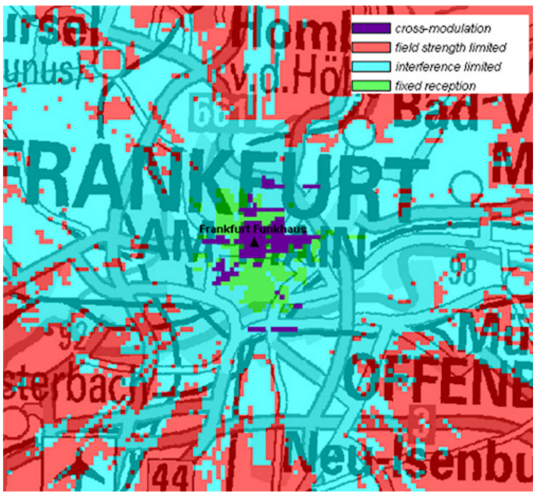


Figure C10: Extract from the relevant area of Figure C9

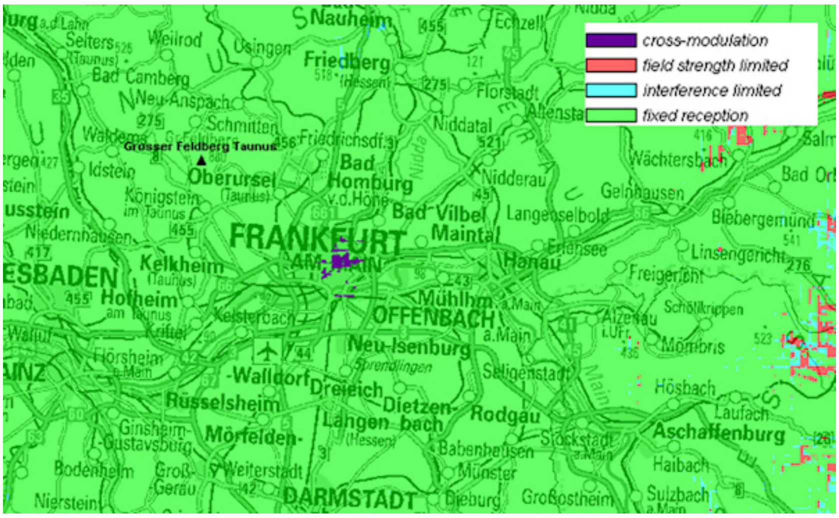


Figure C11: Cross-modulation within FM service area Grosser Feldberg 89.3 MHz

As presented in the study it is possible to introduce one single low power DRM+ station on an existing transmitter site into the FM environment without increasing excessively the usable field strength of existing FM services. The achievable coverage area for the DRM+ service is even larger than for an equivalent FM transmitter. Nevertheless, the existing FM coverage is affected notably by the new DRM+ service near by the DRM+ transmitter site due to cross-modulation effects.

A new DRM+ transmitter located at a transmitter site which is not already used for FM would be a possible alternative for further studies. Another possibility would be to replace an existing FM transmitter by a DRM+ service. Anyway, to avoid FM coverage losses due to cross-modulation effects, the new DRM+ transmitter should not be located within an FM coverage area with a frequency offset up to 4 MHz. This requirement may be quite difficult to realize in the fully occupied FM spectrum.

References

[C1] GE84: Final Acts of the Regional Administrative Conference for the Planning of VHF Sound Broadcasting, Geneva, 1984

[C2] Planning Parameters for DRM Mode E (‘DRM+’) concerning the use in VHF Bands I, II and III (V 3.0), German DRM Platform, 05/2011

[C3] Recommendation ITU-R BS. 412-9: Planning standards for terrestrial FM sound broadcasting at VHF, 12/1998

Annex D: Planning study for DRM+ in Band II (Germany) – Part 2

The purpose of the study is to investigate the possibility of introducing a DRM+ transmitter into the FM environment in Band II. The two main options are those of introducing a new DRM+ transmitter into the existing frequency plan (addressed in **Annex C**) or of replacing an existing FM transmitter by DRM+, which is addressed in this annex (also see **Annex B** for the equivalent Swedish study).

The study was carried out by using a transmitter site near Frankfurt (Grosser Feldberg Taunus) which is located in Hessen/Germany (see Figure D1). One important constraint in this study is the exposed position for the transmitter site, which is occupied by a high power FM transmitter

Figure D1: Location of transmitter site Grosser Feldberg Taunus

At the transmitter site Grosser Feldberg Taunus various FM frequencies are in operation. By means of a frequency scan the optimal frequency for the planned project was detected. The lowest usable field strength of all operating FM frequencies at this transmitter site is given by the frequency 89.3 MHz. Therefore this frequency was taken as a planning basis for the replaced transmitter in the study.

Original FM transmitter site/new DRM+ transmitter site: Grosser Feldberg Taunus 89.3 MHz (max. effective antenna height: 768 m)

The original FM transmitter has an effective radiated power of 50 dBW with non directed antenna radiation patterns. In the first instance, the new DRM+ transmitter was also assumed with non directed antenna radiation patterns but with a reduced effective radiated power of 40 dBW. This transmitter power is an arbitrary assumption based on the reference value of a typical DAB transmitter.

First of all the compatibility of the new DRM+ transmitter with the existing FM services has to be checked. According to the GE84 agreement [D1], the introduction of a new service should not increase the usable field strength more than 0.5 dB. A compatibility analysis was carried out, based on the protection ratios FM interfered with by DRM+ given in "Planning Parameters for DRM Mode E ('DRM+')" [D2].

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* Document source: Kerstin Pfaffinger, IRT Munich, 10 September 2012.

For protection ratios FM interfered with FM the table in ITU-R BS.412-9 [D3] was extended by a constant value of -40 dB from 400 kHz onwards (as given in Annex 2 of [D3]).

Based on the results of the compatibility analysis the antenna radiation patterns of the DRM+ transmitter has been modified (see Figure D2). For this study the radiation patterns are used only for a theoretical case, without consideration of any practical feasibility.

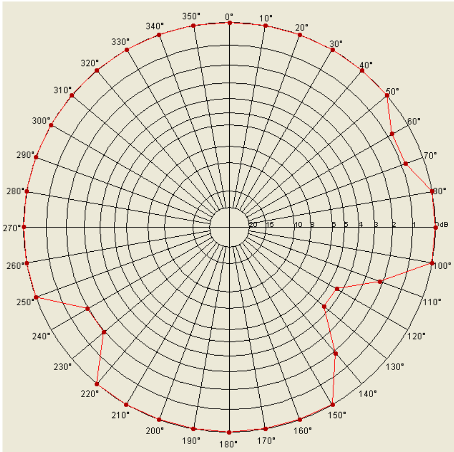


Figure D2: Radiation patterns of the new DRM+ transmitter

After configuring the basic transmitter characteristics of the DRM+ transmitter site on the basis of compatibility with the existing FM environment, the next step is the calculation of the achievable DRM+ service area.

The coverage area of the new DRM+ transmitter for the mobile case is shown in Figure D3.

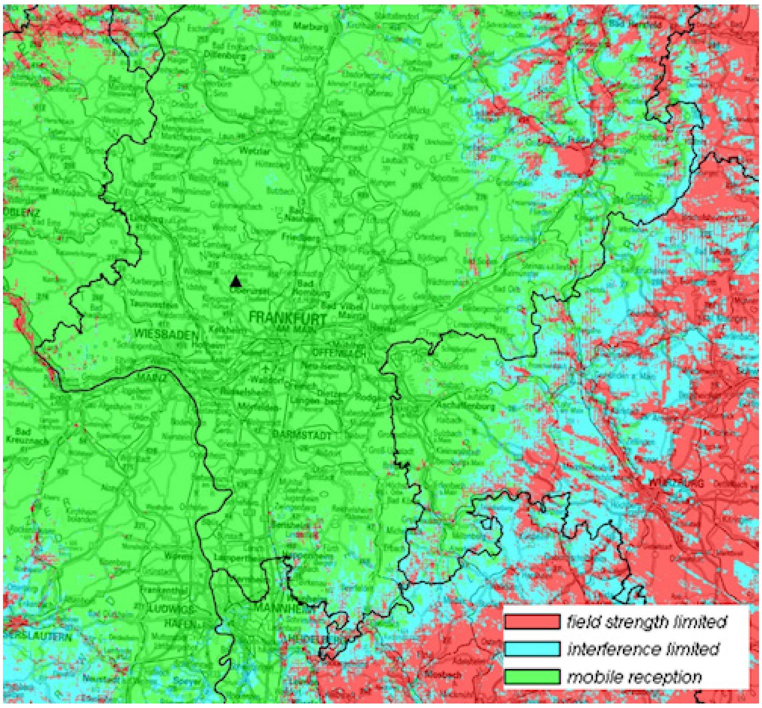


Figure D3: DRM+ mobile reception (4-QAM 1/3)

Figure D4 gives the coverage area for the portable indoor reception and Figure D5 for the portable indoor handheld reception. Planning parameters have been used according to [D2], from the German DRM Platform. The protection ratios DRM+ interfered with by FM are taken from **Annex A.**

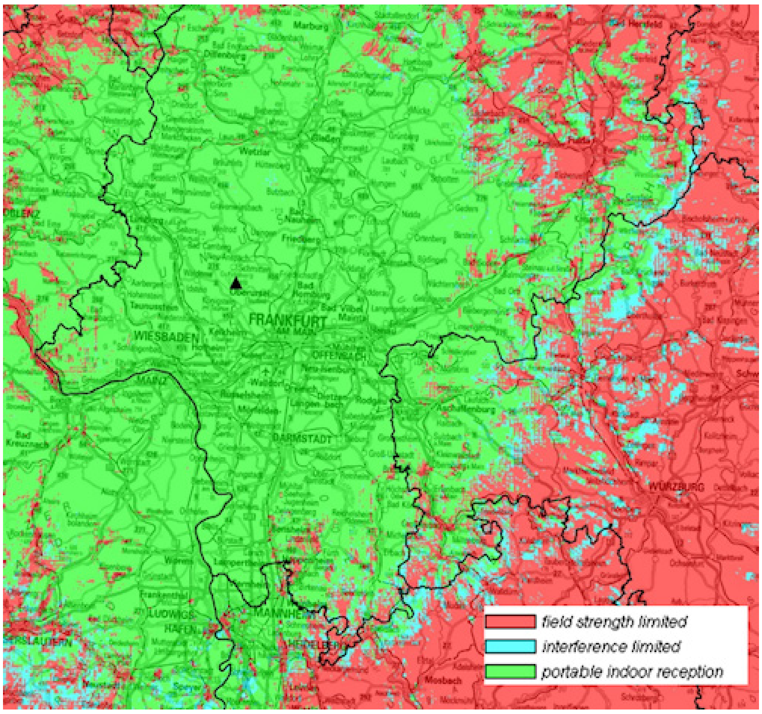


Figure D4: DRM+ portable indoor reception (4-QAM 1/3)

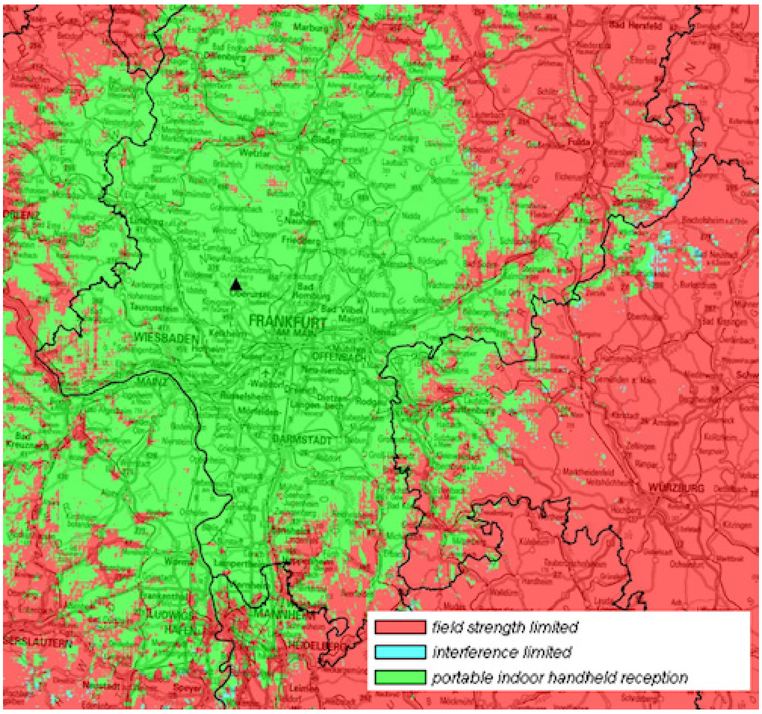


Figure D5: DRM+ portable indoor handheld reception (4-QAM 1/3)

It is obvious that the service areas of all three reception modes are nearly about the same size due to the fact that the service areas are mainly limited by interference. Even though the DRM+ power is reduced by 10 dB compared to the original FM transmitter the DRM+ coverage is comparable to the FM coverage. Figure D6 shows the comparison DRM+ mobile reception versus FM fixed reception for the transmitter site Grosser Feldberg Taunus 89.3 MHz.

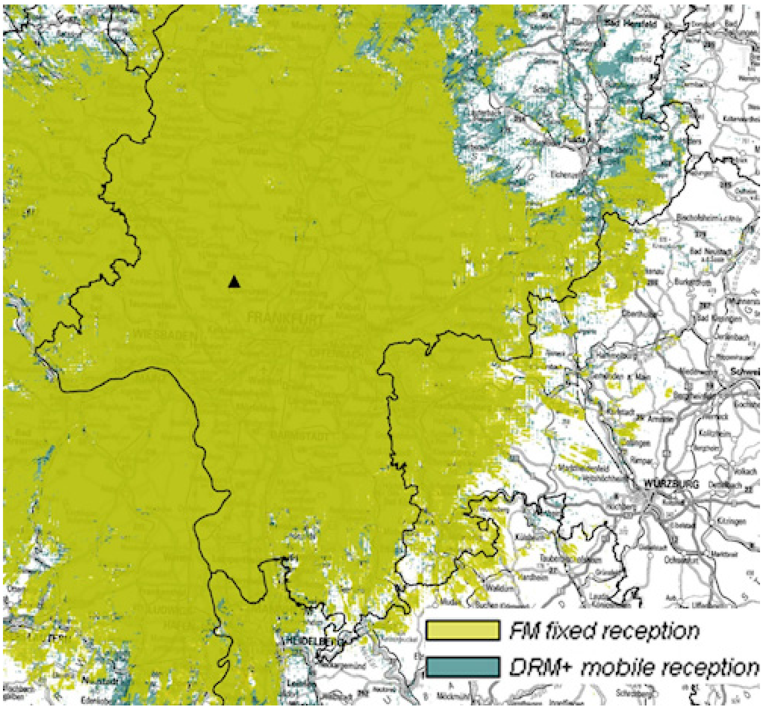


Figure D6: DRM+ mobile (4-QAM 1/3) versus FM fixed reception

Since the DRM+ transmitter characteristics are configured based on compatibility with the existing FM environment, the FM service should not be affected notably by interference from the new DRM+ transmitter. However, one remaining problem is the susceptibility of FM tuners to cross-modulation. If the new DRM+ transmitter is located within the coverage area of an FM transmitter and the maximum interfering signal levels given in **Annex A** are exceeded, the FM service is affected by cross-modulation effects. Figure D7 shows the regions potentially affected by cross-modulation caused by the new DRM+ transmitter. The Figure shows four areas depending on the maximum interfering signal level of the new DRM+ transmitter as given in the following table (included in Figure A1 from **Annex A**):

Maximum interfering signal levels

Frequency offset	[MHz]	0.2 - 1	2	3	4
Maximum interfering signal level	[dBm]	-31	-24	-16	-9

The FM transmitters up to a frequency offset of 4 MHz (grey transmitter icons in Figure D7) have been checked with respect to cross-modulation problems.

There is one FM transmitter located directly in the vicinity of the new DRM+ transmitter (Glashuetten Taunus 93.2 MHz), but the frequency offset is very high. Its interference contour is indicated in Figure D7; it does not touch the relevant region for cross-modulation effects.

Moreover, there is one FM transmitter (Frankfurt 90.4 MHz) whose interference contour touches the corresponding cross-modulation region. However, the affected region is at the edge of the coverage area (also indicated in Figure D7), which seems to be negligible.

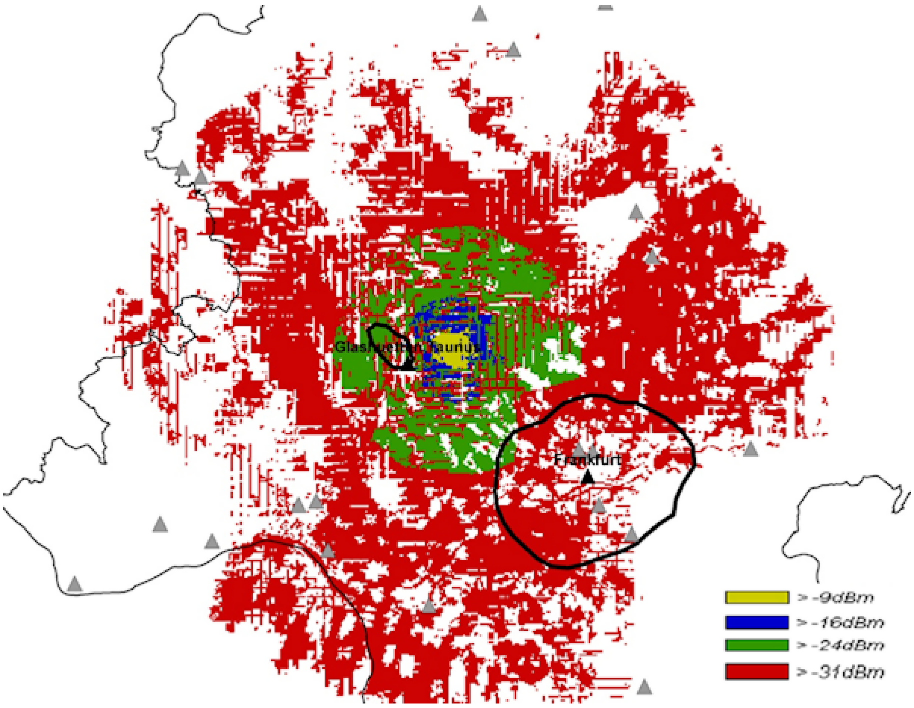


Figure D7: Regions potentially affected by cross-modulation

As presented in the study it is possible to replace one single high power FM transmitter at an exposed position by a DRM+ station. If an appropriate reduction of the DRM+ power is realized, the operation of the DRM+ service is feasible without increasing excessively the usable field strength of existing FM services. In spite of the power reduction the achievable coverage area for the DRM+ service is comparable with the coverage of the original high power FM transmitter.

The impact of cross-modulation effects on the existing FM transmitters is low for this presented case. One reason for this could be the fact that there are usually no further transmitters in the direct vicinity (geographical and by frequency) of such an exposed high power station. That could produce some relaxation with regard to cross-modulation problems. Anyway, to avoid entirely FM coverage losses due to cross-modulation effects, the new DRM+ transmitter should not be located within an FM coverage area with a frequency offset up to 4 MHz. This requirement may be quite difficult to realize in the fully occupied FM spectrum.

References

[D1] GE84: Final Acts of the Regional Administrative Conference for the Planning of VHF Sound Broadcasting, Geneva, 1984

[D2] Planning Parameters for DRM Mode E (‘DRM+’) concerning the use in VHF Bands I, II and III (V 3.0), German DRM Platform, 05/2011

[D3] Recommendation ITU-R BS.412-9: Planning standards for terrestrial FM sound broadcasting at VHF, 12/1998

Annex E: Planning study for DRM+ in Band II (Germany) – Part 3

E1. Introduction

The Swedish study described in **Annex B** analyzes the feasibility of replacing an existing high power FM transmitter by DRM+. The results of this study point to the possible assumption that more interference and a tighter frequency plan may paradoxically make it easier to convert FM transmissions into DRM+.

The scope of the present study is to investigate this assumption. For this purpose two different FM frequencies operating at the same transmitter site were chosen, keeping the important constraint that one of them is affected by low and the other by high usable field strength. The study was carried out by using a transmitter site in Giessen which is located in Hessen/Germany (see Figure E1).

Figure E1: Location of transmitter site Giessen

At the transmitter site Giessen various FM frequencies are in operation. The most suitable frequencies for the intended purpose were detected by means of a frequency scan. The lowest usable field strength of all operating FM frequencies at this transmitter site is achieved by the frequency 93.7 MHz. One frequency indicated by achieving very high usable field strength is 99.2 MHz. Therefore these two frequencies have been taken as a planning basis for the study.

Original FM / new DRM+ transmitter site: Giessen (max. effective antenna height: 169 m)

1) original FM frequency consistent with low usable field strength: 93.7 MHz

2) original FM frequency consistent with high usable field strength: 99.2 MHz

[*] Document source: Kerstin Pfaffinger, IRT Munich, 10 September 2012.

E2. Analysis part 1: low usable field strength

The original FM transmitter at 93.7 MHz has an effective radiated power of 500 W, which has been kept for the new DRM+ transmitter. In the first instance, the new DRM+ transmitter was assumed to have a non directed antenna radiation pattern even though the original FM transmitter has some antenna reductions.

First of all the compatibility of the new DRM+ transmitter with the existing FM services has to be checked. According to the GE84 agreement [E1], the introduction of a new service should not increase the usable field strength more than 0.5 dB. A compatibility analysis was carried out, based on the protection ratios FM interfered with by DRM+ given in "Planning Parameters for DRM Mode E ('DRM+')" [E2] from the German DRM Platform.

For protection ratios FM interfered with FM the table in ITU-R BS.412-9 [E3] was extended by a constant value of -40 dB from 400 kHz onwards (as given in Annex 2 of [E3]).

Based on the results of the compatibility analysis the antenna radiation patterns of the DRM+ transmitter has been modified (see Figure E2). For this study the radiation patterns are used only for a theoretical case, without consideration of any practical feasibility. The analyzed DRM+ transmitter is characterized by low usable field strength from the existing FM environment. It is obvious that the required reductions for the new DRM+ transmitter are quite strong, the reductions are up to 14.5 dB. This result seems to be in accordance with the assumption from **Annex B**, keeping in mind that the study is done for one exemplary transmitter site.

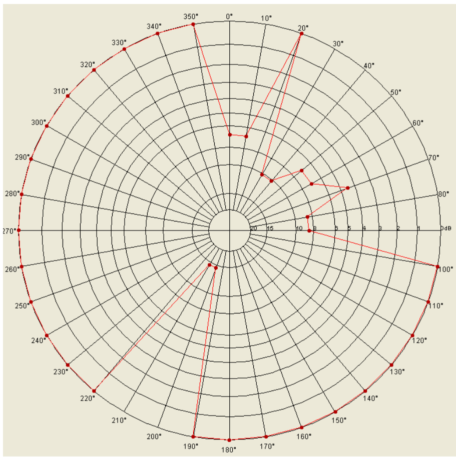


Figure E2: Radiation patterns of the new DRM+ transmitter Giessen 93.7 MHz

After configuring the basic transmitter characteristics of the DRM+ transmitter site on the basis of compatibility with the existing FM environment, the next step is the calculation of the achievable DRM+ service area.

The coverage area of the new DRM+ transmitter for the mobile case is shown in Figure E3. Figure E4 gives the coverage area for the portable indoor reception and Figure E5 for the portable indoor handheld reception. Planning parameters have been used according to [E2] from the German DRM Platform. The protection ratios DRM+ interfered with by FM are taken from **Annex A**.

It is obvious that the service areas of all three reception modes are about the same size due to the fact that the service areas are mainly limited by interference.

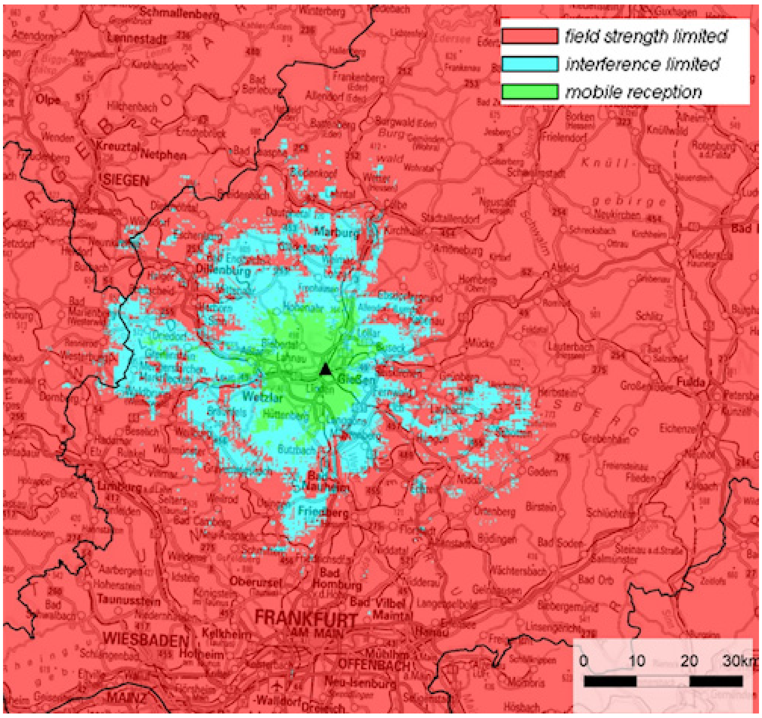


Figure E3: DRM+ mobile reception (4-QAM 1/3)

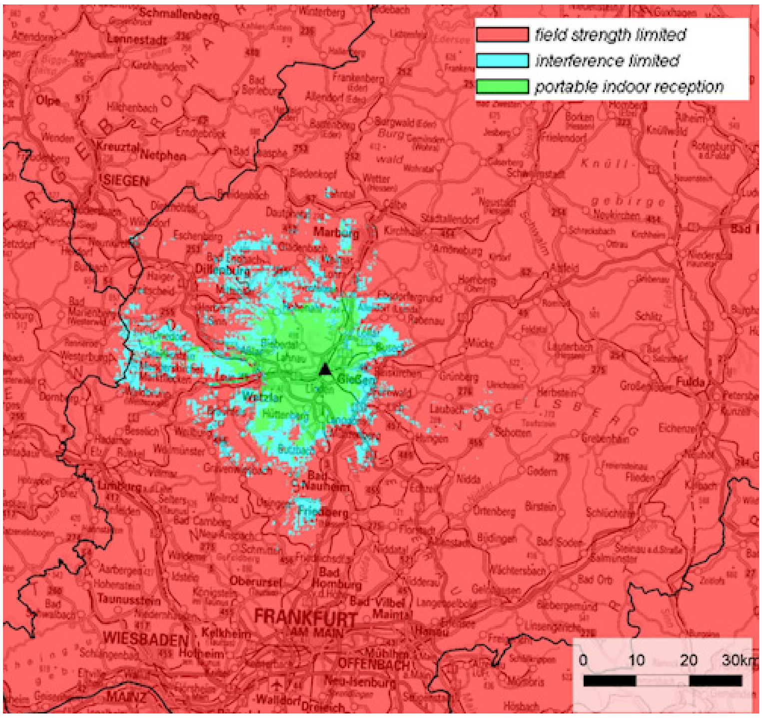


Figure E4: DRM+ portable indoor reception (4-QAM 1/3)

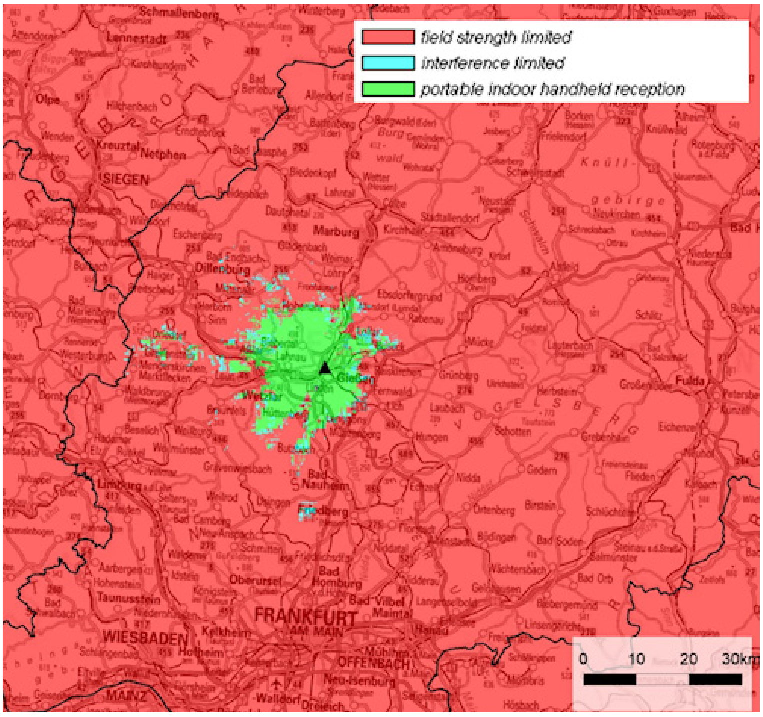


Figure E5: DRM+ portable indoor handheld reception (4-QAM 1/3)

Since the DRM+ transmitter characteristics are configured based on compatibility with the existing FM environment, the FM service should not be affected notably by interference from the new DRM+ transmitter. However, one remaining problem is the susceptibility of FM tuners to cross-modulation. If the new DRM+ transmitter is located within the coverage area of an FM transmitter and the maximum interfering signal levels given in **Annex A** are exceeded, the FM service is affected by cross-modulation effects.

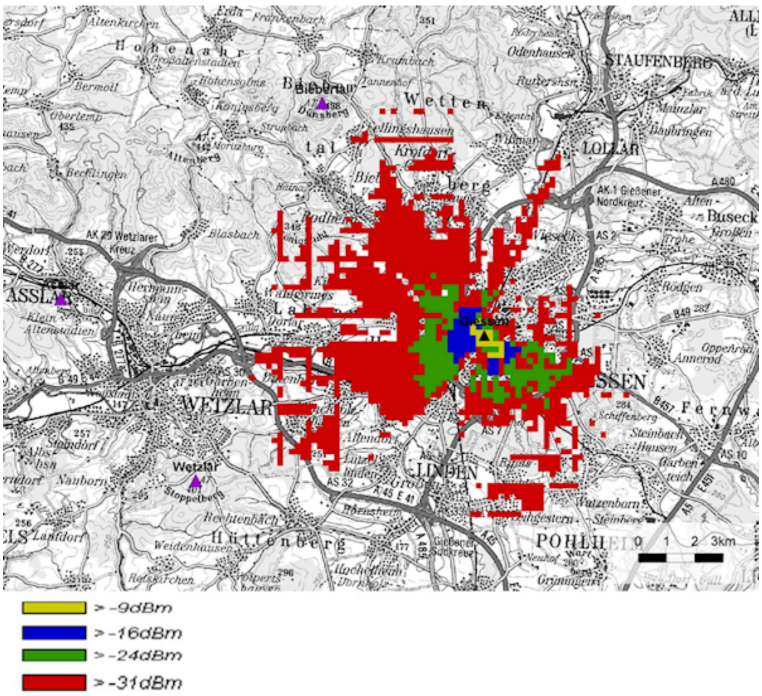


Figure E6: Regions potentially affected by cross-modulation

Figure E6 shows the regions potentially affected by cross-modulation caused by the new DRM+ transmitter. The Figure shows four areas depending on the maximum interfering signal level of the new DRM+ transmitter as given in Table E1 (same as Table A3):

Table E1: Maximum interfering signal levels for FM interfered with by DRM+

Frequency offset	[MHz]	0.2 - 1	2	3	4
Maximum interfering signal level	[dBm]	-31	-24	-16	-9

The FM transmitters up to a frequency offset of 4 MHz have been checked with respect to cross-modulation problems. There are many FM transmitters whose interference contours surround or touch the corresponding cross-modulation region, within which the FM services could be affected by cross-modulation effects.

Three FM transmitters located directly in the vicinity of the new DRM+ transmitter are indicated 'exemplary' in Figure E6 by purple (triangles). Their interference contours are plotted in Figures E7 to Figure E9. In addition, the potentially affected regions are indicated in these figures according to the colour keys given in Table E1, depending on the frequency offset between FM transmitter and DRM+ transmitter. It is obvious that sizeable parts of the original FM coverage areas may be bothered by cross-modulation effects, especially for FM transmitters with small frequency offsets.

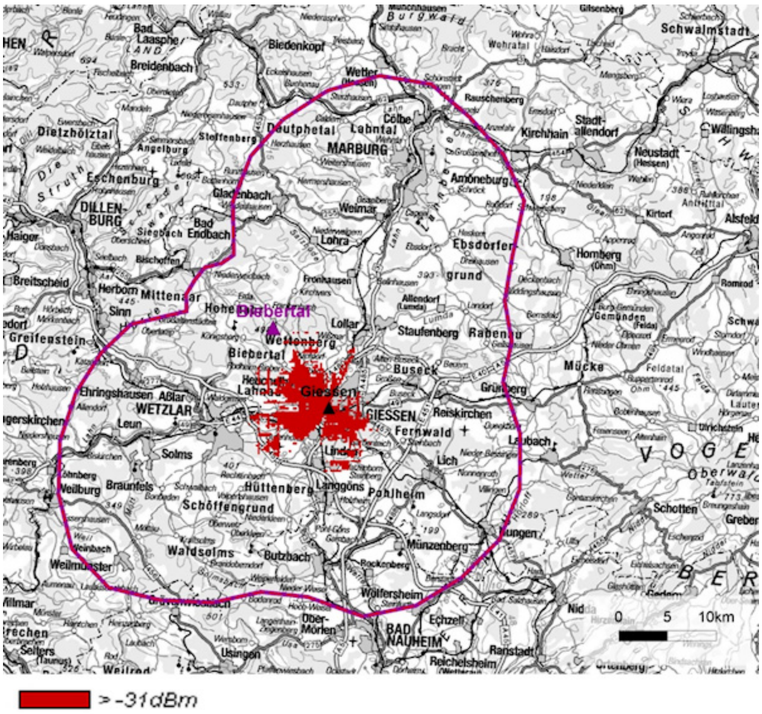


Figure E7: Interference contour of FM transmitter Biebertal 92.6 MHz

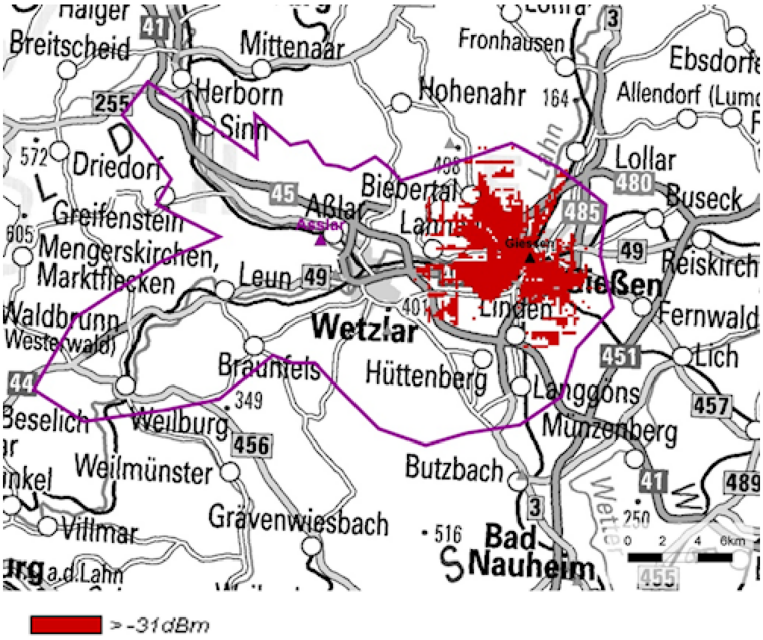


Figure E8: Interference contour of FM transmitter Asslar 93.2 MHz

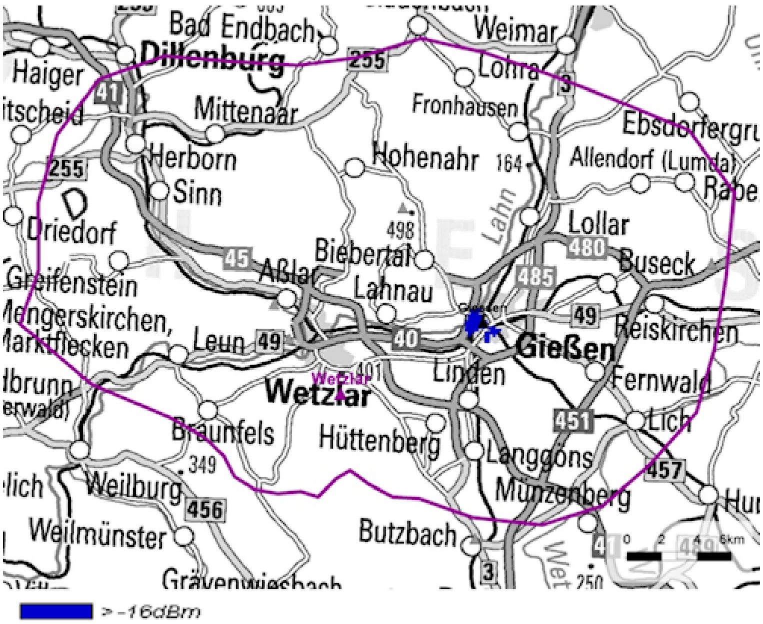


Figure E9: Interference contour of FM transmitter Wetzlar 90.5 MHz

E3. Analysis part 2: high usable field strength

The original FM transmitter at 99.2 MHz has an effective radiated power of 200 W, which has been increased to 500 W for the new DRM+ transmitter, to be in line with the power of the transmitter from the 'analysis part 1'. In the first instance, the new DRM+ transmitter was assumed to have a non directed antenna radiation patterns even though the original FM transmitter has some antenna reductions.

As the procedure undertaken in this 'analysis part 2' is the same as that for 'analysis part 1' only the results from the second analysis are presented here.

E3.1 Compatibility Analysis

The first step is the compatibility analysis; based on the results of this the antenna radiation patterns of the DRM+ transmitter were modified (see Figure E10). The analyzed DRM+ transmitter is characterized by high usable field strength from the existing FM environment. The required reductions for the new DRM+ transmitter are noticeable smaller than for the transmitter in the 'analysis part 1'. The reductions are up to 7.6 dB; half the amount of the reductions for the transmitter above. That result seems to be in accordance with the assumption from **Annex B**, keeping in mind that the study is done for one exemplary transmitter site.

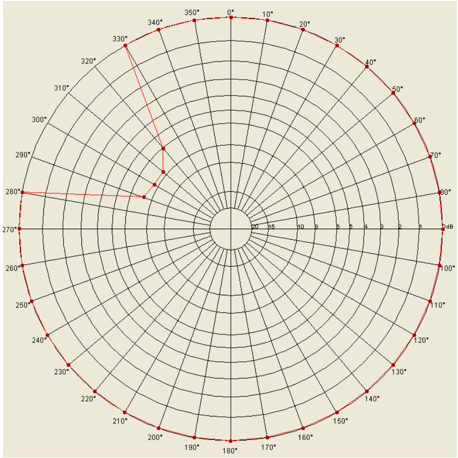


Figure E10: Radiation patterns of the new DRM+ transmitter Giessen 99.2 MHz

E3.2 Calculation of the achievable DRM+ service area

The coverage area of the new DRM+ transmitter for the mobile case is shown in Figure E11. Figure E12 gives the coverage area for the portable indoor reception and Figure E13 for the portable indoor handheld reception. As well the service areas of all three reception modes are nearly about the same size due to the fact that the service areas are mainly limited by interference.

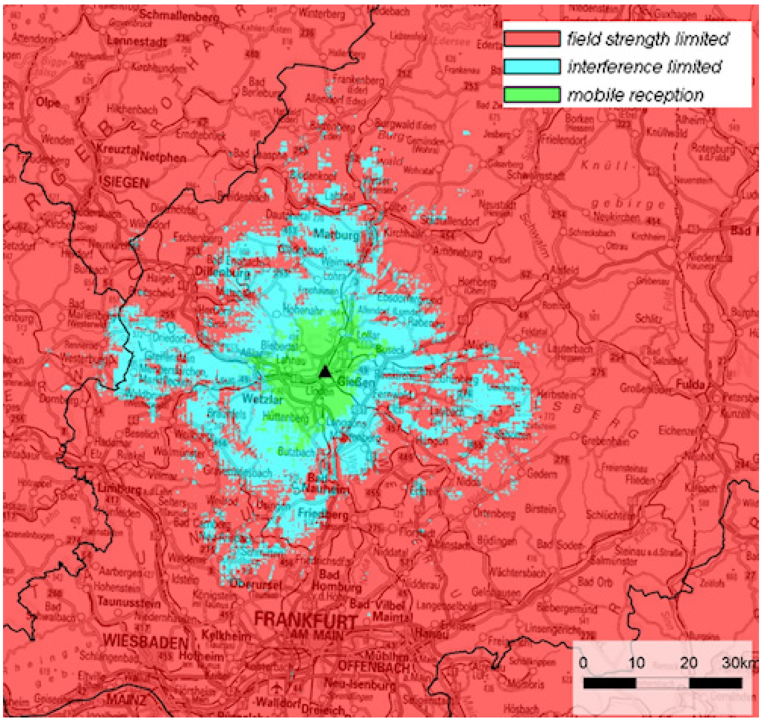


Figure E11: DRM+ mobile reception (4-QAM 1/3)

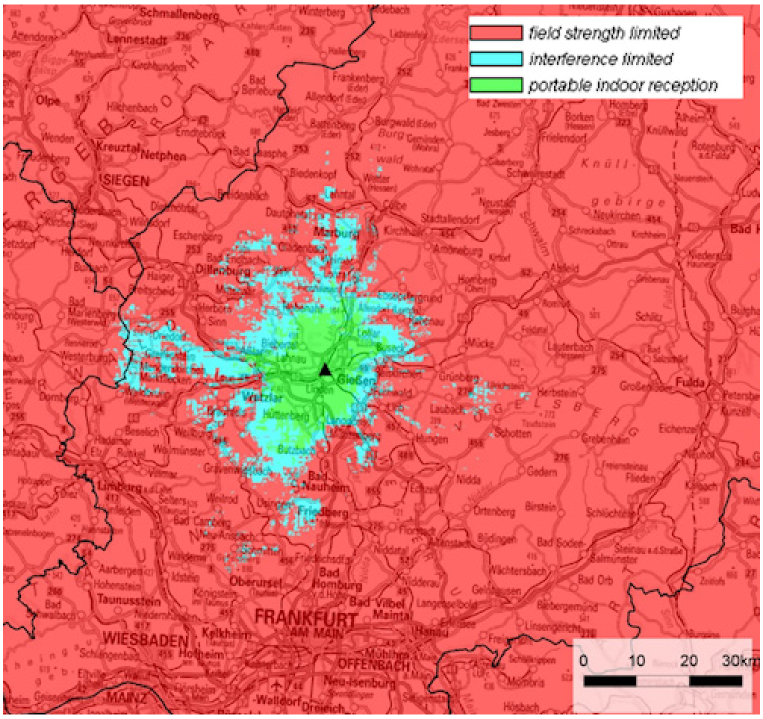


Figure E12: DRM+ portable indoor reception (4-QAM 1/3)

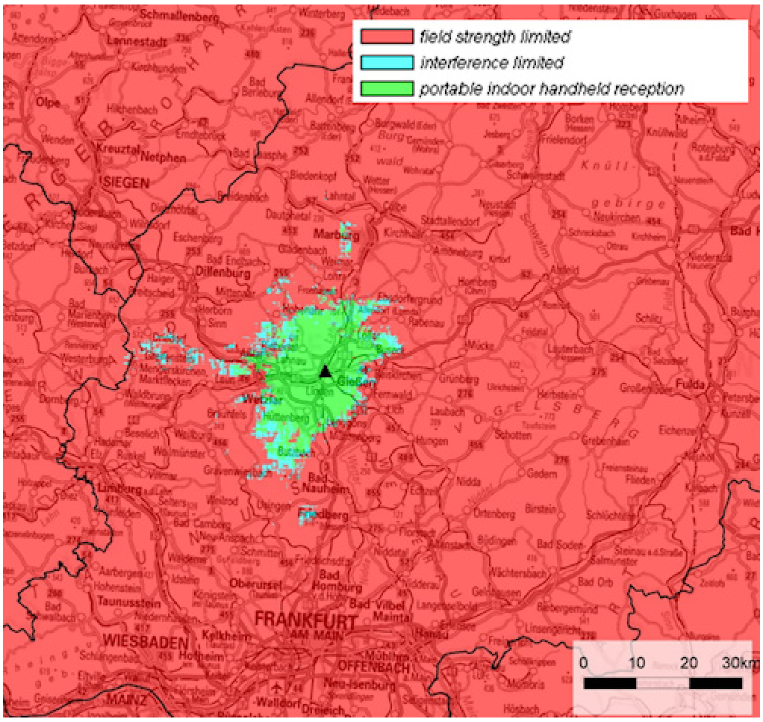


Figure E13: DRM+ portable indoor handheld reception (4-QAM 1/3)

E3.3 The analysis of cross-modulation effects

The analysis of cross-modulation effects has been carried out for the new DRM+ transmitter. Figure E14 shows the regions potentially affected by cross-modulation, according to the colour keys given in Table E1.

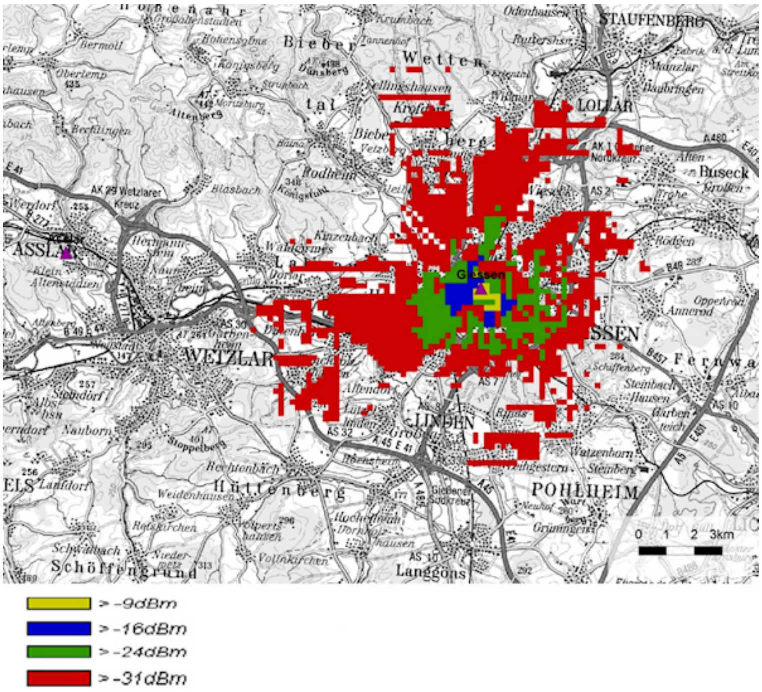


Figure E14: Regions potentially affected by cross-modulation

The FM transmitters up to a frequency offset of 4 MHz have been checked with respect to cross-modulation problems. There are again many FM transmitters whose interference contours surround or touch the corresponding cross-modulation region, within which the FM services could be affected by cross-modulation effects. One FM transmitter located directly in the vicinity of the new DRM+ transmitter is indicated 'exemplary' in Figure E14 by purple (triangles). Beyond that there are three FM services operating at the new Giessen DRM+ transmitter site within the 4 MHz offset, which are certainly affected by cross-modulation effects caused by the new DRM+ transmitter.

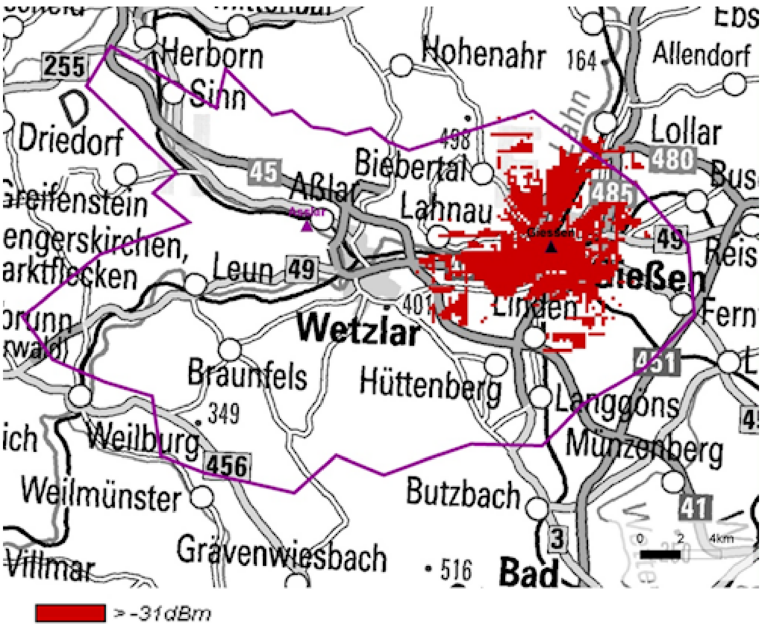


Figure E15: Interference contour of FM transmitter Asslar 100.5 MHz

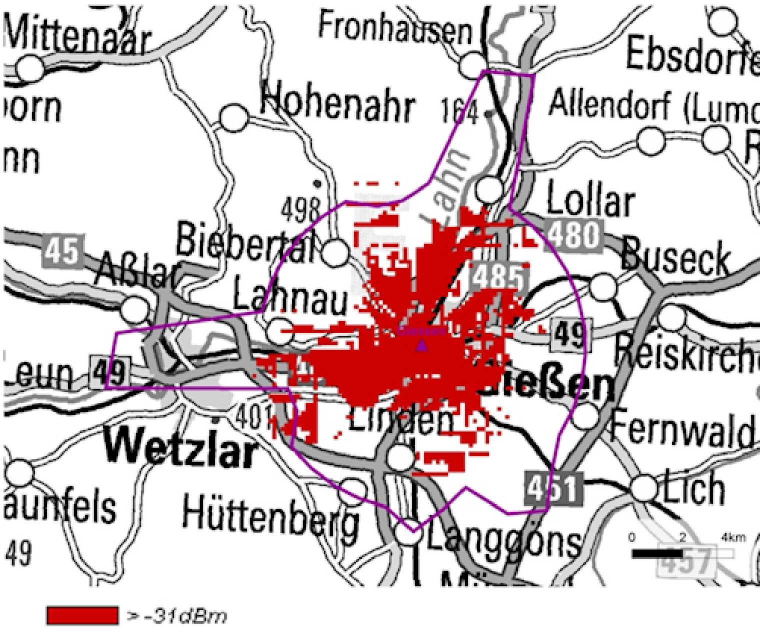


Figure E16: Interference contour of FM transmitter Giessen 97.9 MHz

Two 'exemplary' interference contours are plotted in Figures E15 and Figure E16. In addition, the potentially affected regions are indicated in these figures according to the colour keys given in Table E1, depending on the frequency offset between FM transmitter and DRM+ transmitter. It is obvious that sizeable parts of the original FM coverage areas may be bothered by cross-modulation effects.

E4. Conclusions

The scope of the study was to investigate the possible assumption from the results of **Annex B** that more interference and a tighter frequency plan may make it easier to convert FM transmissions into DRM+. For this purpose two different FM frequencies operating at the same transmitter site were chosen, keeping the important constraint that one of them is affected by low and the other one by high usable field strength.

The most relevant aspect for this assumption is the compatibility analysis, which checks the effects of the new DRM+ transmitter on the FM environment with regard to protection ratios and usable field strength. One analyzed DRM+ transmitter was characterized by low usable field strength from the existing FM environment. The required reductions for this new DRM+ transmitter were quite strong. The other analyzed DRM+ transmitter was characterized by high usable field strength. The required reductions for that new DRM+ transmitter were noticeable smaller than for the transmitter checked before. Regarding the compatibility analysis the conversion to DRM+ is less critical in an FM environment characterized by high usable field strength than in an FM environment with low usable field strength. These results seem to be in accordance with the assumption from above, keeping in mind that the study was done for only one exemplary transmitter for each case.

The achievable coverage areas for the new DRM+ transmitters are comparable in both the cases analyzed.

The study has shown another important effect on compatibility with the FM environment; the impact of cross-modulation on the existing FM service.

It is obvious that many FM service areas are perceptibly affected by cross-modulation from the new DRM+ transmitter. This effect is essentially independent of the present level of usable field strength. The intensity of the cross-modulation effect basically depends on the signal level of the new DRM+ transmitter and the frequency offset between DRM+ and FM services. To completely avoid FM coverage losses due to cross-modulation effects, the new DRM+ transmitter should not be located within an FM coverage area with a frequency offset less than 4 MHz. This requirement may be quite difficult to realize in the fully occupied FM spectrum.

References

[E1] GE84: Final Acts of the Regional Administrative Conference for the Planning of VHF Sound Broadcasting, Geneva, 1984

[E2] Planning Parameters for DRM Mode E ('DRM+') concerning the use in VHF Bands I, II and III (V 3.0), German DRM Platform, 05/2011

[E3] Recommendation ITU-R BS.412-9: Planning standards for terrestrial FM sound broadcasting at VHF, 12/1998

Annex F: Impairment of FM Broadcast Reception by In-Band OFDM Signals

F1. Introduction

Terrestrial radio increasingly makes use of digital transmission techniques, which, however, will have to coexist with well-established FM broadcasting for quite some time. For large area coverage multiplex systems (e.g. from the DAB system family) are providing cost effective state-of-the-art solutions to broadcasters. For regional and local broadcast, however, it occurs that the content available does not suffice to fill the capacity provided by a multiplex system. Hence, in those cases, the use of a single-programme-per-channel digital system seems to be more appropriate. To this end the use DRM+ in Band II is taken into consideration, which gives rise to the question of mutual compatibility between FM and OFDM signals radiated in the same band. Whereas in the case FM vs. FM harmful interference is hardly to be expected when the separation in frequency exceeds 400 kHz, lab experience has shown that FM reception can be impaired by OFDM signals like DRM+ even when the frequency difference amounts to 1 MHz or more. Apparently it has to be decided if the concept of protection ratios can be adapted to ensure compatibility or if other protection measures seem to be more appropriate. Thus it seems necessary to have a closer look on the actual interference mechanism.

F2. Lab measurements

Preliminary experiments with an FM receiver (without AGC) had led to the verification of impairment of FM by OFDM signals 1 MHz apart and to the observation of additional narrowband noise after the mixer stage (before the IF filter).

In the sequel it was decided to try to study the phenomenon more systematically with, in total, 32 different test receivers. The set of devices comprised 12 hifi tuners (low distortion/large IF bandwidth), 10 car receivers (higher selectivity for the price of higher distortion), and 10 other radio sets (different kinds of imperfection). Following the measurement procedure described in ITU-R Rec.641 with a setup according to Figure F1, protection ratios have been determined which specify the minimum level difference between wanted and interfering signal necessary to avoid noticeable impairment of stereo reception.

Figure F2 presents the results for the 12 hifi tuners in the case FM vs. FM, for a wanted signal level of -50 dBm. It can be seen that all receivers comply with the protection ratio curves specified by ITU-R BS.412, with most receivers exhibiting even superior behaviour for differences in frequency equal to and exceeding 200 kHz. When the interfering signal is changed to OFDM, however, it appears that significantly larger level differences between wanted and interfering signal are necessary to ensure unimpaired FM reception. The details are shown in Figure F3.

Figure F4 compares the interference effect of the analogue and the digital interferer by displaying the corresponding median protection ratio curves, clearly indicating a tremendous increase in C/I necessary in the case of a digital interferer, even for large frequency separation.

* Stefan Teuscher (BR), Raul Schramm (IRT) and Johannes Philipp (SWF)

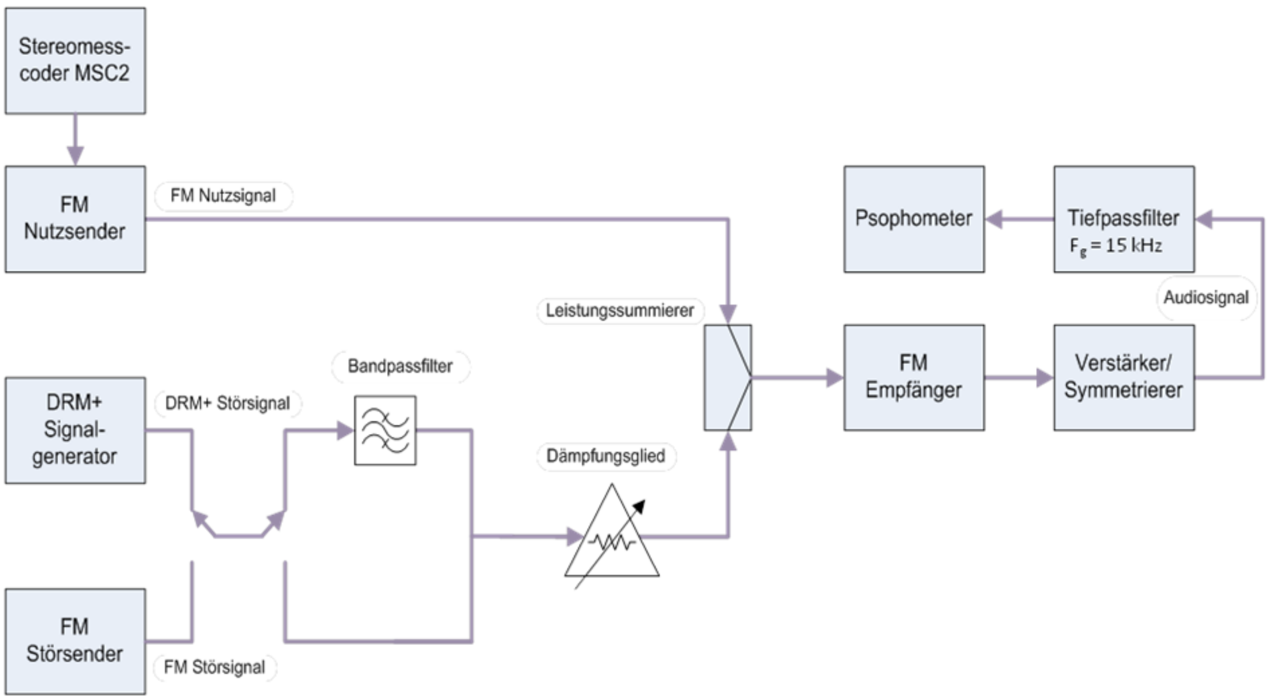


Figure F1: Setup for the measurement (in analogy to ITU-R Rec.641) of protection ratios for FM interfered with OFDM

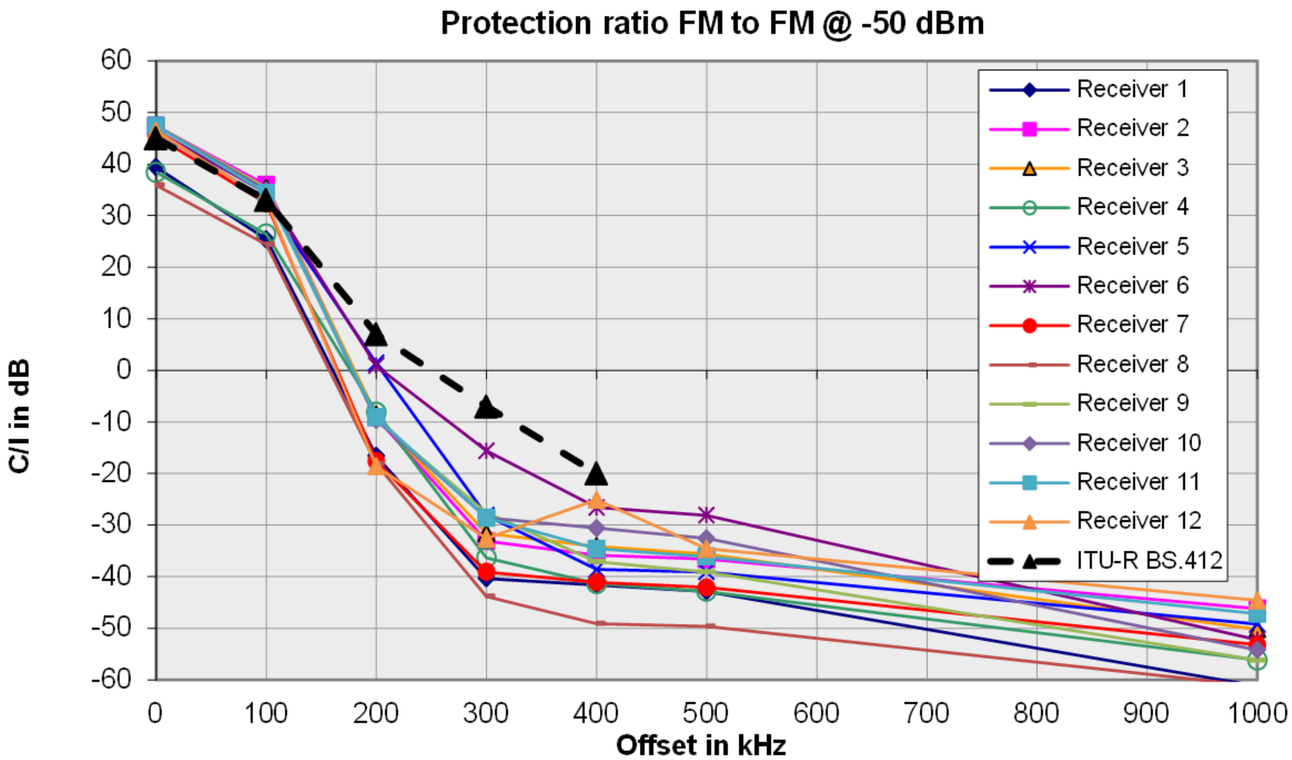


Figure F2: Measured protection ratios for FM interfered by FM; 12 hifi tuners

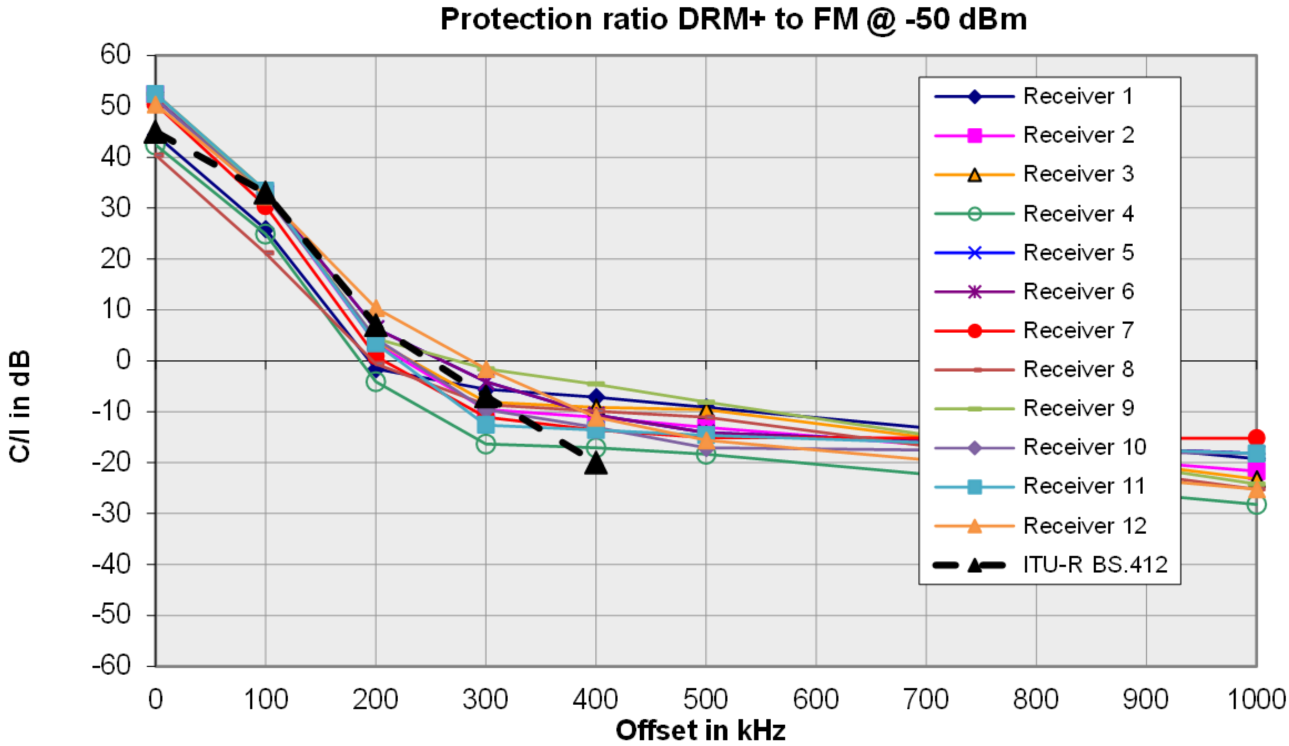


Figure F3: Protection ratios for FM interfered with OFDM (hifi tuners)

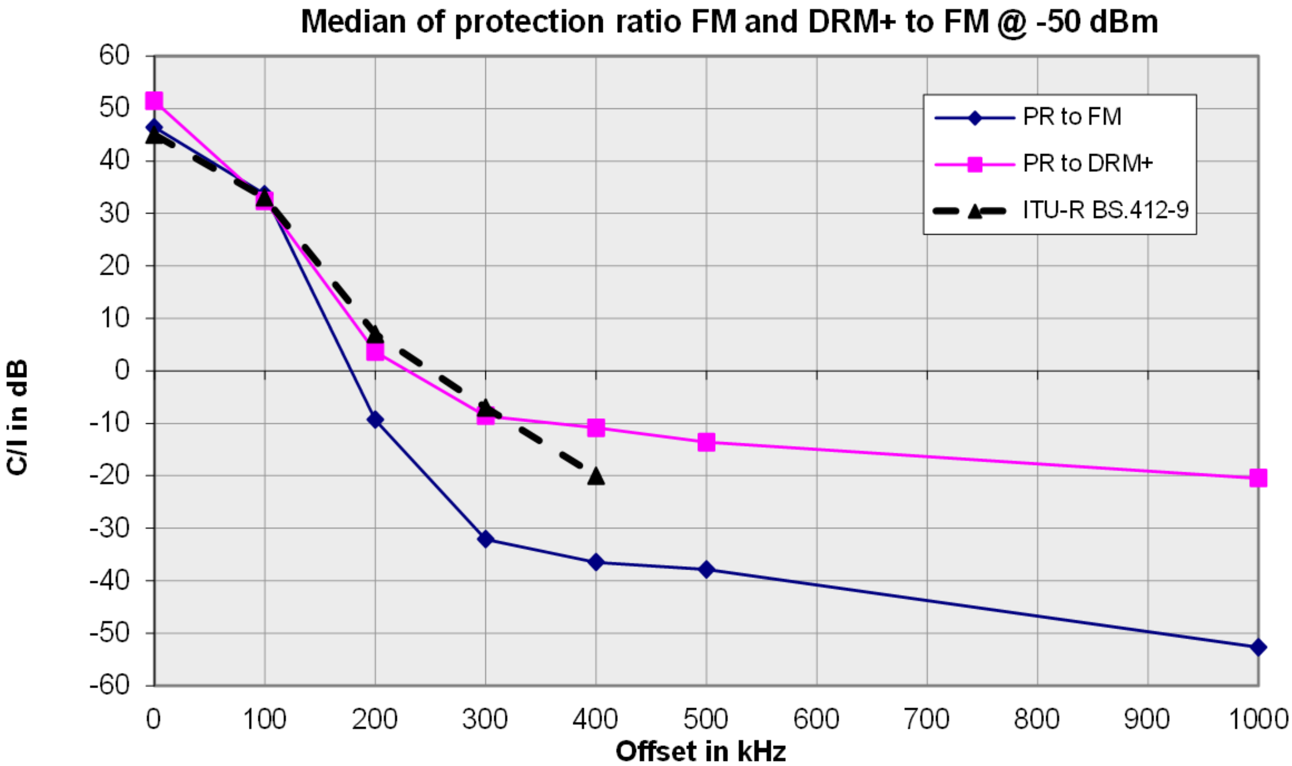


Figure F4: Median protection ratios for analogue and digital interferer (hifi tuners)

Concerning car receivers, Figure F5 presents the results of FM/FM protection ratio measurement. The expectedly larger selectivity of car receivers is clearly reflected in the protection ratio curves at frequency separations of 200 kHz and 300 kHz.

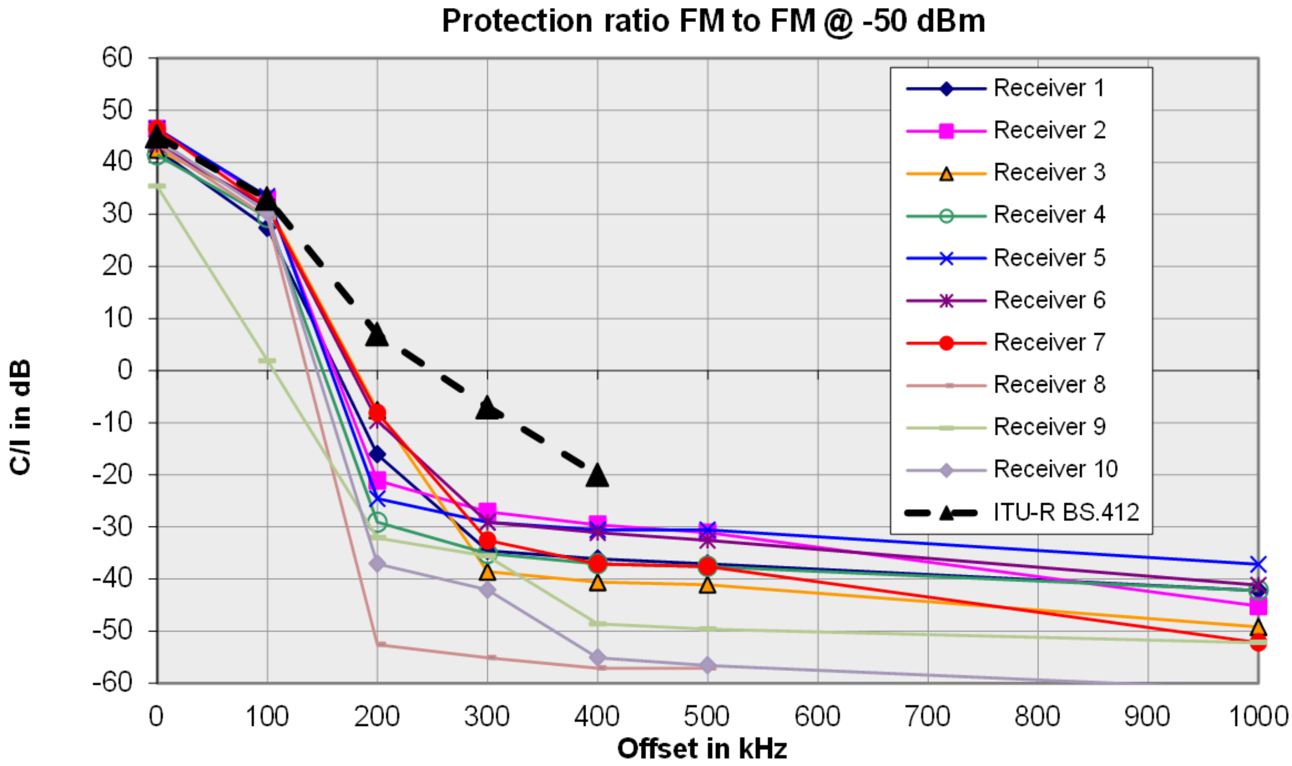


Figure F5: Measured protection ratios for FM interfered by FM; 10 car receivers

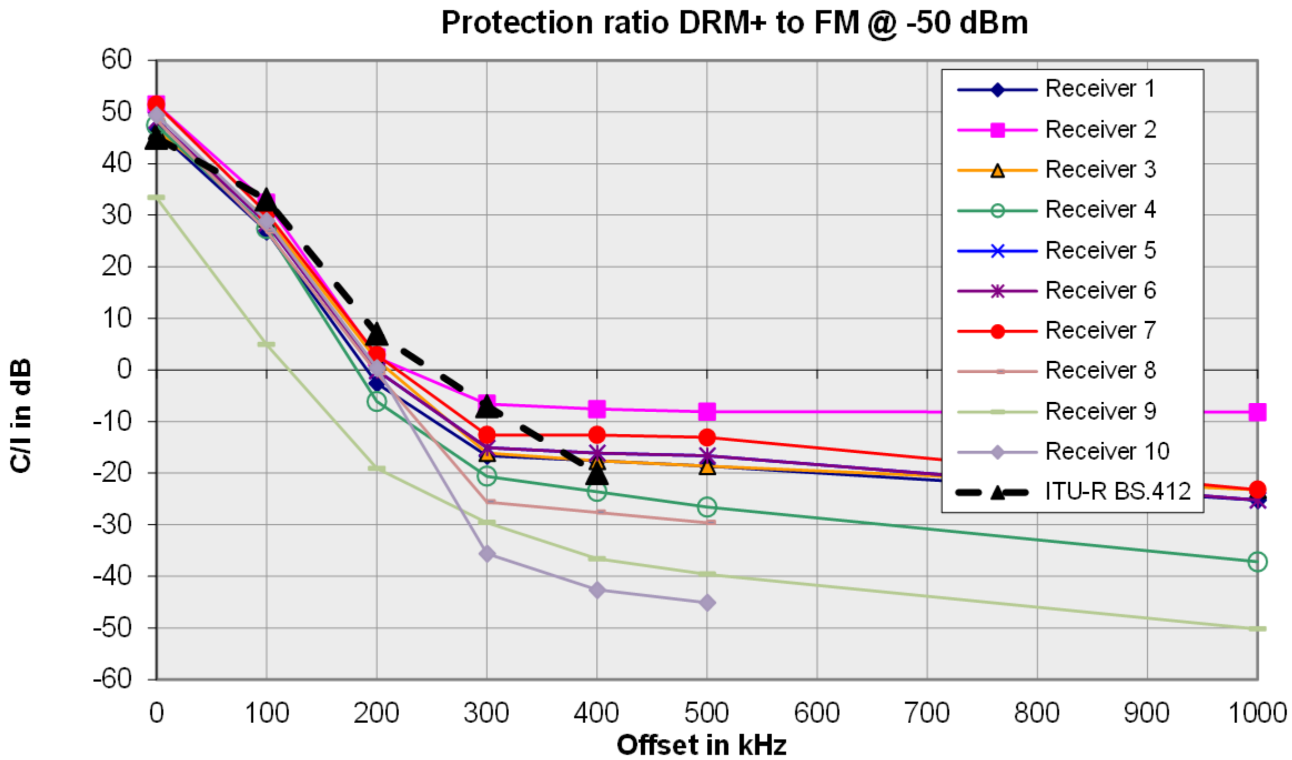


Figure F6: Protection ratios for FM interfered with OFDM (car receivers)

The results of exchanging the analogue interfering signal by the digital one are displayed in Figure F6, which also shows an increase in protection ratio compared to the case of the analogue interferer. For ease of comparison, Figure F7 presents the median protection ratio curves for the analogue and the digital interferer.

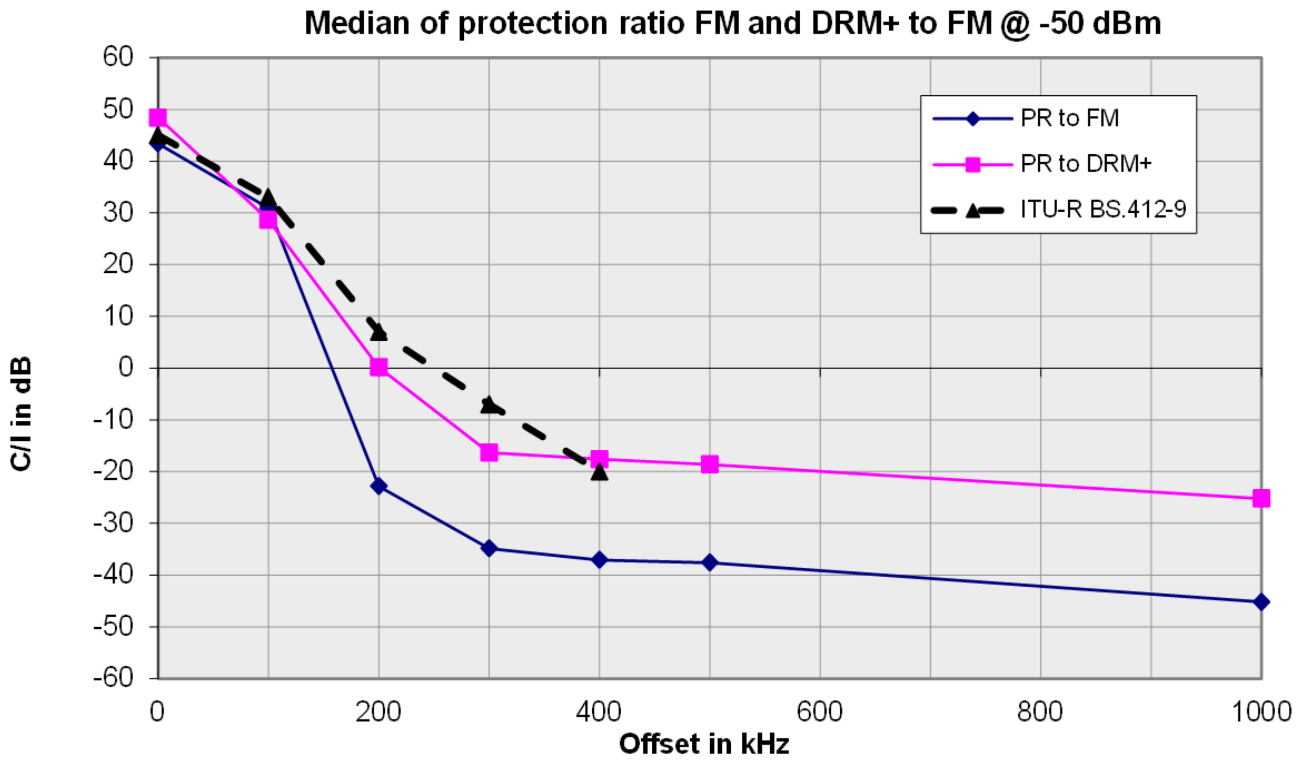


Figure F7: Median protection ratio for analogue and digital interfering signal (car receivers)

The results for the class of “other” receivers differ from the results for the hifi tuners and the car radios predominantly by overall larger variance and larger protection required. The tendency of larger protection for the digital interferer is, however, the same, so that the detailed results can be omitted here.

To further clarify the mechanism of the impairment caused by the digital interfering signal, measurements have been done for a fixed frequency separation of 1 MHz, but various levels of the wanted signal. The surprising result for the hifi tuners is that an increase in wanted signal level does not, in most cases, diminish the restraint for the interfering signal level. Figure F8 presents the interfering level allowable for the maximum impairment of the wanted signal tolerated by ITU-R Rec.641, when the wanted level is varied from -50 dBm up to -20 dBm. The allowable interfering level does not increase correspondingly, but tends to remain constant.

A different result, however, has been obtained in the car receiver case. For most of the receivers, the allowed interferer level increases in proportion to the wanted level (2 exceptions). Figure F9 gives the details.

F3. Interpretation and conclusions

The different behaviour of hifi and car receivers calls for an explanation. One hint might be the observation made with one of the hifi tuners, that an increase of the digital interferer level by x dB increased the audio disturbance by approximately 2x dB. Together with the fact that the disturbance is independent of the wanted signal level, one finds behaviour similar to the familiar case of cross modulation caused by the cubic nonlinearity of the receiver front end characteristic.

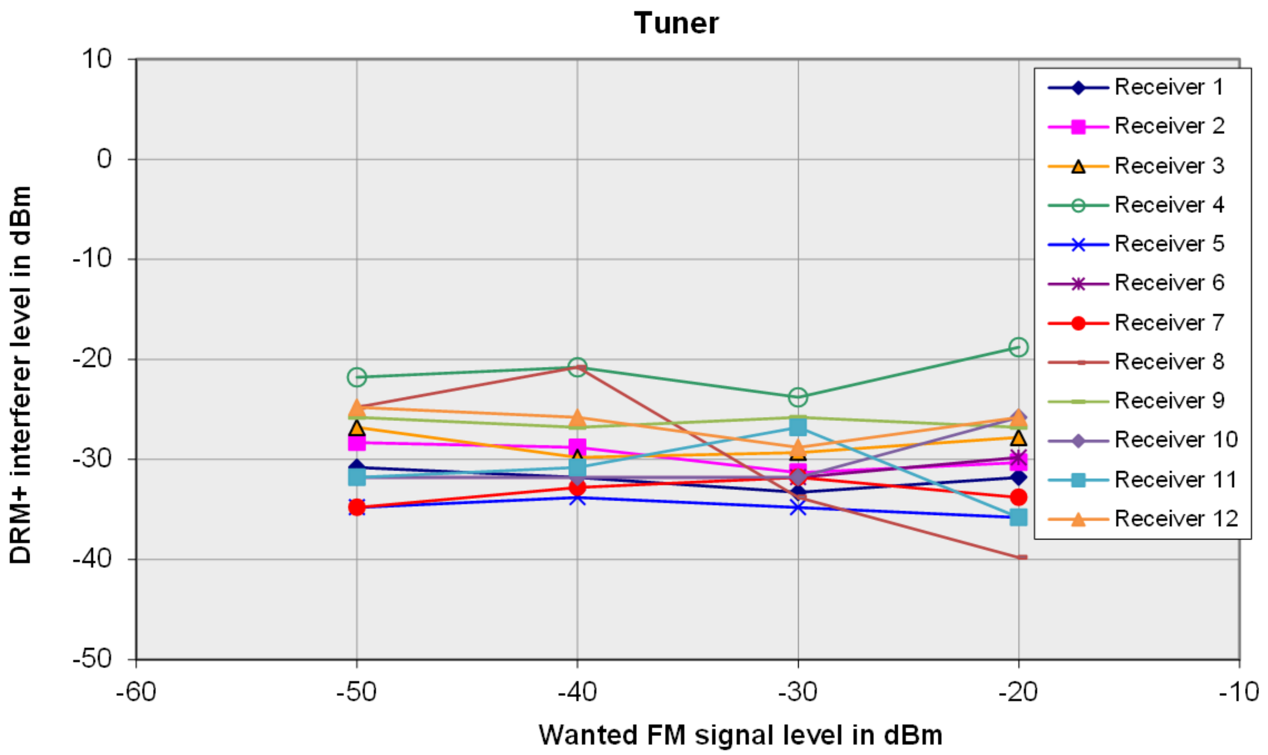


Figure F8: Allowable level of digital interfering signal vs. wanted FM signal level (hifi tuners)

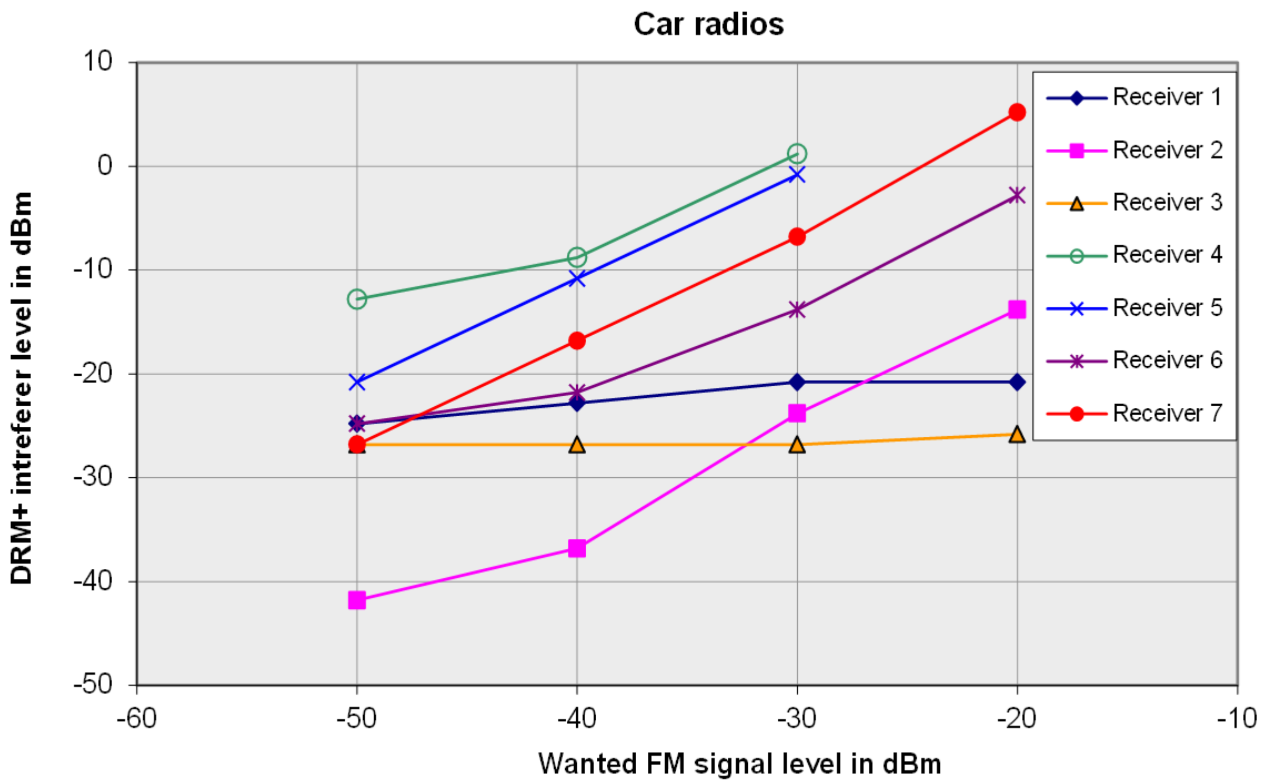


Figure F9: Allowable level of digital interfering signal vs. wanted FM signal level (car receivers)

Let a_3 be the cubic coefficient in a characteristic $y = x - a_3 x^3$, then with an input signal $x = x_w + x_i$ we find in the corresponding output signal, y, a term y_3 proportional to $a_3 \ |x_w||x_i|^2$ with the frequency of the wanted signal x_w. With this cross modulation product we observe that C/I in the IF stages is given by the term $[\ |x_w| \ / \ a_3 \ |x_w||x_i|^2 \ ]^2 = [\ 1 \ / \ a_3|x_i|^2 \ ]^2$, independent of the wanted level $|x_w|^2$ and inversely proportional to the square of the interfering level $|x_i|^2$. However, when the response of an FM demodulator to a cubically distorted input consisting of the sum of an unmodulated "wanted" carrier x_w and an interfering narrowband noise signal (mimicking the OFDM interferer) is computed analytically (see **Appendix**), a zero output signal is found. Thus cross modulation might play a role in the observed FM impairment, but other factors still have to be identified.

A possible explanation for different receiver behaviour in response to increasing wanted signal level might be the presence or absence of automatic gain control. In principle, an AGC is not needed for an FM receiver. Car receivers, however, are subject to an electromagnetically aggressive environment. AGC can help to minimize audio noise in the receiver caused by the electromagnetic disturbances emitted by the car engine. Thus, with increasing level of the wanted signal at the antenna terminal, the interferer is more and more suppressed by the resulting gain reduction. Thus for receivers equipped with AGC it can be expected that the IF C/I increases with increasing wanted level, even in the case of third order intermodulation. However, due to the lack of circuit diagrams for most of the receivers in our test population, it could not be verified that the majority of the car receivers was equipped with AGC while the hifi tuners were not. Thus the "AGC hypothesis" needs further confirmation.

Taking into account the different behaviour of hifi tuners and car receivers, it has to be stressed that the definition of protection ratios (i.e. limits for the ratio of wanted to interfering signal) can ensure unimpaired FM reception in the presence of in band OFDM signals in the case of car receivers only. Since in the case of hifi tuners the impairment depends – irrespective of the wanted signal level – solely from the interfering level, absolute limits for the interfering signal are necessary.

Appendix to Annex F: Cubic nonlinearity and impairment of FM reception by an in-band COFDM signal

Summary

FM receivers without AGC and tuned preselection can suffer from interference by in-band OFDM signals even when the separation in frequency is large. Though it seems to be an IM3 phenomenon, it is shown by analytical treatment of the effect of a front end cubic nonlinearity on the FM demodulation that mere cross modulation is insufficient to explain the observed impairment.

FA1. Complex envelope

Let x(t) be a narrowband real signal with vanishing spectral power outside the intervals [ω-Δω/2, ω+Δω/2] and [-ω-Δω/2, -ω+Δω/2], and let $h_{TP}(t)$ be the impulse response of an ideal low pass filter with corner frequency Δω/2. Then the complex envelope of x (the equivalent base band signal) x_{BB} with respect to ω is given by

$$x_{BB}(t) = \sqrt{2}\left[e^{-i\omega t}x(t)\right] * h_{TP}(t) \qquad \text{(FA1.1)}$$

or, equivalently,

$$x_{BB}(t) = \frac{1}{\sqrt{2}}e^{-i\omega t}x^{+}(t) \qquad \text{(FA1.2)}$$

Where x^{+} is denoting the analytic signal corresponding to x. The baseband signal is normalized in a way to make its power equal to that of the original narrowband signal (see Kammeyer 2011).

FA2. The model characteristic

To characterize the typical receiver nonlinearity, we neglect the frequency shift introduced by superheterodyning and make use of a cubic transfer function model with small signal amplification of unity:

$$y(t) = x(t) - ax(t)^{3} \qquad \text{(FA2.1)}$$

The cubic model is meant to be defined between its extrema at abscissas $\pm x_s$. Beyond, the function might be extended as a horizontal line (clipping characteristic). The parameter a and the saturating drive x_s are related as follows:

$$a = 1/\left(3x_s^{2}\right) \qquad \text{(FA2.2)}$$

We will use the critical drive x_s as reference for defining signal power levels P. That is, the absolute power level of a sinusoid of amplitude x is given by

$$P = 20\log\left(x/x_s\right) \text{ dB} \qquad \text{(FA2.3)}$$

FA3. Interfering signal model

The OFDM interferer will be simulated by narrow band noise n(t) with centre (circular) frequency ω and bandwith Δf, generated by appropriate filtering of stationary white Gaussian noise. Let N_0 be the spectral power density of the bandpass noise, then n(t) can be written as (Ohm 2010)

$$n(t) = n_I(t)\cos\omega t - n_Q(t)\sin\omega t \qquad \text{(FA3.1)}$$

Where $n_I(t)$ and $n_Q(t)$ are two uncorrelated (lowpass) Gaussian processes of bandwidth Δf, each with variance (power)

$$\sigma^2 = 2N_0\Delta f \qquad \text{(FA3.2)}$$

Which also can be attributed to the bandpass process. The complex envelope of the bandpass signal n(t) is then, according to (FA1.1), given by

$$n_{BB}(t) = \tfrac{1}{2}\sqrt{2}\left(n_I + i n_Q\right) \qquad \text{(FA3.3)}$$

Where n_I and n_Q appear as in-phase and quadrature components, respectively.

FA4. Wanted signal

Let v(t) be an audio signal limited to the interval [-1,1], which is to be transmitted on a carrier of frequency ω_0 by means of frequency modulation. The modulated RF signal then is given by

$$x(t) = A\cos\left(\omega_0 t + \Omega\int_0^t dt'\,v(t') + \Phi_0\right) \qquad \text{(FA4.1)}$$

Where Ω denotes the maximum deviation of a (circular) frequency. The corresponding (quasi-) analytic signal is approximately (provided the deviation Ω is not too large) given by

$$x^+(t) = A\exp\left[i\left(\omega_0 t + \Omega\int_0^t dt'\,v(t') + \Phi_0\right)\right] \qquad \text{(FA4.2)}$$

Then, together with (FA1.2) the equivalent baseband signal x_{BB} relative to the carrier frequency ω_0 is given by

$$x_{BB}(t) = \frac{1}{\sqrt{2}}A\exp\left[i\left(\Omega\int_0^t dt'\,v(t') + \Phi_0\right)\right] \qquad \text{(FA4.3)}$$

It is easily verified that the modulation signal can be recovered by demodulation according to

$$v(t) = \Omega^{-1}\ln\frac{\dot{x}_{BB}(t)}{x_{BB}(t)} \qquad \text{(FA4.4)}$$

FA5. Cross modulation

Now we consider the case of simultaneous transfer of a wanted signal (FA4.1) and an additive interfering signal (FA3.1) via a characteristic according to (FA2.1). The summed input signal is given by:

$$x(t) = A\cos\left(\omega_0 t + \Omega\int_0^t dt' v(t') + \Phi_0\right) + n_I(t)\cos\omega t - n_Q(t)\sin\omega t \qquad \text{(FA5.1)}$$

Where we assume that the centre frequency ω of the interferer is separated from the wanted signal centre frequency ω_0 by more than the effective receiver bandwidth.

By insertion of (FA5.1) into (FA2.1), with application of the multinomial theorem and the formulas for products of trigonometric functions it can be verified that (among other things) a product is generated, the spectrum of which is centred around the wanted signal frequency ω_0.

It is given by

$$y_{cm}(t) = -\tfrac{3}{2}\mathrm{aA}\left[\mathrm{n_I}^2(t) + n_Q^2(t)\right]\cos\left(\omega_0 t + \Omega\int_0^t dt' v(t') + \Phi_0\right) \qquad \text{(FA5.2)}$$

After the receiver filter, the signal

$$y(t) = x(t) + y_{cm}(t) \qquad \text{(FA5.3)}$$

will be fed into the demodulator (where the contribution of $-ax^3(t)$ has been neglected). The corresponding baseband signal y_{BB} is, according to (FA1.2), approximately given by

$$y_{BB}(t) = A\left\{1 - \tfrac{1}{2}\left[n_I^2(t)/x_s^2 + n_Q^2(t)/x_s^2\right]\right\}\exp\left[i\left(\Omega\int_0^t dt' v(t') + \Phi_0\right)\right] \qquad \text{(FA5.4)}$$

Where the parameter a has been replaced by means of (FA2.2). To evaluate the impairment, the demodulator output with unmodulated, wanted carrier is used, which means v(t) = 0 for all t. Then (FA5.4) is simplified to

$$y_{BB}(t) = \frac{1}{\sqrt{2}} A\left\{1 - \tfrac{1}{2}\left[\mathrm{n_I}^2(t)/x_s^2 + n_Q^2(t)/x_s^2\right]\right\}\exp(i\Phi_0) \qquad \text{(FA5.5)}$$

Application of the demodulation operator (FA4.4) onto (FA5.5) yields a vanishing demodulated signal. This once more demonstrates the immunity of FM transmission to amplitude modulation. Moreover, it has been shown that mere 3rd order cross modulation is not sufficient to explain the observed impairment of FM reception by in-band OFDM signals.

References

Kammeyer 2011 Kammeyer, Karl-Dirk: Nachrichtenübertragung. Wiesbaden (Vieweg+Teubner) 2011

Ohm 2010 Ohm, Jens-Rainer; Lüke, Hans Dieter: Signalübertragung. Heidelberg(Springer) 2010

Annex G: Results of the DRM+ high power field trial in the UK

Abstract

The DRM Consortium carried out a high-power field trial of the DRM+ system [G1] in the FM band in the central Scotland area, centred on the city of Edinburgh, in the United Kingdom during January to May 2011. The DRM Consortium members contributed their expertise and equipment to the trial to enable the system to be tested in a real commercial environment with a wide variety of reception conditions. The BBC provided project management and measuring effort for the trial. This document describes the trial and results.

G1. Location and environment for the trial

The trial was conducted in the eastern Central belt area of Scotland from the Craigkelly transmitting station located just to the north of the town of Burntisland, Fife. The area is characterised by a mixture of dense urban, urban, suburban, and rural terrain, including the city of Edinburgh, several towns, open farmland and light industrial districts. The physical geography includes open water, gently undulating hills and rocky outcrops which contribute to various challenges for radio services, including multipath and terrain shielding.

Figure G1: DRM+ trial location

* Original title: BBC White Paper WHP 199, Results of the DRM+ high power field trial in the UK. Lindsay Cornell, 07/2011.

Figure G2: DRM+ trial location - detail with terrain

The Craigkelly transmission site is owned and operated by Arqiva. It is a commercial broadcasting site which provides transmission facilities for analogue and digital television (using the PAL-I and DVB-T standards), analogue and digital radio (using the FM and DAB standards), and a variety of ancillary mobile communications, links facilities, etc. The site is 182 m above sea level.

The FM radio services use two antenna systems providing mixed horizontal and vertical polarisation. Each antenna system is fed from a combiner. The site provides the following FM services:

Table G1: FM radio services from Craigkelly

Station Name	Freq. (MHz)	Erp Power (kW)	Antenna	Antenna height (m)
BBC Radio nan Gàidheal	104.1	5	A	119
Capital FM	105.7	10	B	107
Forth FM	97.3	9.8	A	119
Real Radio	101.1	9.6	B	107
Talk 107*	107.0	10	A	119

* Talk 107 is no longer on-air

Figure G3: Craigkelly tower (left) and top section showing FM arrays (right)

The trial made use of the licensed assignment at 107.0 MHz. The antenna pattern is shown in Figure G4. This pattern has a restriction to the east due to the Firth of Forth estuary and open sea.

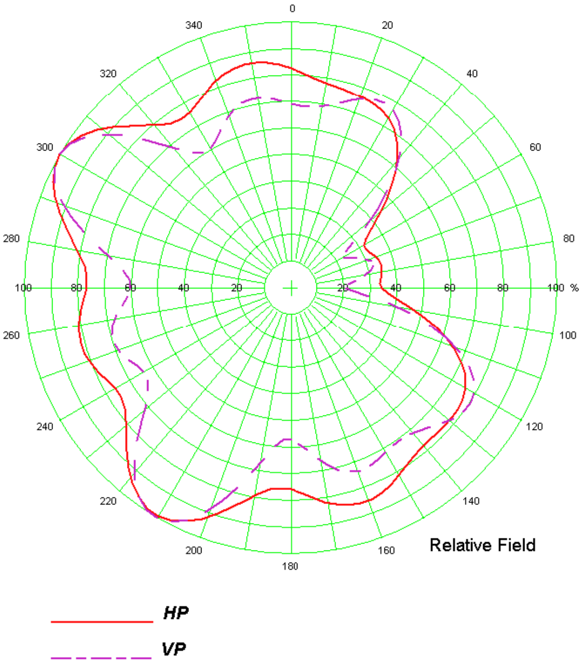


Figure G4: Antenna pattern of antenna A

All frequencies and powers used at the site are coordinated and licensed by UK Ofcom, as are the frequencies used from neighbouring transmission sites.

For reference, the frequencies and powers of all services on-air in the 106.5 MHz to 107.5 MHz range are shown in Figure G5.

It can be seen that there are no co-channel transmissions in the area, and the only close adjacent transmission with any significant power is from Durris on 106.8 MHz at 10 kW erp.

However, a range of hills provides terrain shielding to maintain the required planning rules.

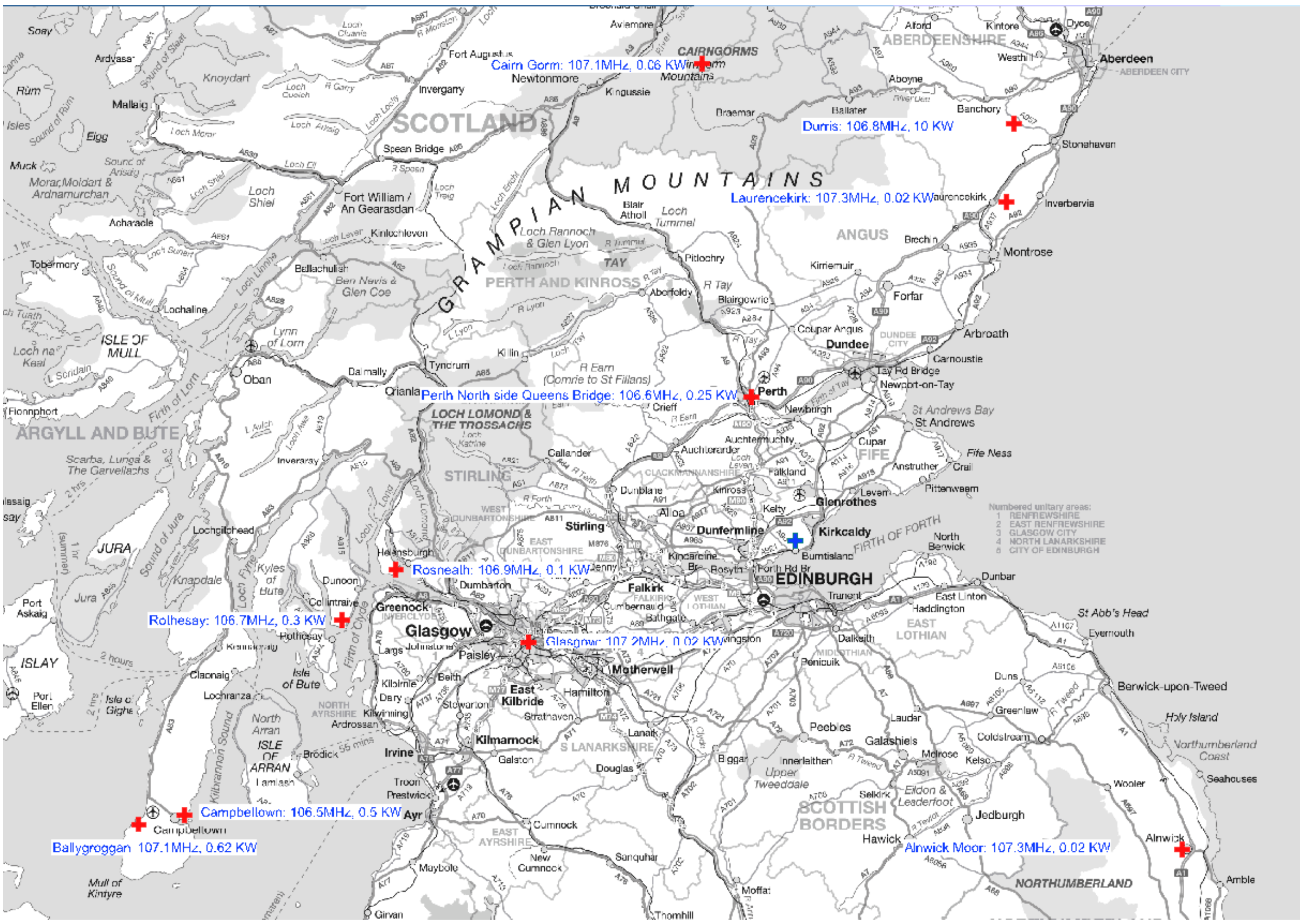


Figure G5: FM transmissions operating on frequencies from 106.5 to 107.5 MHz (Craigkelly marked with blue cross)

G3. Transmission Equipment

The transmission equipment was provided by DRM Consortium members for the duration of the trial. The block diagram of the equipment configuration is shown in Figure G6. The transmitter formerly used for Talk 107 was removed and replaced by the DRM+ transmitter and associated equipment. The main audio source for the trial was the BBC Gaelic language service BBC Radio nan Gàidheal which is also radiated as an FM service from the same antenna system. This allowed a direct comparison to be made between the analogue FM and DRM+ coverage.

The outputs of the two FM transmitters for Forth FM and BBC Radio nan Gàidheal are fed into a combiner which is then fed into the wideband port of a constant impedance module. The output of the DRM+ transmitter was fed into the narrowband port formerly used by the FM service Talk 107. The output of the constant impedance module is fed to the high power splitter and antenna.

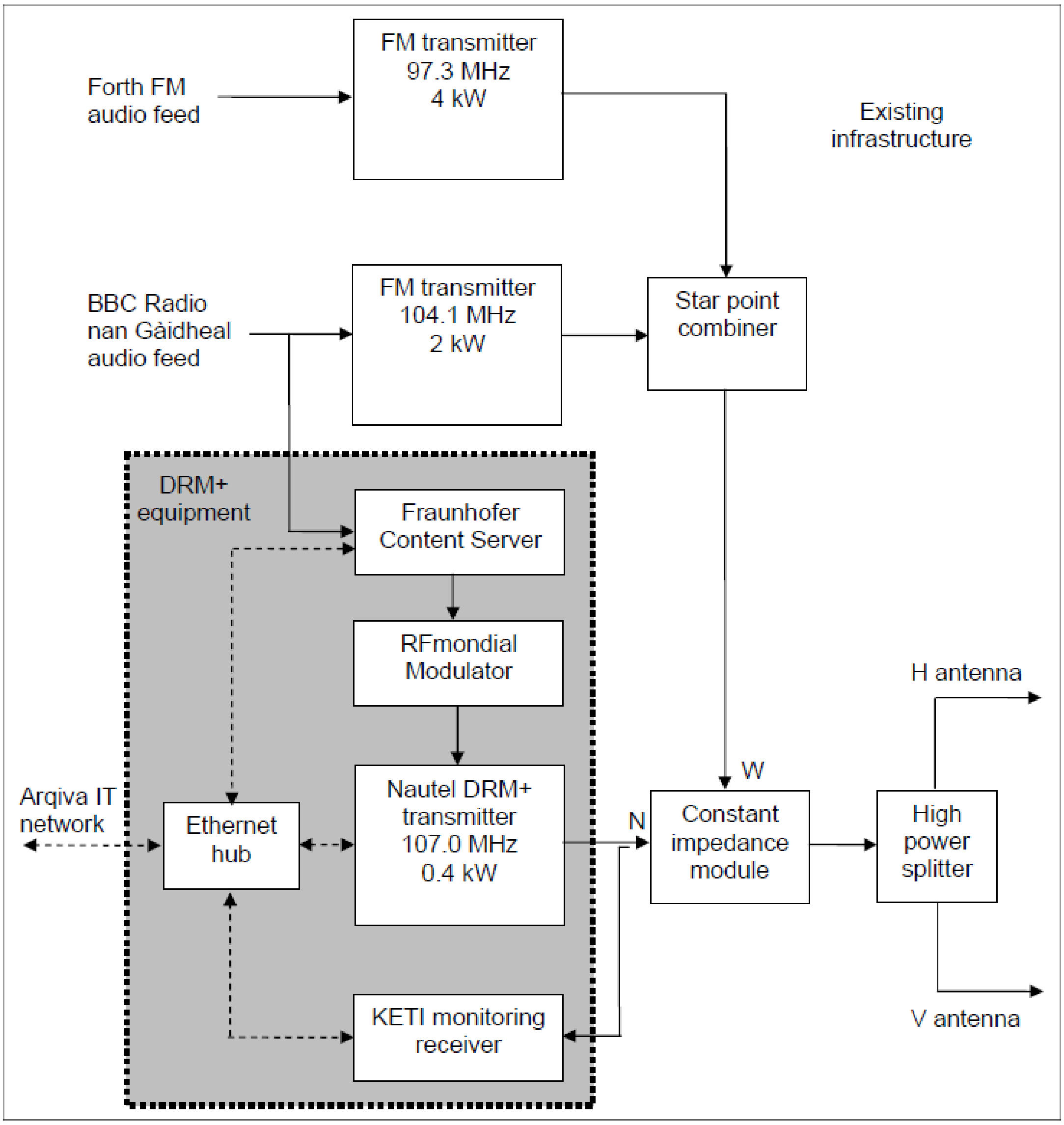


Figure G6: Block diagram of transmission system (simplified) showing existing infrastructure and additional DRM+ equipment

The Fraunhofer content server was configured to allow two DRM+ parameter sets to be switched to air - a more robust mode using 4-QAM modulation and rate 1/3 coding, which provided 49.7 kbit/s payload, and a higher capacity mode using 16-QAM modulation and rate 1/2 coding, which provided 149.1 kbit/s. In each case, BBC Radio nan Gàidheal was broadcast with text messages and a PRBS sequence to allow bit error ratio (BER) measurements to be made. In the higher capacity mode, the audio bit rate was increased and a second audio service consisting of music stored on the hard disk of the content server was included.

The content server was connected to the RFmondial modulator which in turn fed the Nautel NV5 transmitter. The transmitter was set to radiate at 107.0 MHz with a transmit power of 400 W. The antenna system provides a 4 dBi gain and therefore the DRM signal was broadcast at 1 kW erp. The KETI DRM+ receiver was fed from a directional coupler on the output of the transmitter.

The content server, transmitter and monitoring receiver were each connected via an ethernet hub to the Arqiva technical IT network. This allowed remote control and monitoring of the equipment permitting mode changes as required during the measuring process. It also ensured that the DRM+ system was monitored continuously by the Arqiva central control facility.

Figure G7: The DRM+ transmitter (left) and content server, modulator and monitoring receiver (right)

G4. Acceptance Tests

A test and development license was issued by the UK regulator, Ofcom, for the duration of the trial. Prior to the start of transmissions, Ofcom visited the Craigkelly site to carry out an acceptance test to ensure that existing services using the same antenna would not suffer as a result of the introduction of the DRM+ trial service. A full compliance test was carried out to ensure that no spurious intermodulation products or out-of-band emissions were radiated that could impact on other broadcast services or to aeronautical services using the spectrum immediately above the FM band. The full test procedure was followed, starting with measuring the transmitter into a dummy load, and continuing through the transmission chain. No problems were found with the installation and permission to begin the trial was given.

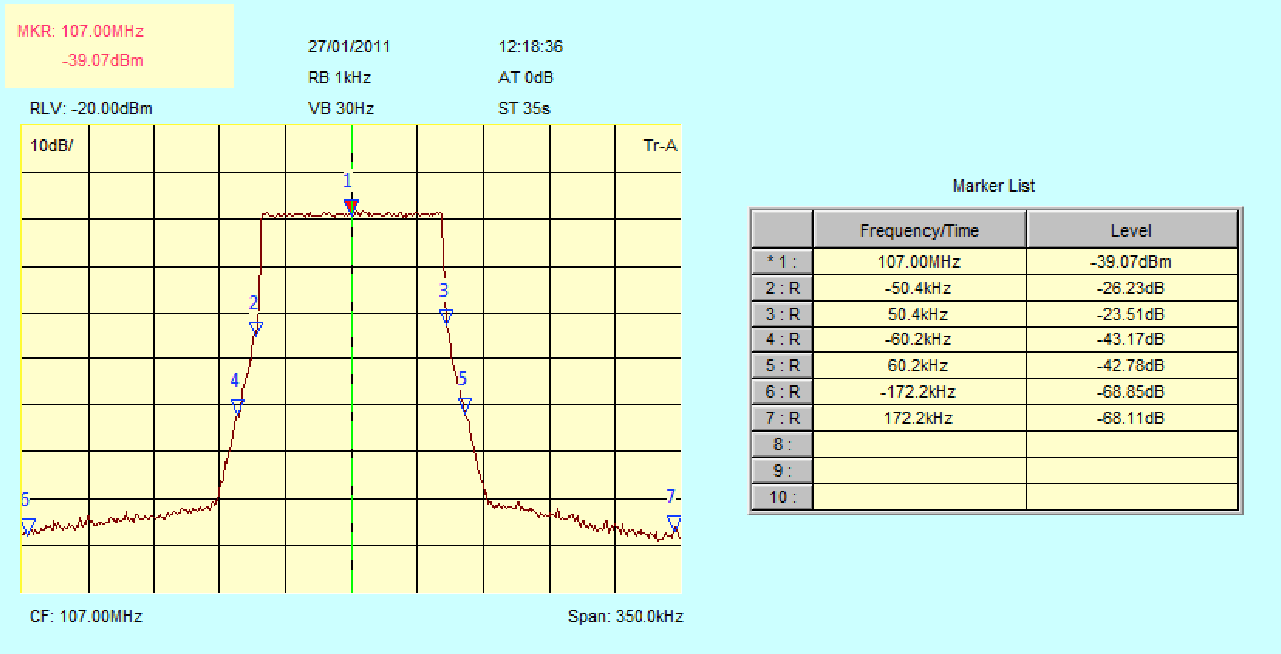


Figure G8: Recorded spectrum of DRM+ signal

G5. Receiving Equipment

Mobile measurements were carried out using a BBC measuring vehicle, which has a technical power supply and various items of standard measuring equipment installed. For the DRM+ trial additional equipment was installed.

Figure G9: BBC Measuring vehicle

The schematic of the DRM+ measuring equipment is shown in Figure G10.

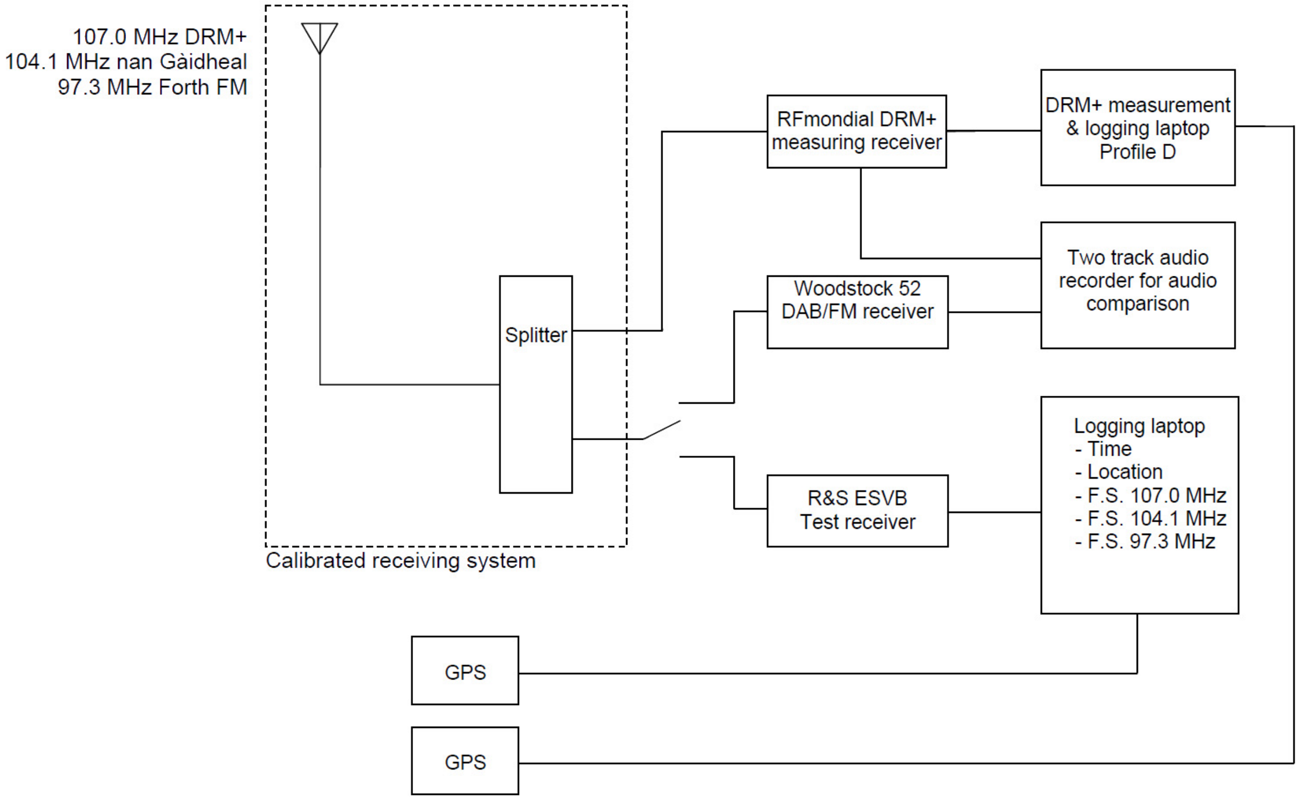


Figure G10: Receiver equipment schematic

The antenna is mounted on the roof at a height of approximately 1.5 m above ground level and fed to a 3 dB splitter. One output of the splitter was fed to the RFmondial DRM+ measuring receiver, the other to a switch to allow either the Blaupunkt Woodstock 52 receiver or the Rohde & Schwartz ESVB measuring receiver to be connected.

The audio outputs of both the DRM+ receiver and the DAB/FM receiver were connected to an audio recorder to allow offline listening when analysing the recorded data. The DRM+ reception was monitored in real-time on a laptop computer, which also continuously recorded the DRM RSCI profile D [G2] data for later analysis.

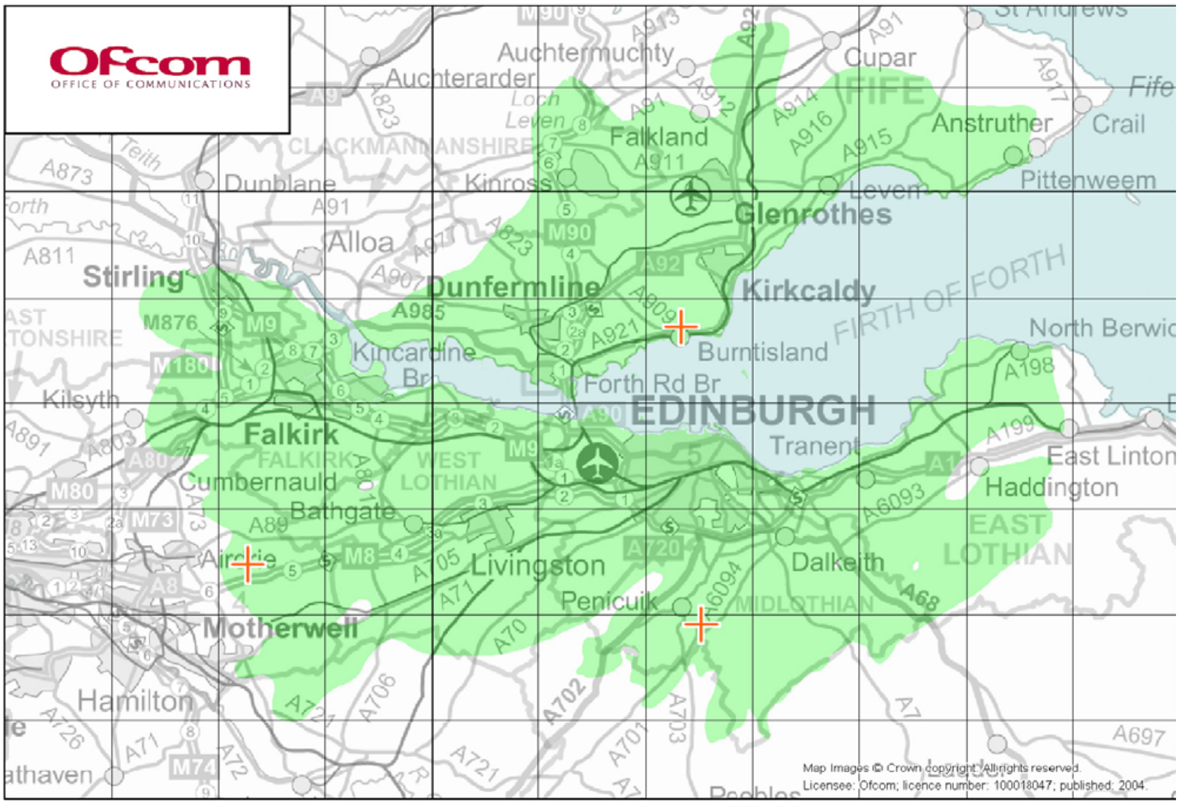
A second laptop computer was used to log the field strength measurements from the R&S ESVB receiver which was set up to measure the field strength of each of the three signals from the common antenna. GPS data was provided to both laptops to allow the data to be geographically referenced.

G6. Predicted Coverage

The UK planning model, derived from the output of the GE84 planning conference, was used to predict coverage from the Craigkelly antenna for a DRM+ station operating at 1 kW and in 4-QAM, rate 1/3. The prediction is for mobile reception, interference limited for 50% time and 99% locations exceeding a field strength of 39 dBμV/m at 10 m.

Figure G11: Predicted coverage area for a 1kW DRM+, 4QAM, rate 1/3 station

For comparison, the official licensed coverage area of Forth FM, radiated from the same antenna system, is given in Figure G12, corresponding to areas where the minimum median field strength is greater than 54 dBμV/m. Note that coverage is made up of 9.8 kW erp from Craigkelly, plus two repeaters with 500 W erp from Penicuik and 100 W erp from Black Hill.



Edinburgh FM MCA (Forth FM) - 29th December 2003

Figure G12: Official licenced coverage area of Forth FM

G7. Trial Routes and Analysis Method

The measurement of the coverage area was conducted over two two-week periods during February and March 2011. Note that additional measuring periods, including both mobile and indoor measurements, were made during April with final tests due to be made in May, but the results from these measurements are not included in this report.

Overall coverage was measured by driving along all major routes through the region, around 600 route miles in total. Several roads were passed more than once as each route crossed across another. First, measurements were made in the 4-QAM mode, and then the driving was repeated for the 16-QAM mode, although the precise driving routes used were varied according to local traffic conditions.

In addition, the performance in a dense urban environment was measured by driving many of the smaller roads in the city of Edinburgh, an area known to be extremely challenging for FM reception due to the hilly nature of the city, the narrowness of the streets and the height of the buildings.

The total distance covered during the four weeks of measuring was in excess of 1500 miles.

The RFmondial receiver was configured to record RSCI profile D. This essentially means that all parameters are decoded and recorded for later analysis, including the coded audio.

For the preparation of the maps showing coverage, the data was divided into two sets, one corresponding to measurements made whilst receiving the 4-QAM transmission mode, and the other for the 16-QAM mode. Each set was processed to aggregate all reception points within 100 x 100 m squares for display. The audio quality flag is provided in the RSCI "rsta" TAG item for each received audio super frame and provides a binary indication of correctly received audio for the 200 ms audio super frame period, or impaired audio (i.e. not all audio frames decodable). The percentage of error free audio super frames is assigned to each square for plotting calculated as the number of error free audio super frames divided by the total number of audio super frames decoded within the 100 x 100 m square.

G8. Results

The results of the trial are presented as a series of maps showing the quality of the audio received. Additional information is provided as appropriate to assist with the interpretation of the presented data. A spectrum analyser was used to measure the spectrum at two locations approximately equidistant from the transmitter at North Queensferry and Leith Docks. The locations and plots are shown in Figure G13 and Figure G14.

Figure G13: Map showing location of Craigkelly transmitting station and reception sites at North Queensferry (left) and Leith Docks (right).

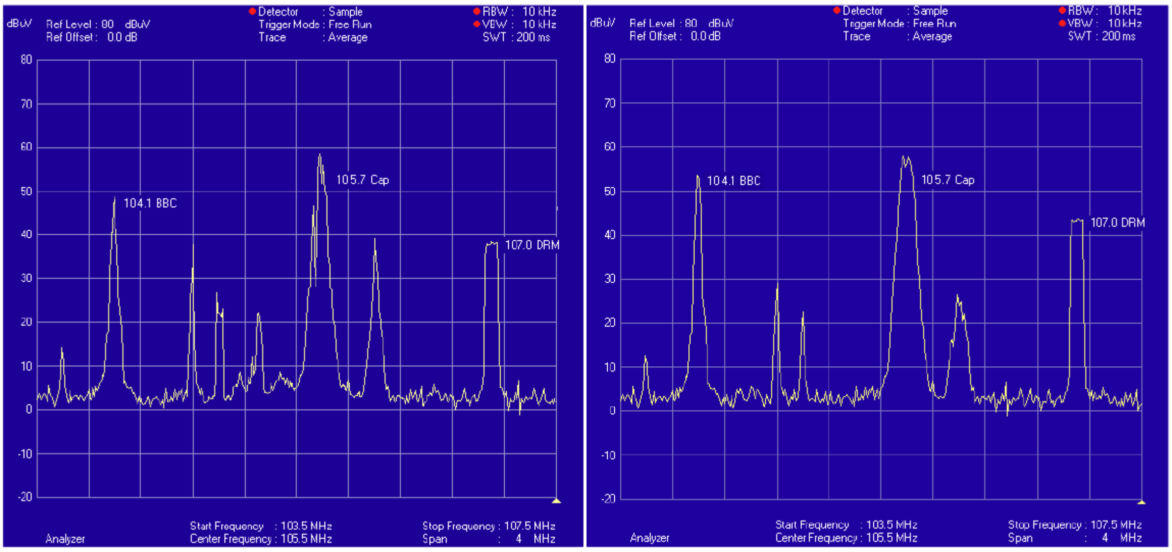


Figure G14: Spectrum plots taken at North Queensferry (left) and Leith Docks (right) showing BBC Radio nan Gaidheal, Capital FM and the DRM signal

BBC Radio nan Gaidheal and the DRM signal share the same antenna, whilst Capital FM uses the lower antenna from Craigkelly. Also visible are FM services from other transmitters.

The colouring of the reception paths on the maps is as follows:

green	>99% audio super frames within the square are error free
yellow	70%< audio super frames within the square are error free ≤99%
orange	50%< audio super frames within the square are error free ≤70%
red	≤50% audio super frames within the square are error free

G8.1 Overall results for 4-QAM, rate 1/3

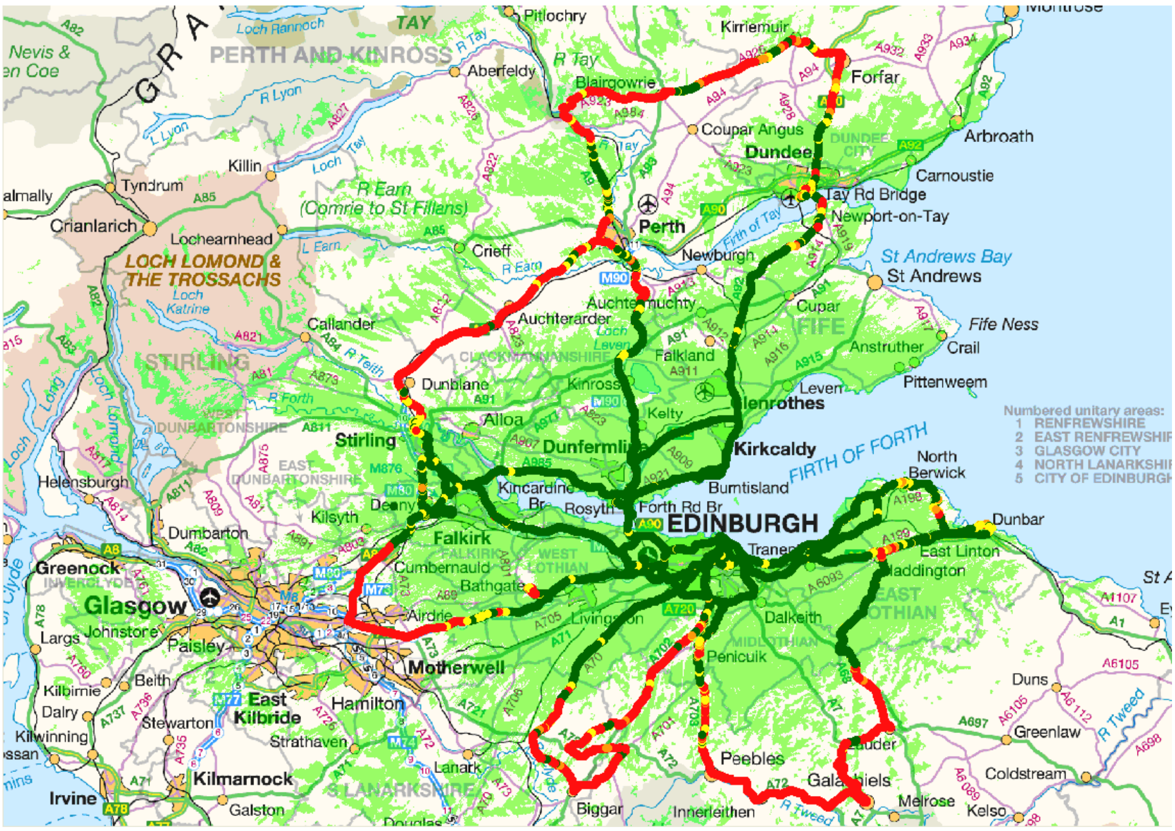


Figure G15: Overall coverage, 4-QAM rate 1/3.

The coverage is shown overlaid onto the predicted coverage. There is very strong correlation between the prediction and the measured results.

G8.2 Overall results for 16-QAM, rate 1/2

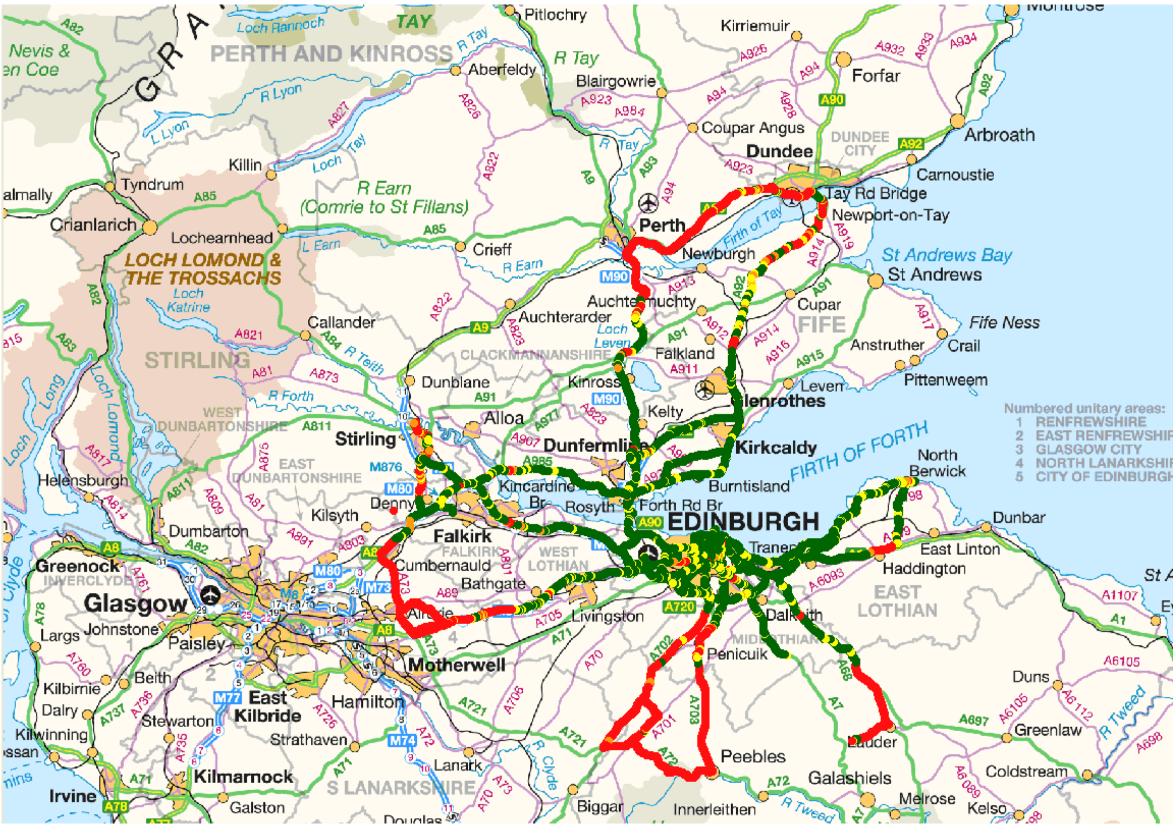


Figure G16: Overall coverage, 16-QAM, rate 1/2

The coverage is slightly less than that for 4-QAM as expected. The difference in the required SNR for the two modes is approximately 8 dB in a Gaussian channel.

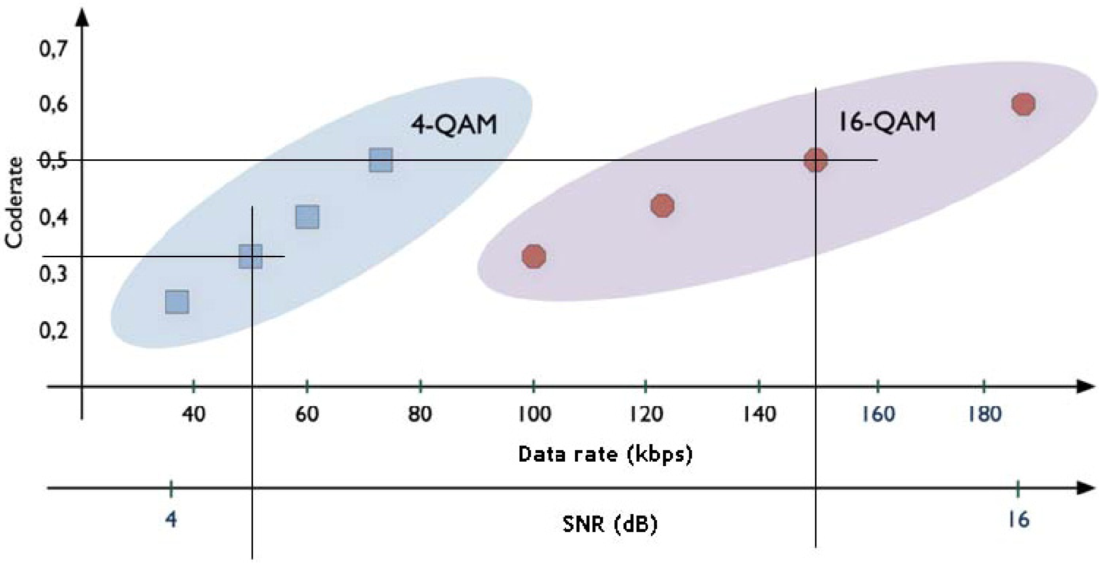


Figure G17: Comparison of data rate and required SNR in a Gaussian channel for different constellations and code rates

G8.3 Detailed results comparing 4-QAM and 16-QAM coverage

G8.3.1 Edinburgh

Figure G18: Edinburgh city centre

Edinburgh suffers from extensive multipath effects on FM causing regular noise, clicks and fuzz at various locations. The hilly nature of the city also produces some dead areas where terrain prevents reception. In spite of this, the proximity of the transmitter means that in general Edinburgh receives a strong signal.

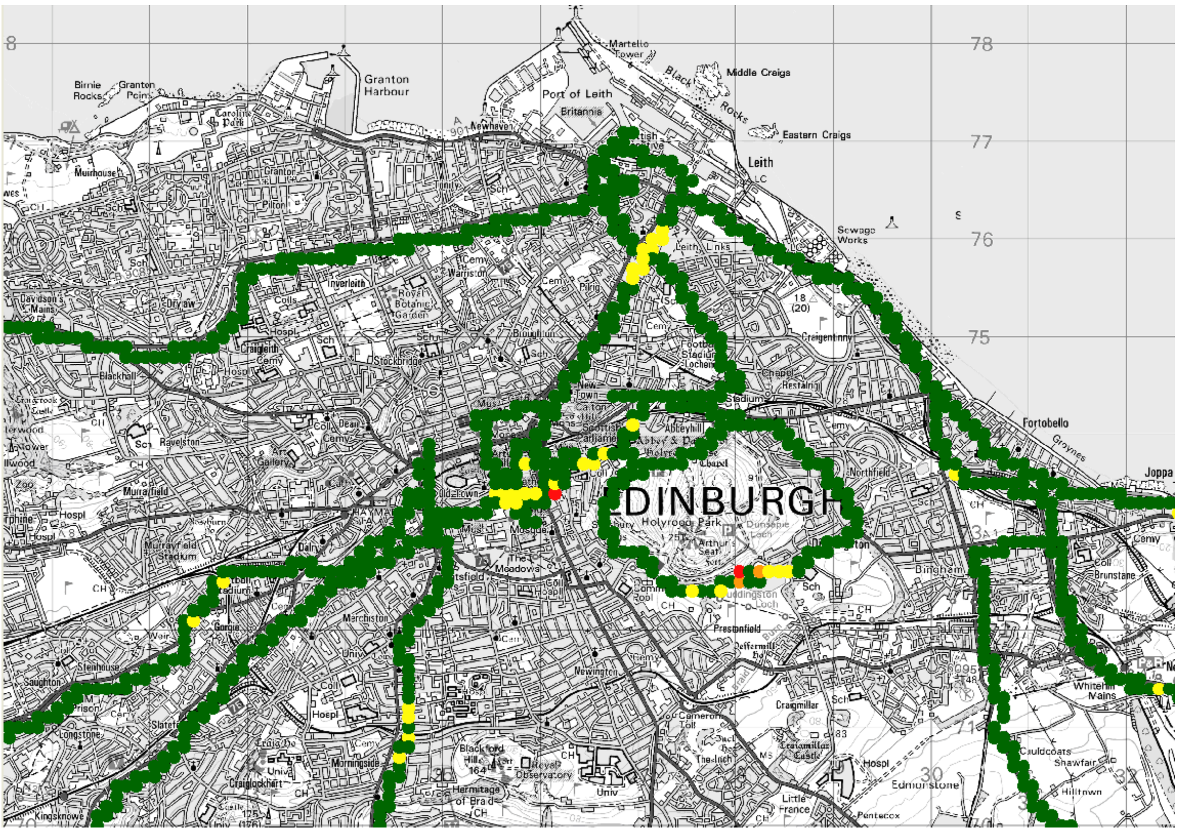


Figure G19: Edinburgh coverage, 4-QAM rate 1/3

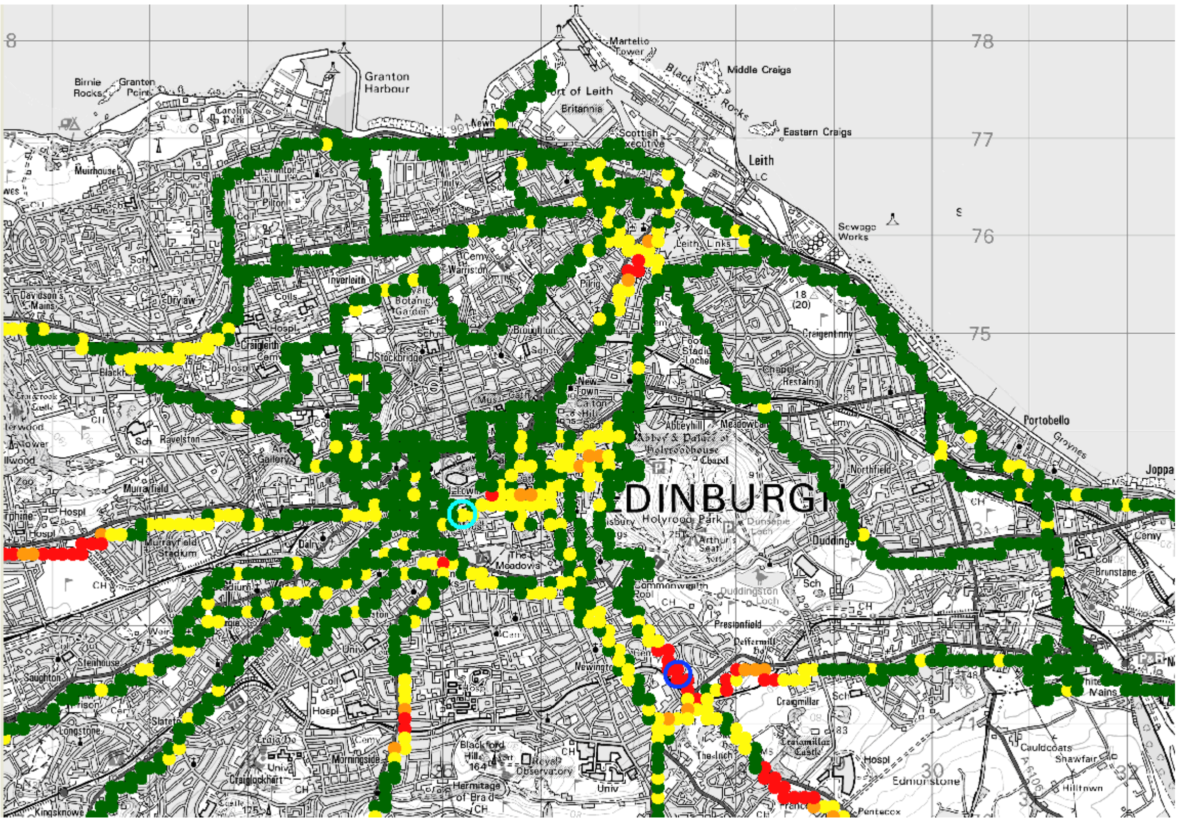


Figure G20: Edinburgh coverage, 16-QAM rate 1/2

It can be seen that areas of poor reception in the 4-QAM mode are exacerbated in the 16-QAM mode. Two areas of poor reception on the 16-QAM plot are marked with blue circles for which terrain path profiles were plotted.

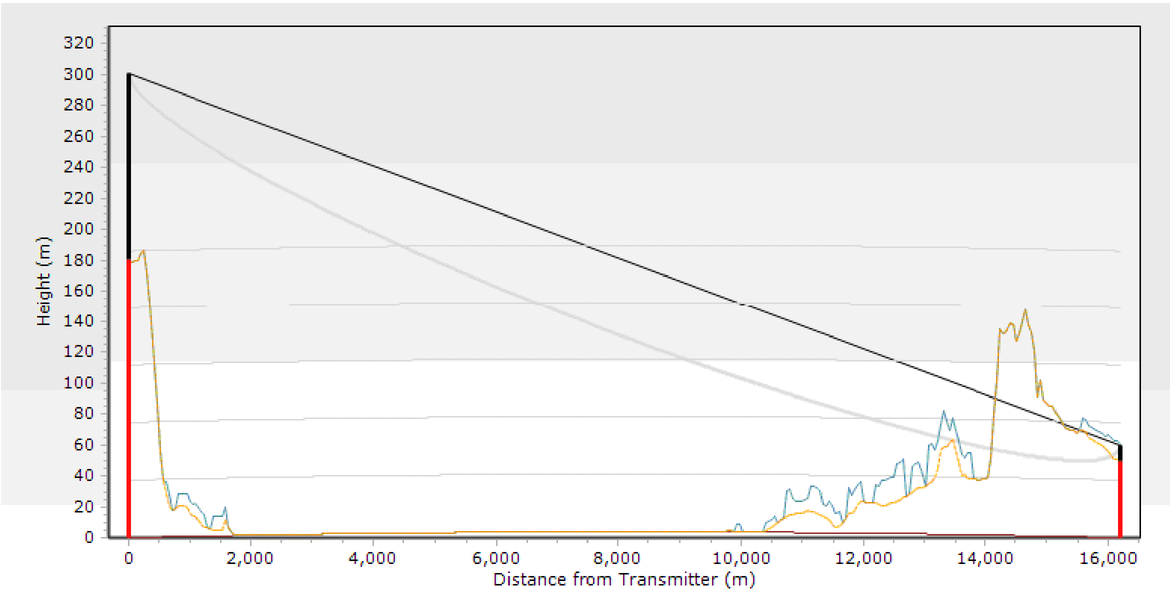


Figure G21: Path profile for dark blue ring in Figure G20

The path profile shows terrain with the brown trace and building clutter with the blue trace. It can be seen that this area of poor reception is caused by terrain shielding from the rocky promontory known as Arthur's Seat.

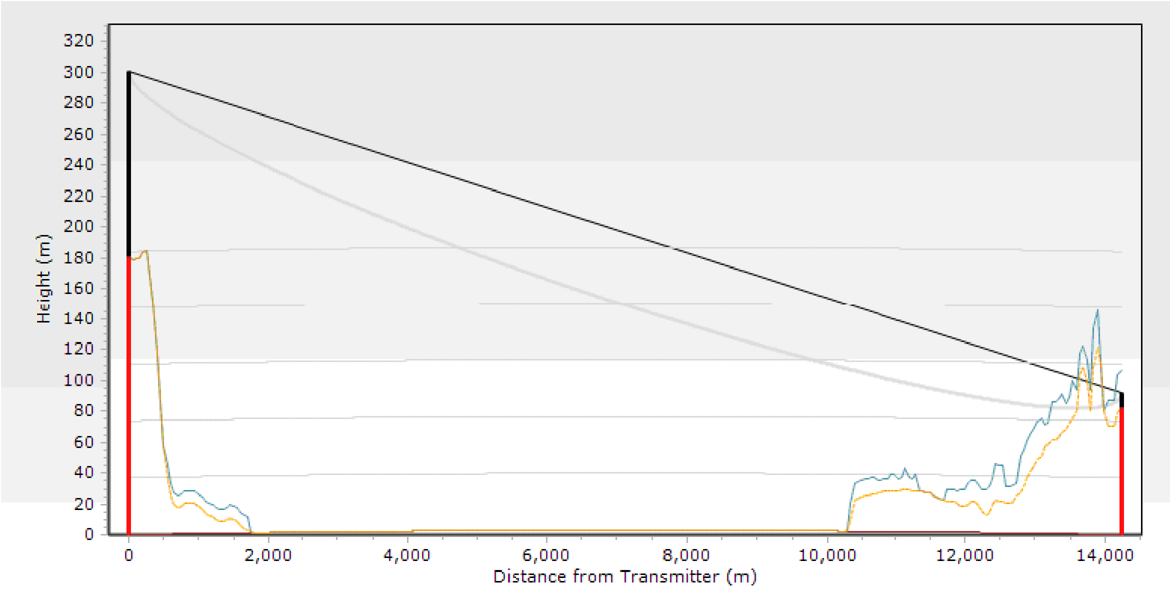


Figure G22: Path profile for light blue ring in Figure G20

The path profile for light blue ring corresponds to the junction of Grassmarket and Victoria Strret, where again the path is obscured by physical geography and building clutter. Google Earth allows an alternate view to be constructed showing the obstructions from the transmitter to reception location.

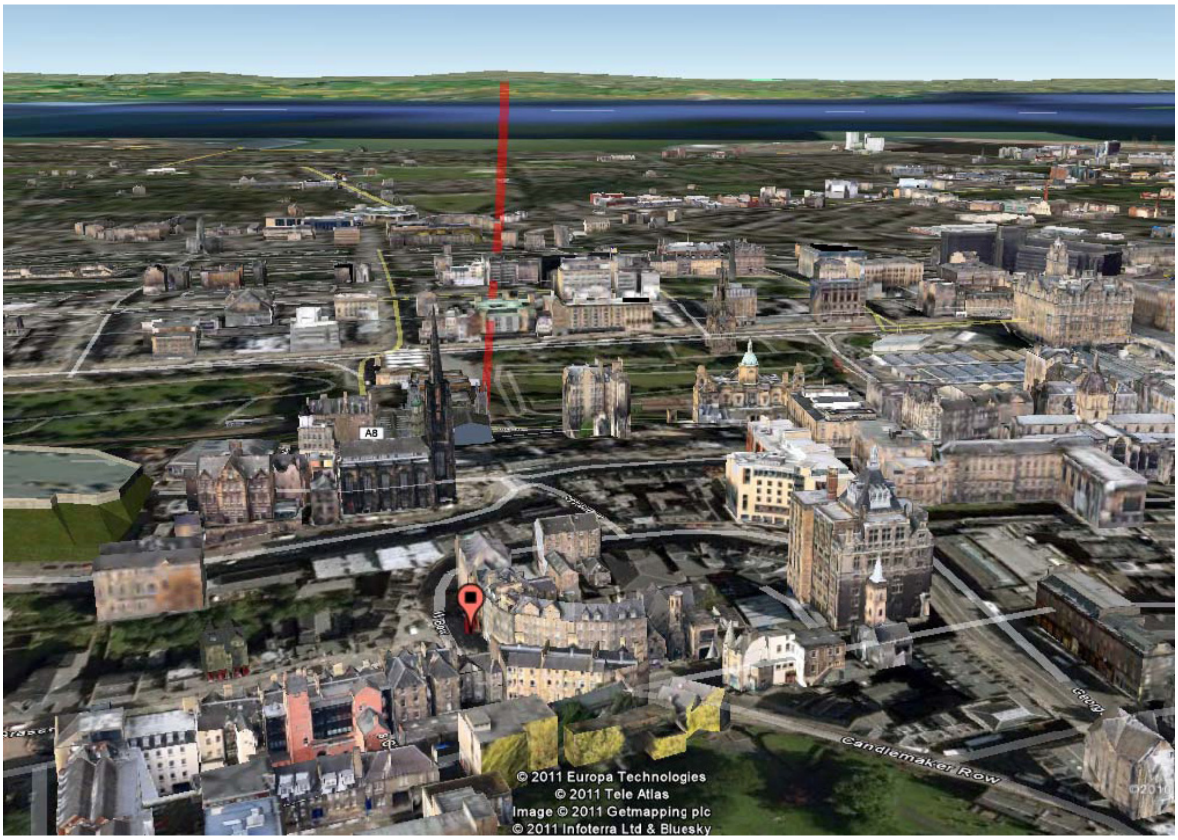


Figure G23: Google Earth plot for dark blue ring in Figure G20

G8.3.2 Edinburgh west and airport

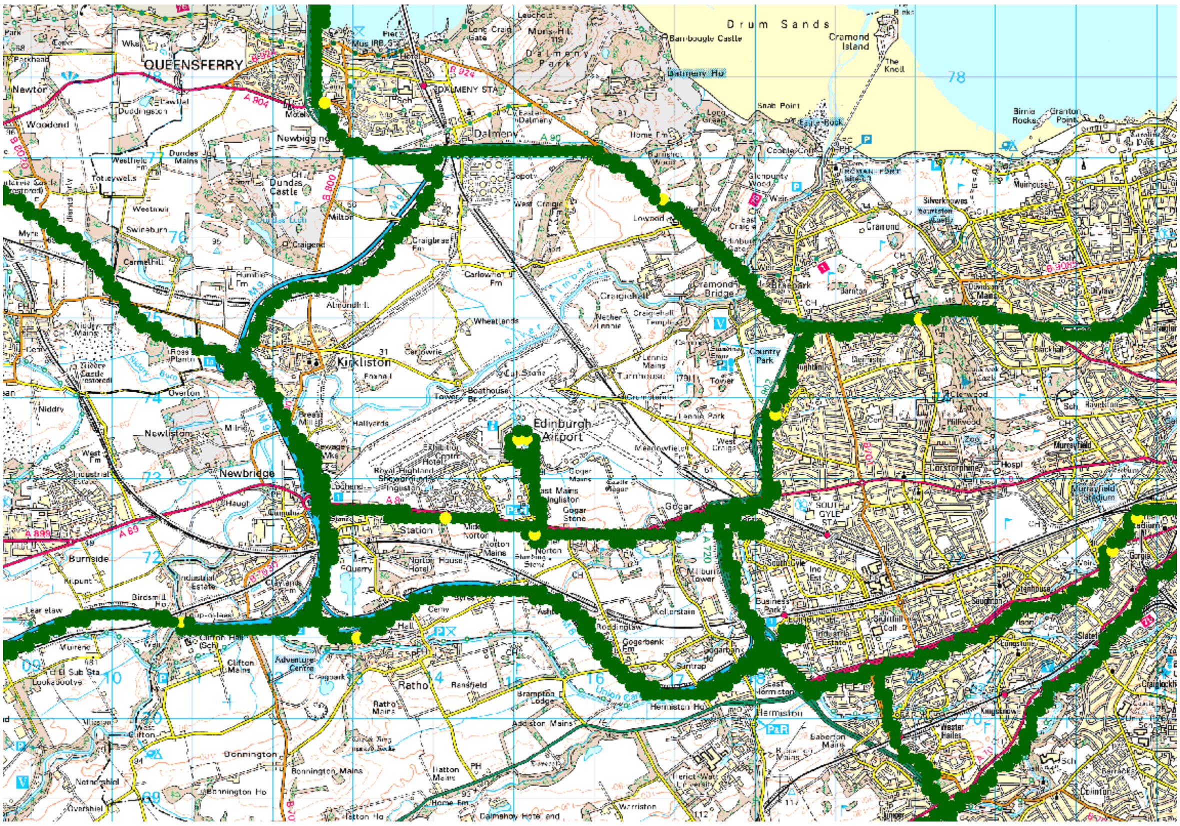


Figure G24: Edinburgh west and airport coverage, 4QAM rate 1/3

Figure G25: Edinburgh west and airport coverage, 16-QAM rate 1/2

For the 4-QAM mode, reception was very good with only occasional points with less than 100% audio quality. In practice, these manifested themselves as very short mutes. In both the modes used, each audio super frame contained five audio frames (24 kHz sampling with SBR). Therefore at the onset of impairment the audio super frame flag will indicate an errored audio super frame, but the impairment may actually be only a single audio frame of the five in error. This can be concealed by the audio decoder reconstructing the errored frame from the previous and following frames. The plots therefore show impairments that may not be heard by a listener.

For the 16-QAM mode the impairments are more frequent and more severe, with several stretches of road with short interruptions to the audio. The 16-QAM plot shows one area of severe audio loss, indicated by the red trail and corresponding to fewer than half of the audio super frames being received error free. A terrain profile plot was created for the location marked with the blue ring.

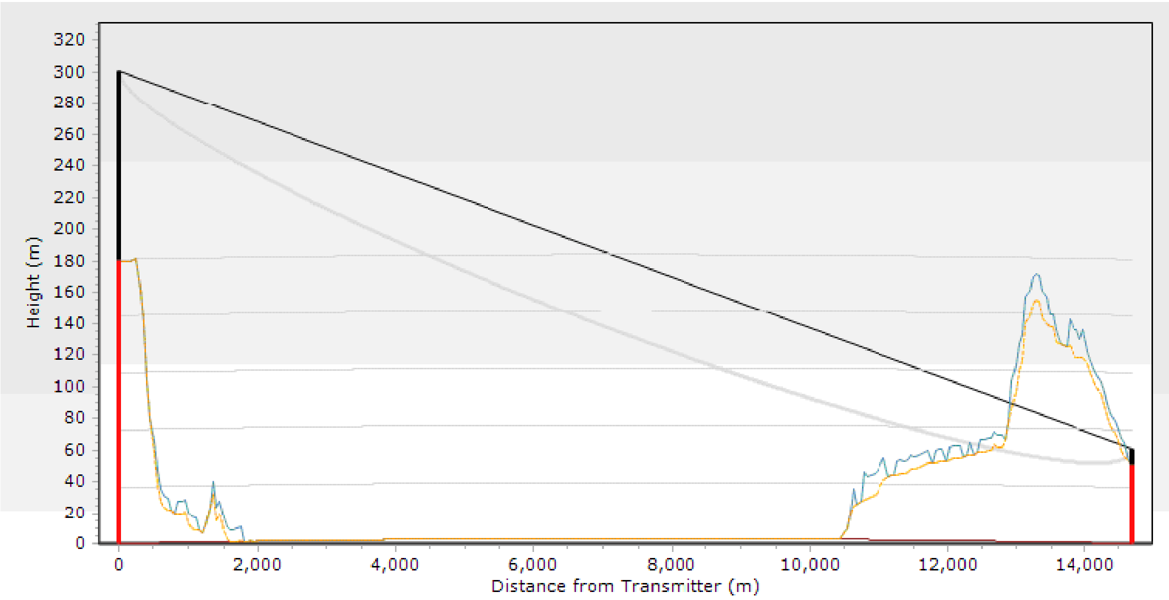


Figure G26: Path profile for dark blue ring in Figure G25

Again the cause of the impairment is clear; the reception location is close to a significant terrain barrier.

G8.3.3 Dundee

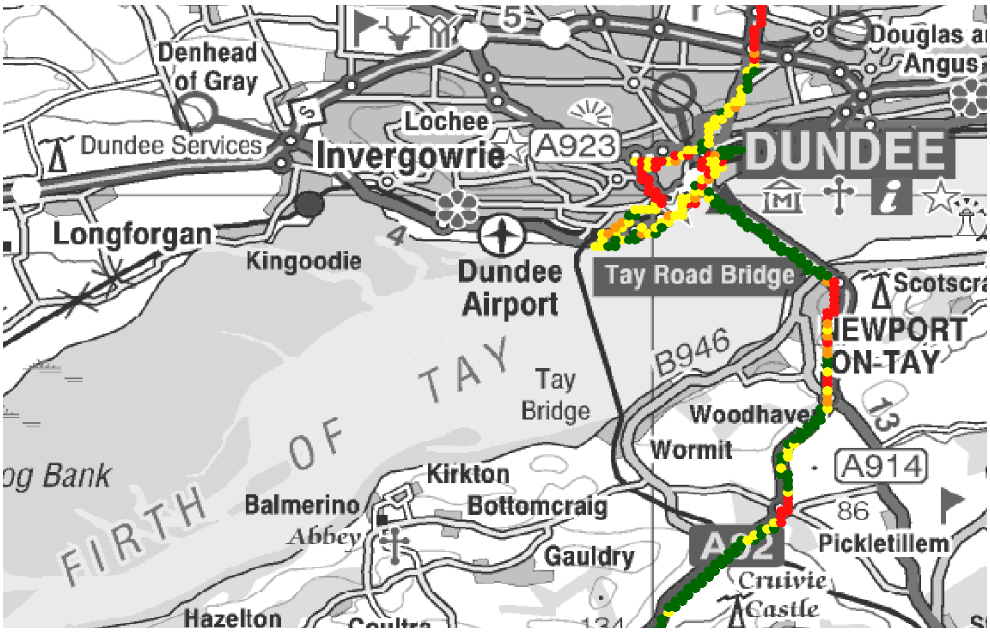


Figure G27: Dundee coverage, 4-QAM, rate 1/3

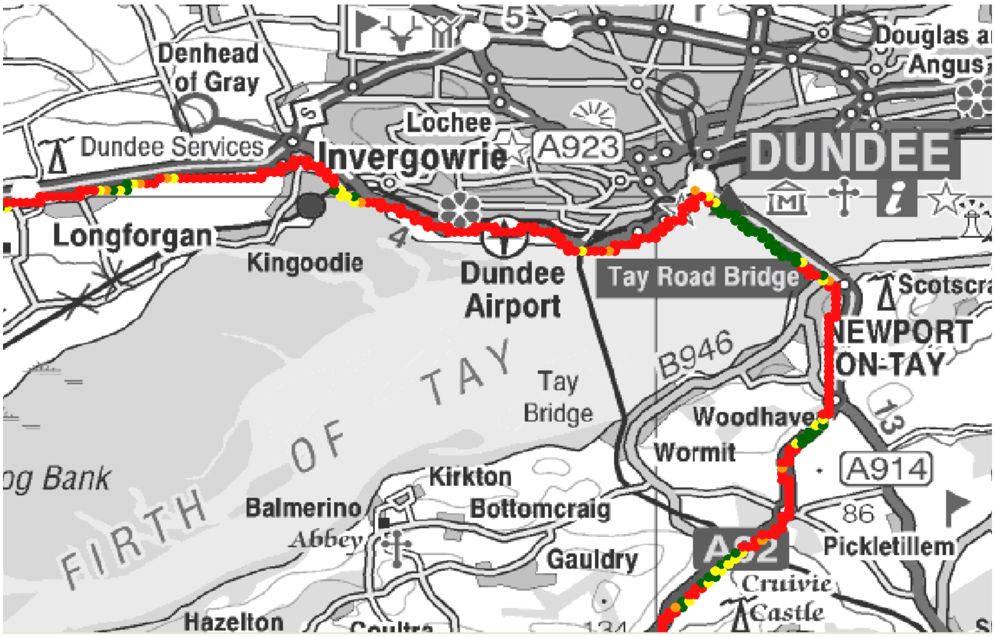


Figure G28: Dundee coverage, 16-QAM, rate 1/2

Dundee is at the edge of coverage for 4-QAM and beyond the coverage for 16-QAM. The ground also dips down to the Firth of Tay, and the maps mark three small transmitter sites close to the city to provide repeaters for analogue radio and television.

G8.3.4 Falkirk to Stirling

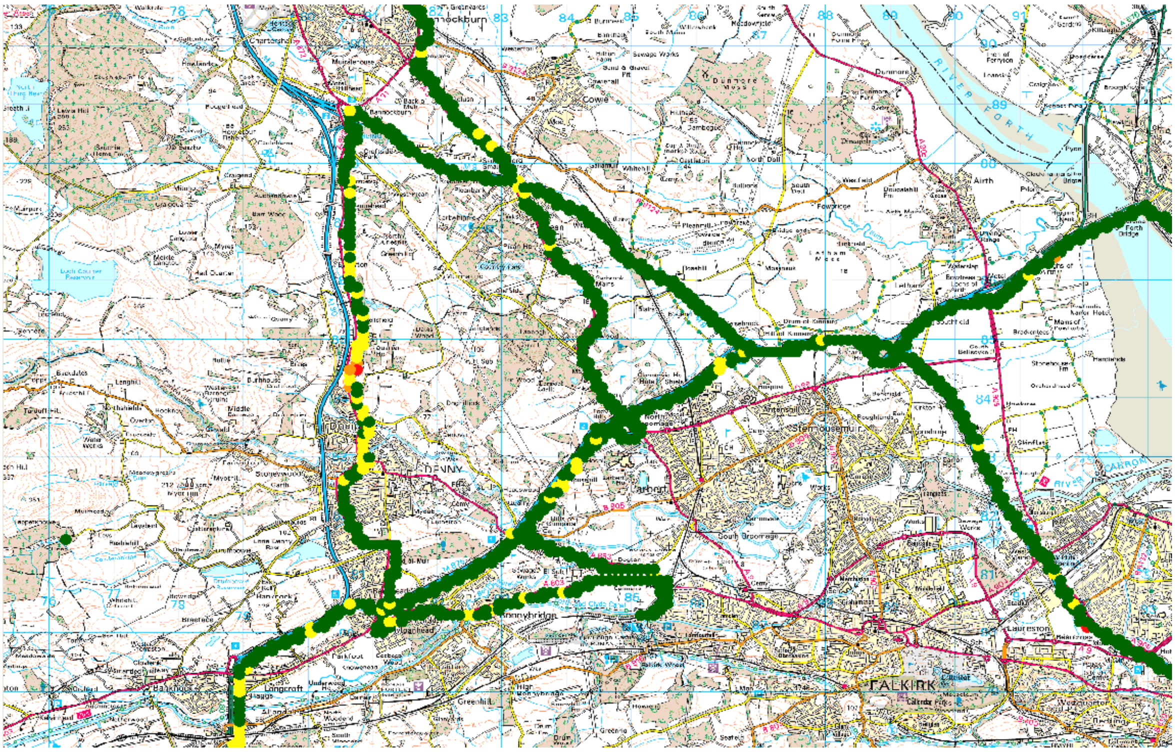


Figure G29: Falkirk to Stirling coverage, 4-QAM, rate 1/3

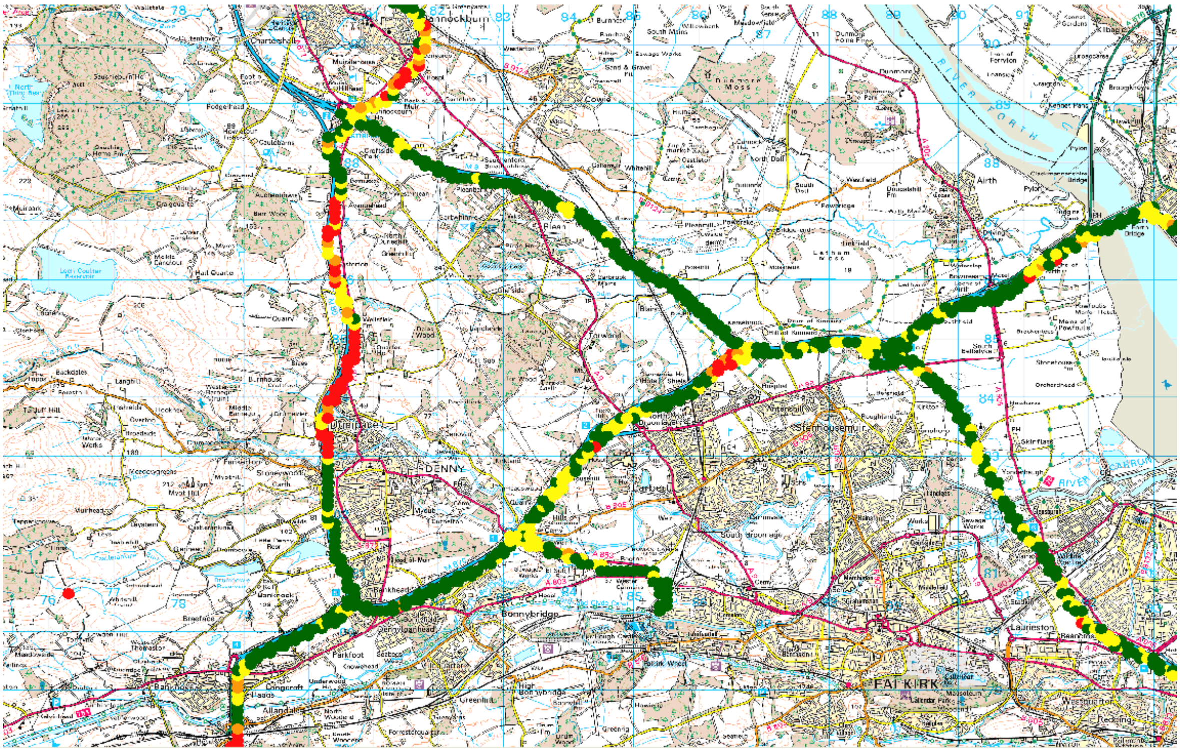


Figure G30: Falkirk to Stirling coverage, 16-QAM, rate 1/2

This area has very good coverage in the 4-QAM mode with only occasional impairments. Again the 16-QAM mode exacerbates the impairments; the western vertical route no longer being served.

G8.3.5 North Berwick

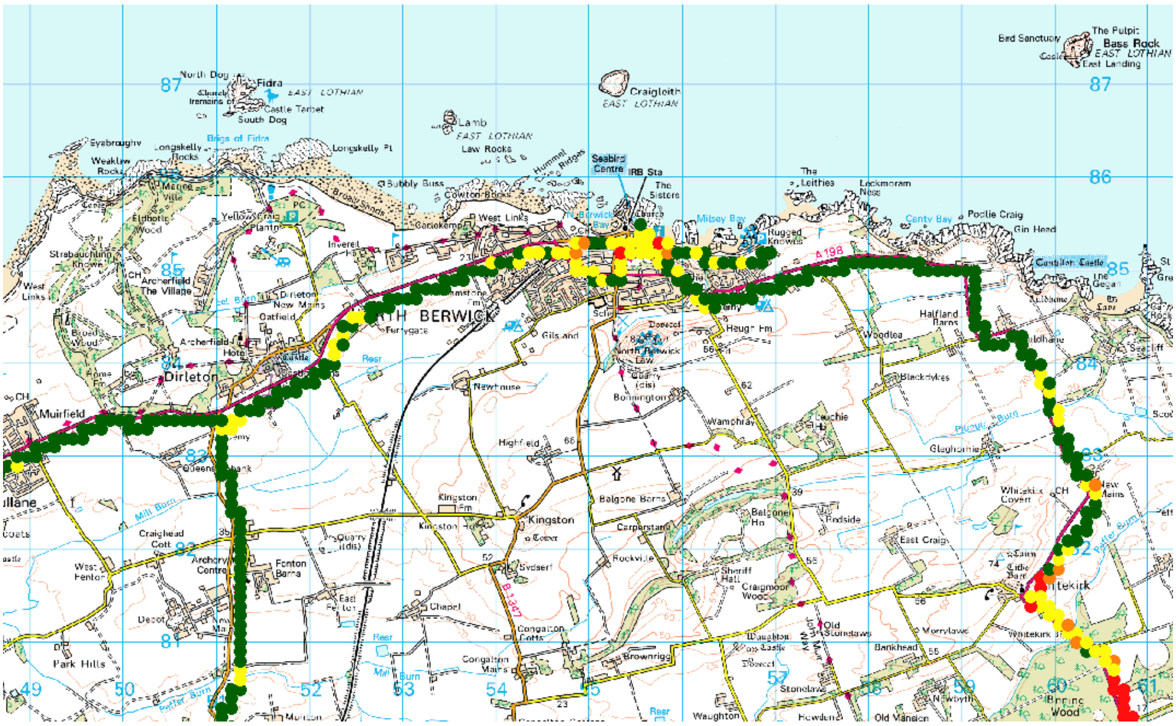


Figure G31: North Berwick coverage, 4-QAM, rate 1/3

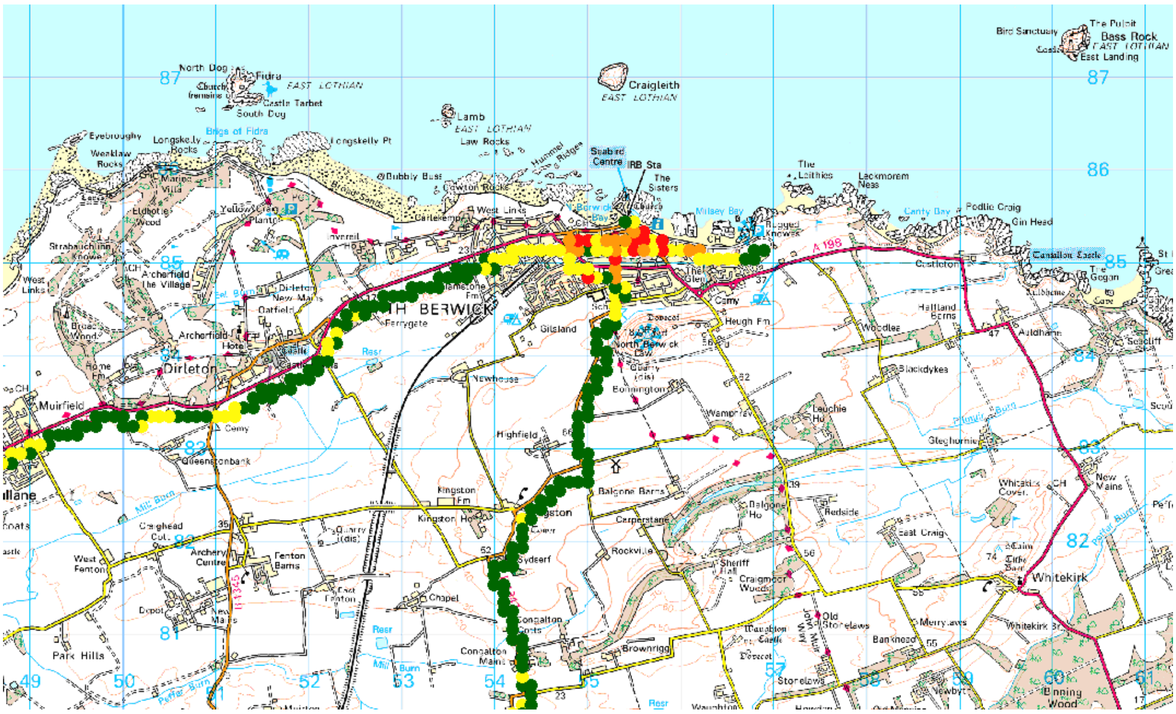


Figure G32: North Berwick coverage, 16-QAM, rate 1/2

Finally, North Berwick shows the eastern edge of coverage with impairments in the town centre for both 4-QAM and 16-QAM.

G9. Conclusions

DRM+ was extensively tested in the UK in a highly credible 'real environment'. The frequency and antenna system was previously used by a commercial FM station. A large number of measurements were taken over an extended period and extensive geography with a calibrated receiving system and analysis was performed on the data.

The trial has shown that DRM+ is capable of excellent coverage in good quality at reduced power levels compared with FM and that as expected 4-QAM was more robust than 16-QAM. Urban coverage was superior to FM, especially in the more rugged 4-QAM mode, because despite a few drop-outs, the overall subjective experience was found to be better than that of FM with noise, clicks and fuzz. The audio decoding method includes error concealment algorithms to fade-out to silence when audio frame errors are detected and fade-in again when the error rate falls. In rural areas, the coverage was also excellent although terrain shielding did cause some audio failure, although this was comparable to the experience with FM from the co-sited transmitters.

G10. References

[G1] **ETSI ES 201 980** Digital Radio Mondiale (DRM), System specification, 2009.

[G2] **ETSI TS 102 349** Digital Radio Mondiale (DRM), Receiver Status and Control Interface (RSCI), 2009.