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Digital Radio Mondiale (DRM)

DIGITAL RADIO MONDIALE DRM MULTI-CHANNEL SIMULCAST, URBAN AND INDOOR RECEPTION IN THE MEDIUM WAVE BAND

Abstract

In 2007 the Spanish broadcaster "Sociedad Española de Radiodifusión" (SER) has carried out some DRM (Digital Radio Mondiale), experimental tests in close collaboration with other companies experienced in broadcasting:, VIMESA, AXION and the University of the Basque Country.

This report presents the study on the performance and related propagation aspects of the DRM system after an extensive measurement campaign in the coverage area of an experimental network installed in the vicinity of Madrid (Spain). The testing was done from July to November 2007.

Firstly, an Introduction section describes the transmission and reception infrastructures. Subsequently, results will be summarized in three sections: Simulcast, Monocast DRM and Monocast DRM Indoor Reception. The first study analyzes the quality of analogue and digital services in the multi-channel simulcast based on a set of static and mobile measurements. Also the potential interference between the analog and digital signals is studied providing different power ratios between them. In the second study the performance of an operational DRM broadcasting station in order to cover a city as Madrid can be assessed. Finally, the indoor reception of the mentioned DRM broadcasting service was studied. This report contains information regarding, received audio quality statistics and minimum usable field strength thresholds.

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1 Introduction

In 2006 the Spanish broadcaster "*Sociedad Española de Radiodifusión*" (SER) raised the need to gain experience in DRM technology using the medium wave band. The test period should be long enough to evaluate properly the following issues:

– the system operation parameters for planning AM-DRM Simulcast services;

– a comparative study of AM and DRM transmission powers that are needed to obtain similar coverages;

– an evaluation of indoor DRM reception;

– an estimation of the DRM transmission power for correct reception using domestic receivers and antennas.

To this end, such broadcaster asked the Telecommunication State Department for permission to carry out experimental tests of DRM signal emissions. The digital signal would be broadcasted from the medium wave transmitter located in Pozuelo de Alarcón (Madrid) using the Simulcast mode during 6 months (from May to November 2007). The permission was obtained.

Also, a collaboration agreement was signed with other companies that have extensive experience in broadcasting, since they could cooperate and add an extra value to the project. These companies were the University of the Basque Country UPV/EHU (experience in DRM tests and measurements), Vimesa (transmission equipment) and Axión (availability of the transmission centre and experience in broadcasting using the Medium Wave band). On the other hand, the collaboration of TRANSRADIO, a German company of transmission equipment, should be taken into account, since it contributed with its experience, knowledge and some material lent to this experimental transmission.

Different field trials have been carried out with the experimental network from July to November 2007. These trials were performed in order to study the DRM system and specifically, to obtain operating thresholds and planning parameters of the AM-DRM Simulcast broadcasting and DRM Monocast broadcasting for big cities; considering both indoors and outdoors environments.

The transmission equipment and content server installation, the audio samples to be transmitted, the types of test and the measurement equipment and routes were planned during the meetings with the involved societies.

This document is divided into ten sections. Section 2 summarizes the general and specific objectives of the project. The transmission experimental network is described in Section 3. Then, Section 4 includes the description of the reception system and the most important parameters. In Section 5 the measurement methodology is stated. In Sections 6, 7 and 8 the obtained results are given. These ones are classified according to the objectives of the project: Simulcast, DRM in urban areas and indoor reception. Section 9 analyzes the results obtained with commercial receivers. Finally, Sections 10 and 11 are the corresponding conclusions and bibliography.

2 Objectives

The main objective of this project is the evaluation of the DRM system (Digital Radio Mondiale) when using the medium wave band. The project is focused on simultaneous broadcasting tests of the AM analog and DRM digital signals with the configuration known as MCS (multi-channel simulcast), as well as the evaluation of the DRM system in urban areas; considering both indoors and outdoors environments.

Specifically, the objective is to find the operating parameters according to three issues:

Evaluation of the DRM-AM Simulcast system: obtaining the system operating parameters for planning an AM-DRM commercial service. Specifically three objectives are stated in this case:

a) to determine the coverage area, thresholds values and QoS of an AM-DRM MCS signal. The operating thresholds, coverage limit and quality of the transmitted Simulcast signal will be obtained by means of field measurements;

b) to evaluate the influence of the DRM signal over the AM signal when using the Simulcast configuration. That is the evaluation of the digital signal effect over the analog one by means of objective quality parameters of the DRM signal and the subjective audio evaluation of the AM signal considering a representative set of commercial receivers;

c) to evaluate the optimum back-off ratio between both the AM and DRM components of the Simulcast signal. The objective would be the estimation of the AM and DRM signals power ratio which allows the digital signal transmission with the maximum power that does not cause the worsening of the audio quality of the analog signal.

Evaluation of the DRM reception in a city with dense urban areas: transmitting the maximum power that is permitted for the transmitter equipment, without the restrictions of the Simulcast configuration.

Evaluation of the indoor DRM reception: obtaining the reception thresholds according to different reception conditions inside different buildings in order to compare them with the corresponding ones of outdoor reception.

3 Transmission infrastructure: transmitted signals

The transmission infrastructure for the DRM tests of this project was successfully installed in the AXION's transmitting station in Pozuelo de Alarcón, located about 9 km away from Madrid downtown (Figure 1).

Once the project specifications were defined, difficulties to fulfill minimum requirements were found. Tests should be carried out in a big city, if possible Madrid. Therefore, it was needed a transmission center close to the downtown, with an appropriate radiating system, electric power supply and enough infrastructure to accommodate the transmission equipments. The working group tried to fulfill such requirements as far as possible. To this end, different operative transmission centers providing Medium Wave Band broadcasting services to big cities, like Madrid, were studied.

Only one center fulfilled all the requirements. It was located in Pozuelo, about 9 km away from the Madrid downtown (Puerta del Sol). It was a perfect location excepting that other high power broadcasting services were provided from this place.

FIGURE 1

Medium wave transmitting station in Pozuelo (Madrid)

This implied the installation of one filter for each transmitter in order to ensure the compatibility of the corresponding transmissions, that is, the 2 existing analog transmissions and the new digital one.

The medium wave services were broadcasted from a 96 m high mast which is 85 m away from another 60 m high mast. The last one is used for FM broadcasting, and also, as an emergency radiating system. In order to broadcast simultaneously the AM and FM signals, a folded monopole was selected. This choice proved later to be the right one.

In that moment, the main mast was connected to a 50 + 50 kW operative diplexer for the frequencies of 810 and 954 kHz. The selected frequency for DRM transmissions was 1 260 kHz and the lower adjacent channel was chosen for simulcast use (see spectrogram).

Later, a measurement set of the 60 m high mast's impedance was carried out for the DRM transmitter frequency (1 260 kHz). Impedance must be measured for the central frequency and in the ± 20 kHz interval, considering 2 kHz steps. In order to fulfill the objectives, the variation along this interval should not be high. To this end, the folded monopole was very useful because if the impedance has not a right value, short circuits can be applied to obtain the desired value.

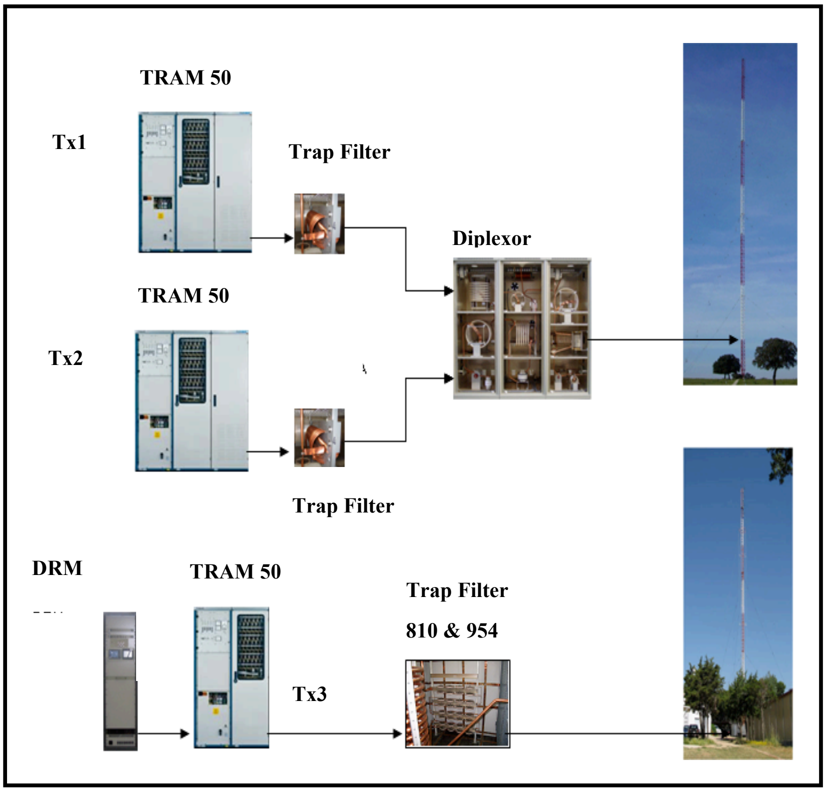
According to the previous considerations, the working group and TRANSRADIO decided use the 60 m high mast as the DRM transmitter's radiating system and appropriate filters were designed and installed.

A TRANSRADIO TRAM 25 transmitter with maximum peak power of 25 kW, a Fraunhofer content server, a M-Audio Delta 1010 sound system and a TRANSRADIO DRM-DMOD2 signal generator were installed, as well as a remote control system in order to make easier the measurements of different DRM and Simulcast transmission modes.

The DRM-DMOD2 signal generator allows both MCS (Multi Channel Simulcast) and DRM Monocast modes. When using Simulcast mode, the DRM signal was transmitted considering the central frequency of 1 251 kHz and the AM signal was centered in 1 260 kHz, as seen on Figure 3.

FIGURE 2

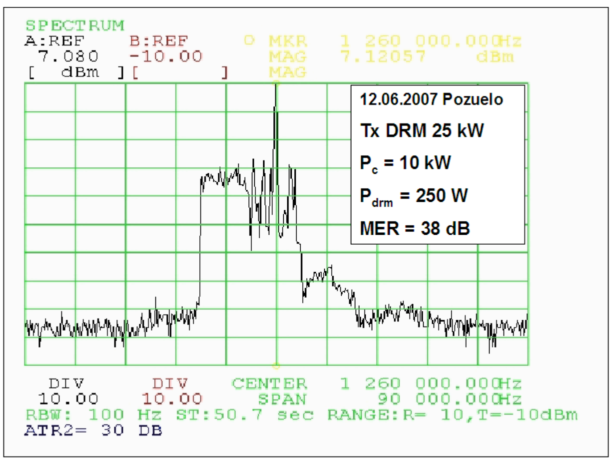
DRM transmission system diagram installed in Pozuelo



For the simulcast mode, DRM standard considers different configurations for transmitting simultaneously the analog AM and digital DRM signals, using the same transmission equipment and radiating system. In this project multi-channel simulcast (MCS) configuration has been evaluated. Such configuration, consists in the ITU Region I of two adjacent signals of 9 kHz bandwidth, one of them analog and the other one digital. During the tests, the DRM signal was centered in 1 251 kHz and the AM carrier was in 1 260 kHz, as shown on Figure 3.

FIGURE 3

Transmitter antenna's output MCS spectrum



The multicarrier digital signal causes interference to the adjacent analog channel. In order to establish the harmony between the digital signal radiated power – and in consequence, its coverage – and a negligible grade of perturbation of the analog signal, a relative level of the analog power higher than the digital one is needed. The recommended back-off ratio between the AM carrier and the DRM signal that has been obtained from different laboratory tests carried out by the DRM consortium is 16 dB. Since such value has also been proved a right ratio as a result of field trials in ITU regions 2 and 3 [1], the MCS configuration with 16 dB back-off ratio has been considered the reference mode and it has been significantly analyzed during the field trials.

On the other hand, if the analog component of the Simulcast signal would allow back-off ratio values lower than 16 dB, the coverage area of the digital service could increase. In order to study the application of power ratios lower than 16 dB, three MCS configurations with other back-off ratios have been suggested. The four configurations have been specifically transmitted in order to carry out a comparative analysis of the mutual interference between analog and digital components of the Simulcast signal. The main characteristics of such MCS configurations are included in Table 1. Apart from these configurations, the transmission of the AM signal without the digital component is considered in order to evaluate the quality of the analog service in absence of the possible DRM interference.

TABLE 1

Proposed MCS transmission configurations

Reference code	DRM RMS Power (kW)	AM Peak Power (kW)	Power Ratio (dB)
10001	0.25	10.0	16.0
10002	0.5	7.5	11.8
10003	0.75	4.0	7.2
10004	0.9	1.25	1.5

On the other hand, the transmission of a DRM monocast service allowed the test of the transmitter power performance without the MCS limitations, for both outdoor static and mobile reception, as well as indoor reception. In this way, the difference of this type of transmission is the spectrum occupancy, now only 9 kHz for the DRM signal centered in the frequency of 1 260 kHz, and the transmitted power that increases up to 10 kW.

The DRM standard [2] includes several transmission parameters that are configurable for all the modes. Such parameters provide different robustness levels against noise, multipath or interference of the DRM signal. The more robustness, the lower available bit rate and therefore, lower subjective audio quality. According to the results of previous measurements campaigns, Table 2 shows the selected transmission DRM modes for, both Simulcast and monocast configurations.

In general, the selected DRM mode is a robust configuration for the ground wave propagation, the only propagation mode that existed during the tests. Using the AAC+ coding (MPEG-4 advanced audio coding with spectral band replication) with the available bit rate, a parametric stereo audio quality is obtained from the transmitter which is a clearly higher quality than the one obtained with AM emissions.

TABLE 2

Tested DRM Configuration

OFDM Mode	Data Channel Constellation	Redundancy	Interleaving	Bit rate (kb/s)	Min. SNR UIT-R BS.1615 [3] (dB)
A	64QAM	40%	Short (0.4 s)	23.6	15.1

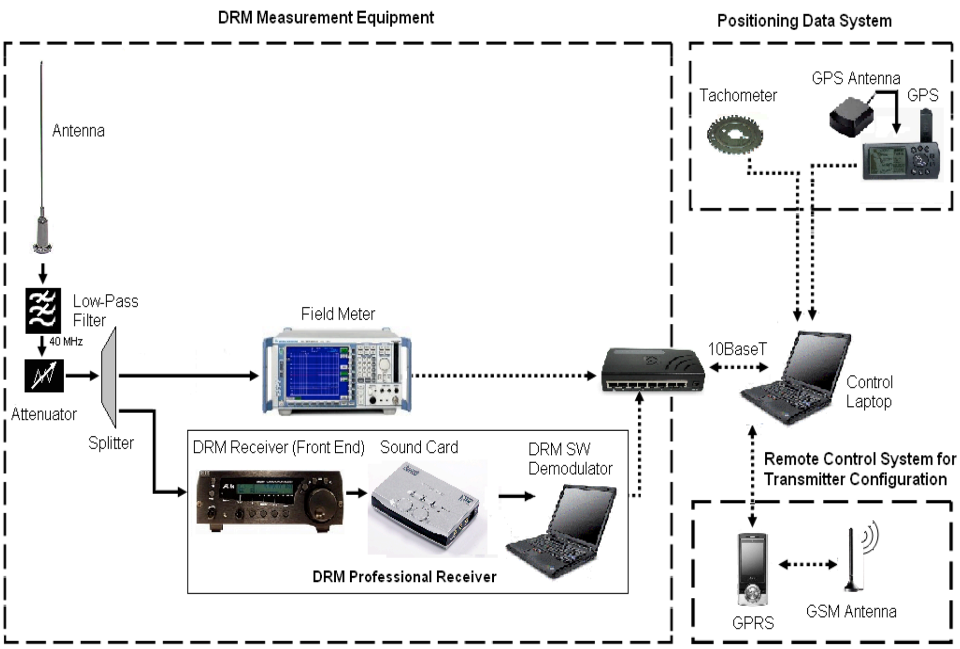
The same base band audio source was used for the analog and digital signals during these tests in order to compare them. The audio contents were compiled by Cadena SER from its commercial emissions. In fact, recordings of the signal corresponding to *M-80 Radio* and *40 Principales* broadcasting services were used, including speech and music contents. Broadcaster and other advertising was previously removed from such contents.

4 Reception infrastructure: measurements

The University of the Basque Country (UPV/EHU) installed a measurement system in a mobile unit that was specifically conditioned in order to carry out an extensive measurement campaign in Madrid. In this way, outdoor static and mobile reception measurements were done. A scheme of the measurement system is shown on Figure 4.

FIGURE 4

Measurements system's block diagram situated in the mobile unit



The measurements system is divided into three sections: the acquisition and distribution section, the measurements equipment section and the control section. The acquisition consist of a fully characterized short monopole active antenna R&S HE010 [4], placed on the top of the measurement vehicle over a specified ground plane. Also a helicoidal passive antenna with a measured K factor of 29.9 dB was used to carry out measurements and compare them with the ones corresponding to the active antenna. The received signal by both antennas was distributed towards the equipment of the measurement system: the R&S ESPI3 [5] field strength meter and the DRM professional receiver, composed of an AOR7030 front-end, a Presonus Firefox digitizer card and the Fraunhofer SW DRM Demodulator [6].

The control system was based on a laptop computer running a control software tool over a GNU/Linux platform to configure and control the rest of the equipment. Besides, a GPS receiver and a tachometer provided ancillary data such as time, position and trip data.

Another module of the measurement equipment (not in the figure) was a set of commercial receivers to evaluate the subjective audio quality of the AM Simulcast service from a standard user's point of view, that is, without using instrumentation antennas. In this way, a high end receiver was installed in the mobile unit with its own external antenna, as well as five different receivers of mid-range quality; two of them were digitally tuned.

A set of DRM or AM signal parameters and ancillary data was automatically recorded by the measurement system (Figure 4) and stored in plain text format files. On the other hand, the commercial receivers provided the audio of the demodulated analog service. Table 3 and Table 4 show the types of measurements carried out by the different system modules for AM and DRM signals. Besides, noise measurements were performed in an empty channel by means of the field strength meter. In any case, only measurements of a single signal were taken simultaneously.

TABLE 3

Measured parameters: AM signal

Provider	**Type**	**Parameter**	**Fs**
DRM Receiver	RF	Field strength	400 ms
	IF	IQ signal	
Commercial Receivers	Baseband	Subjective audio quality	Continuous
Field Strength meter	RF	Field strength	400 ms

TABLE 4

Measured parameters: DRM signal

Provider	**Type**	**Parameter**	**Fs**
DRM Receiver	RF	Field strength	400 ms
		S/N	
		Delay spread and Doppler	
	IF	IQ signal	
	Baseband	Erroneous audio frames distribution	
Field Strength meter	RF	Field strength	400 ms

The base band parameters, the calculated statistics, the sampled input IF signal and the measurement parameters of the DRM signal, given by the RSCI standard [7], were stored in binary files. The received DRM, AM and noise IQ samples of the whole measurement campaign were thus stored for any subsequent processing.

The ancillary data, such as space and time references are shown in Table 5. The tachometer module provides the traveled distance and the instantaneous speed. In order to calculate statistics, it also allows the configuration of a trigger when traveling a specific distance

TABLE 5

Ancillary data

Provider	**Type**	**Parameter**	**Fs**
Ancillary data	Tachometer	Distance	Every 2.2 meters
		Trigger	
		Speed	
	GPS receiver	Time	1 s
		Position – Speed	

In order to complete the information given by the measurement system, a detailed description of each measurement location was done and several photos of the surrounding reception area were taken. Such description takes into account the presence of high buildings or vehicles obstructing the reception antenna, as well as the radio electric noise sources.

So far, general considerations for the outdoor measurement system have been described. Regarding the indoor measurement system, the most relevant difference is the antenna, now the active magnetic loop *Wellbrook Communications ALA 100*. This antenna does not require ground plane and thus, it is easier to use than the previous ones for outdoors environments. Nevertheless it is not omni directional. Thus, its K factor has been measured considering the direction of maximum reception and it is 20 dB.

5 Data acquisition methodology

The measurement acquisition methodology is different for static and mobile reception. For static reception, the measurement parameters of each analyzed signal were recorded in each location during three minutes without interruption. This period is enough to show that channels' time variability since they are very stable in the medium wave band. Also, noise measurements were carried out during one minute in an empty channel close to one where the evaluated signals were transmitted. This channel was centered in 1287 kHz. According to this, nine different measurements had been obtained at each location where the proposed four Simulcast configurations were measured: four of them containing AM signals, four with DRM signals (each one with duration of 3 minutes) and finally, one noise measurement. Besides, for each AM signal, one decoded audio minute was recorded with each commercial receiver.

The indoor measurement acquisition methodology presents some differences with the others static measurements. The non omni-directional antenna of this system has two nulls along the loop axis, so each measurement was taken considering two different positions of such antenna. Firstly, the data acquisition was done positioning the antenna in order to obtain the maximum signal to noise ratio for the DRM signal. In this first position, a 3 minute signal measurement and 1 minute noise measurement were done. Then, the same operation was done turning the antenna 90 grades; signal and noise measurements were carried out during one minute respectively.

For mobile reception, the measurements were carried out by stretches. Each one of them was usually the link between two static locations. Since it is only possible to measure one single signal in each measurement process, it is necessary to travel each route twice in order to carry out the measurements of both DRM and AM Simulcast components: once measuring DRM and once measuring AM. In this way, statistically meaningful parameters could be obtained in order to compare both signals when mobile reception, although the reception conditions were not identical for DRM and AM reception in the same route. The mobile AM reception quality with commercial receivers was evaluated in a guidance way during the measurement campaign; taking into account the conditions of AM service unavailability.

6 Simulcast trials

In this section, the DRM multi-channel simulcast system trials are presented. The transmitted signal consisted of two components: a DRM component centered on 1 251 kHz and an analog AM one on 1 260 kHz. The power was distributed between them according to four MCS configurations, namely, 10001, 10002, 10003 and 10004 as explained in Table 1.

The so-called MCS 10001 configuration, which specifies 16 dB of AM-over-DRM power ratio, has been extensively measured. This value was successfully tested both in former laboratory and field trials. The rest of configurations have been measured in a subset of fixed locations of the extensive trials, in order to assess the potential mutual interference between the two parts of the MCS with different power ratios between them. At some of these locations AM Monocast measurements were performed in order to establish a subjective audio quality reference. Man-made noise was measured at every fixed location.

Contents are displayed as follows. Firstly, the trials planning and extension as well as the coverage evaluation criteria for both DRM and AM are commented in Subsections 6.1 and 6.2. Thereupon, the methodology for obtaining and evaluating AM audio samples is explained in Subsection 6.3.

Subsequently the trials results are shown in two different subsections. The **first block** (Subsection 6.4) consists of the analysis of **coverage and operational thresholds of both parts, that is, DRM and AM, of the 10001 MCS configuration** (16 dB of power ratio). The **second results block** (Subsection 6.5) analyzes the **compatibility of the two signals that integrate the Simulcast taking into consideration different power ratios between them and different receivers**. The potential interference of each part on the other is studied as well as the influence of such interference on incorrect reception situations.

6.1 Trial description

The medium wave simulcast trials of Madrid were organized into two groups. In the first group an extensive measurement campaign was carried out in order to analyze the behavior of the MCS signals, the digital one as well as the analog one, in different areas and reception environments provided a 16-dB AM-over-DRM power ratio. In the subsequent analysis, the system operational thresholds as well as the coverage of both services of the MCS 10001 Simulcast configuration were set, both in static and in mobile reception. The MCS measurement campaign was performed along some preset routes whose features are shown in Table 6.

More than 200 static reception measurements were carried out in 42 locations and more than 210 km were measured along the corresponding routes overall. The so-called radial routes or coverage routes were set up in order to assess the system coverage limits in areas further than the city of Madrid. The so-called urban routes begin at the closest location to the transmitter, Pozuelo de Alarcón, but they are mainly focused on Madrid as the main aim of both the digital and the analog services of the MCS signal.

TABLE 6

Measurements routes of the MCS 10001 Simulcast

Designation	Environment description	Area	Measured stretch overall distance	Number of measured locations	Average distance to transmitter
East Radial	Urban of different types	Pozuelo towards Madrid, downtown Madrid, M-40 East	57 km	1	9 km
South Radial	Mainly rural Suburban	M-40 South, Carabanchel, South up to Toledo	50 km	-	30 km
Pozuelo	Urban. Buildings of average size	Pozuelo de Alarcón	50 km	17	2 km
Gran Vía	Urban. Irregular narrow streets	Madrid West-SW West of Castellana Walk	37 km	16	8 km
Salamanca	Urban. Wide perpendicular streets	Paseo de la Castellana East of Castellana Walk	17 km	8	10 km
Carabanchel	Urban (non dense)	Madrid South	3 km	-	9 km

On the other hand, a group of static reception specific trials was carried out in order to evaluate the power ratio values between the analog part and the digital part of the MCS signal. By means of these trials it has been tested how much the DRM power could be increased without degrading the adjacent AM QoS (Quality of Service). In order to accomplish this, 11 of the 42 locations included in Table 6 were selected for measuring the four proposed MCS configurations. This subgroup of locations were chosen so as to have more points in the areas that were expected to be more difficult to cover, namely, 8 locations in the Gran Vía route, 2 in the Salamanca route and 1 in Pozuelo de Alarcón.

In order to perform a rigorous, exhaustive and quantitative study of MCS AM QoS using different AM receivers, static reception was mandatory. That is the reason why the comparison amongst MCS 10001, 10002, 10003 and 10004 configurations has been carried out by means of static reception measurements.

6.2 QoS Criteria

QoS is studied on the basis of RF (Radio Frequency) measured parameters of the signal (field strength and SNR), as well as parameters of reception audio quality. RF signal parameters were measured every 400 ms, but in the static reception analysis, median values were considered for the study of each location.

The audio quality at reception is the key criterion for evaluating coverage. The quality criteria considered to evaluate Simulcast AM and DRM coverage are explained below.

AM QoS

The availability of the analog service at a certain location is assessed by the subjective evaluation of the audio demodulated by a receiver. Subjective AM audio quality assessment was carried out following the audio quality degradation criteria of Recommendation ITU-R BS.1284 [8]. Hence, each evaluator scores the degradation of the audio sample under study according to the scale shown in Table 7. In this scale, 4 and 5 values can be considered as good reception while the rest can be considered bad reception.

TABLE 7

AM subjective quality criteria

Quality		Degradation	
5	Excellent	5	Imperceptible
4	Good	4	Perceptible, but not annoying
3	Fair	3	Slightly annoying
2	Insufficient	2	Annoying
1	Bad	1	Very annoying

The analog QoS evaluation procedure of each location audio sample was carried out by each of the evaluators. Therefore, each audio sample, which was obtained using a receiver at a certain location, had as many evaluation scores as evaluators or listeners.

Taking into consideration all the above, an audio sample has been considered to show correct quality, that is, to show AM service coverage, if the mean value of its evaluation scores was higher than 3.5. On the other hand, at a certain location, all the listeners evaluated a certain AM service using all the receivers proposed, so that there was a mean evaluation score for each receiver. Thereby a certain location could be covered by an AM service with a certain receiver but could remain uncovered according to the mean evaluation score of another receiver.

As for subjective evaluation of mobile reception audio using several receivers, mobile reception conditions are so changing that even driving along the same route several times (one per receiver) was not enough to perform a direct quantitative comparison. That is why subjective audio quality of the AM service of the Simulcast signal was not quantitatively evaluated but only approximately.

DRM QoS

The subjective audio quality available with a certain DRM service depends on the bit rate provided by the transmitted DRM configuration. However, only if the DRM signal is correctly decoded at reception will this available audio quality be enjoyed by the listener. As a digital system, if the DRM signal is not correctly received audio frames could be lost thus causing audio dropouts. In this way, it is possible to obtain objective quality values of the DRM service as a function of the wrongly decoded audio frames at reception.

The parameter used to measure DRM audio objective quality is the so-called AudioQ. Given an analysis time interval, this parameter is defined in terms of percentage as follows:

$$AudioQ(\%) = \frac{Number\ of\ correctly\ decoded\ audioframes}{Number\ of\ transmitted\ audioframes}$$

Considering this parameter, in static reception, **the minimum threshold for an average listener perceptible audio error free reception is 98%**. This threshold means that within 1 minute there is a 1.2 second cumulative error time. According to statistics, this error time is distributed in several minor errors thus providing a quasi error free reception experience for an average listener. This threshold has been taken as a reference value of correct reception audio quality which has been used in many trials within the DRM Consortium. This value is in fact a very conservative criterion for time intervals of several minutes, so it is suitable for the three-minute measurements performed in this measurement campaign static reception.

The number of wrongly decoded audio subframes has also been considered for DRM mobile measurements quality assessment. However, in this case, instead of calculating AudioQ parameter every three minutes, it has been calculated every 400 ms, that is, the duration of one DRM frame which contains 10 audio subframes. With this AudioQ figure two different coverage criteria have been used for each mobile reception DRM frame. According to the first one, a DRM frame is considered correctly received if all the audio frames were correctly decoded, i.e., if provided perfect reception. The second criterion admits one wrong audio subframe within a DRM frame, thus it is a bit less restrictive than the 98% AudioQ criterion that was assigned to static reception.

6.3 Methodology for obtaining AM audio evaluation scores

AM QoS quantitative study was carried out in static reception by means of evaluating the subjective quality of the audio that was demodulated using several receivers at each location. This way, an audio sample was obtained from the demodulation of the AM part of a single MCS configuration signal at one location. That is, at a single location and considering one MCS configuration there were as many audio samples as receivers were used. Besides, every audio sample was evaluated by all evaluators so that each one scored the sample quality according to the above-mentioned scale.

In the simulcast trials six AM receivers were used in order to obtain AM quality quantitative evaluations. Onwards, These receivers will be referred to as Receiver A, B, C, D, E and F. Receiver A was a high-end one. Receiver B was an upper mid-range AM receiver. The rest were a representative set of commercial mid-range receivers. Each AM audio sample, which was obtained from one receiver at a certain location, was evaluated by four expert listeners. The mutual interference of the two signals of the Simulcast was analyzed through samples of MCS configurations 10002, 10003 and 10004 that featured nominal AM-over-DRM power ratios of 11.8 dB, 7.2 dB and 1.5 dB, respectively. Likewise, AM Monocast QoS was evaluated as a subjective audio quality reference of the AM service without the influence of the simulcast DRM adjacent signal.

6.4 MCS coverage results with 16 dB power ratio

The first section about Simulcast results consists of the analysis of reception quality and the operational thresholds obtained for the MCS signal in the 10001 configuration (AM-over-DRM 16 dB power ratio) in its two components: DRM and AM. With this aim, the parameters measured in the reception of both signals of the MCS have been analyzed in different zones of the expected coverage area, each one characterized by a type of reception environment and located at a certain distance from the transmitter. In order to check the feasibility of the MCS system as a useful transition system for AM, the subjective quality of the analog signal received in the Simulcast by commercial receivers was analyzed. In the subsequent analysis, the system operational thresholds have been established, as well as the coverage areas for the analog and the digital services of the MCS for both static and mobile reception.

In this section, first of all the analog service of simulcast in static and mobile reception is analyzed. Then, the DRM service is studied. In both cases, the availability and the coverage area as well as several causes of reception failure are studied in different environments.

6.4.1 AM service reception

The global results for the static reception trials of the analog part of the MCS 10001 configuration are shown in Table 8. The number of test points which have been considered for the analysis is 32. These locations have been distributed among the areas mentioned above. Using the best receiver, a total of 29 points featured subjective assessment average scores higher than the 3.5 threshold for correct reception.

TABLE 8

MCS 10001 AM quality global results

AM Power	10.0 kW
Total number of assessed locations	32
% of locations with correct reception (average > 3.5). Best receiver	90.6%
% of locations with correct reception (average > 3.5). Worst receiver	43.7%

The best receiver was the high end one. The mid-range receiver featured fair lower quality results. Table 9 shows those points where reception has not been correct using the best receiver, as well as the values of the signal parameters that were measured.

TABLE 9

Problematic points for AM reception. Best receiver

Point	Area	Environment	DistanceTx (m)	Field str. (dBµV/m)	SNR (dB)	AM-DRM Power ratio (dB)	Average subject. evaluation score
mcsGVp2	Gran Vía	Dense	7166	86	54.5	16.6	3
mcsGVp8	Gran Vía	Dense	8701	77.3	45.4	18.4	3.3
mcsPp3	Pozuelo	Suburban	583	106.4	44.4	17.3	3

In these three points the average subjective evaluation had a value very near the correct reception threshold (3.5). The third location was the nearest point to the transmitter in the whole measurement campaign. The proximity to the transmitter caused the saturation of the AM receivers, so even though a very high electric field strength value (106 dBµV/m) was measured, the SNR value was low.

If analyzed by area by area, the AM service coverage around Pozuelo de Alarcón, which is quite near the transmitter, is rather good using the high end receiver and acceptable using the mid-range receiver.

Coverage in the center and West of Madrid is very good using a high end receiver. Using the mid-range receiver, the service was incorrectly received in half of the locations which were usually located in narrow streets. Anyway, the AM service degradation was not very high. Both in this area and in Pozuelo, the electric field strength had a very stable behavior.

Results obtained in Salamanca route confirm what has been pointed out in previous routes. In this case the distance to the transmitter is longer and therefore the electric field strength is lower, which makes the situation worse. This is the reason why two points featured incorrect reception using a mid-range receiver in the presence of very dense traffic, that is, being affected by radio electrical noise sources. The large vehicles traffic, as well as radio electrical noise, increases field strength variability too.

Mobile reception

MCS 10001 AM service mobile measurements did not make possible the evaluation of the received audio subjective quality with more than one receiver simultaneously. However, in those stretches where there were also DRM measurements, an estimative comparison was done between the DRM service quality and the AM service quality with the high end receiver. Overall, the AM part reception results with the high end receiver are very good, better than the DRM results. Following the East Radial route, which goes further away from the transmitter across the center of Madrid, correct audio quality was obtained up to distances of 13 km away from the transmitter. In the case of the South Radial route which goes further away from the transmitter but not across Madrid, the maximum distance featuring AM service correct reception exceeded 80 km.

6.4.2 DRM Service Reception

MCS 10001 DRM static reception global results are shown in Table 10. The total number of analyzed test points is 33, which were distributed among the above mentioned areas. Out of the 33 locations, 29 featured AudioQ values higher than 98%.

TABLE 10

MCS 10001 DRM reception quality global results

DRM part with power	**0.25 kW**
Total number of assessed locations	33
% of locations with correct reception (AudioQ > 98%)	87.9%

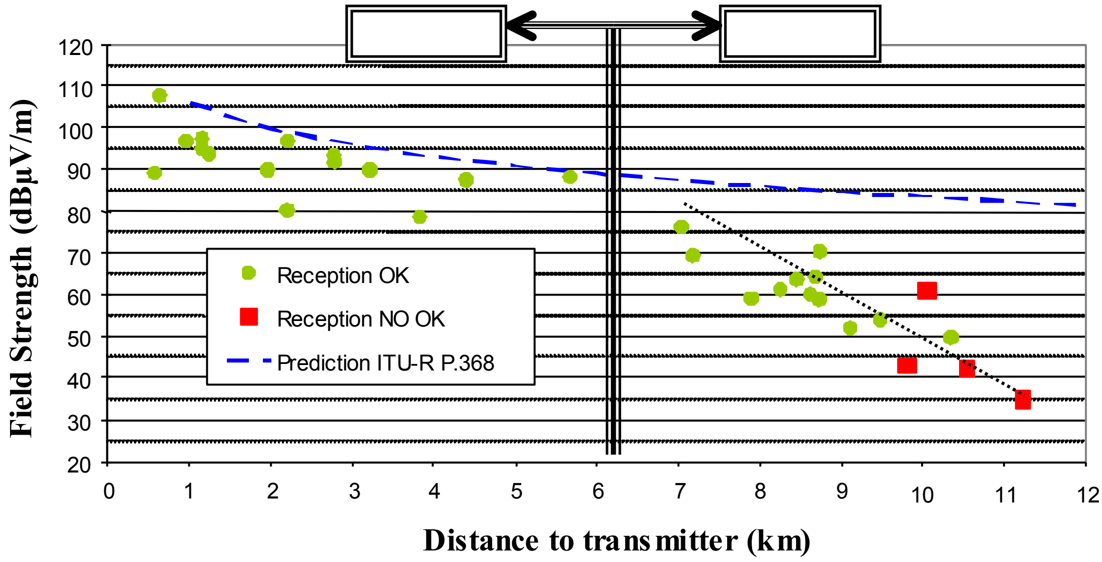
Figure 5 shows DRM field strength received in fixed locations versus the distance to the transmitter, in order to check the coverage range. The values of the locations presenting correct reception are depicted in green while the rest are depicted in red. Thus, a Simulcast DRM service coverage radius of 9.5 km from the transmitter can be appreciated in static reception, with only 0.25 kW transmitted power.

Besides the measured field strength, the predicted field strength according to Recommendation ITU-R P.368-9 [9] for ground-wave propagation prediction is represented using a discontinuous blue line. The chosen values for the prediction parameters have been 16 mS/m for conductivity (average value for the center of Spain) and 6 for relative permittivity.

In the figure, what has previously been observed for the AM signal is confirmed in the DRM one. When locations measured in Pozuelo de Alarcón are compared with locations in Madrid, the different attenuation caused by the diverse urbanism densities between the two environments is confirmed. In Pozuelo, the measured field strength follows the prediction tendency. In Madrid the behavior of the measured electric field strength versus the distance to the transmitter follows a decreasing tendency, which is far more abrupt than the predicted one, as it is represented by the black discontinuous line. Thus, the difference between the measured electric field strength in locations of Madrid and the ITU-R prediction can be up to 40 dB against the 15 dB of Pozuelo.

FIGURE 5

DRM Electric field strength marking points with correct and incorrect reception



As far as the DRM field strength threshold is concerned, three points presenting incorrect reception are depicted in the figure. Those two points with incorrect reception not affected by impulsive radioelectrical noise had an electric field strength value lower than 43 dBµV/m, so this value has been taken as an approximated threshold of the electric field strength for the DRM service correct reception. The disagreement between this threshold and the one suggested by the ITU in Recommendation ITU-R BS.1615 can be explained by the difference between the values of man-made radioelectrical noise considered by the ITU and the actual measured values in such an urban environment as Madrid's, which are quite higher. Following the same procedure with the MER, a value of 18 dB has been established, which represents a valid MER threshold. This value is near the 17.5 dB MER threshold value for the DRM service reception obtained in previous trials.

Table 11 shows the points where reception has not been correct and the values of the measured signal parameters. In the third point, the electric field strength is very low as a result of the great distance to the transmitter and the reception environment.

TABLE 11

DRM reception in impaired points

Point	Area	Environment	Distance Tx (m)	Field Str. (dBµV/m)	SNR (MER) (dB)	AudioQ (%)
mcsGVp2f1	Gran Vía	Dense	9 814	42.9	17.8	95.2
mcsSp0	Salamanca	No Dense	10 054	60.8	16.3	97.4
mcsSp1	Salamanca	Dense	11 231	34.7	5.4	0
mcsSp4	Salamanca	Dense	10 539	42.3	20.1	91.4

In the other three points, the AudioQ value remained quite close to the threshold of 98% for correct reception. The second point, mcsSp0, shows a high field strength value, but due to a close radioelectrical noise source, its SNR (MER) value is a bit lower than the threshold for correct reception, which has been set in 18 dB.

The first (mcsGVp2f1) and fourth (mcsSp4) points have field strength values lower than the threshold for correct reception. This was due to the distance to the transmitter as well as to the reception environment.

Mobile reception

As far as mobile reception concerns, overall results of the reception are quite good. Table 12 shows a summary of the percentages of correctly received audio subframes in the measured routes in urban environments.

TABLE 12

Summary of routes of DRM in urban environment

Total Stretches	**34**
Total Kilometers	**88**
% Stretches with AudioQ > 90%	**70.6**
% Stretches with AudioQ > 98%	**35.3**

The results of the table refer to the percentages of correct audio in the total of the stretches and not by time interval. This clarification is important, as it can be seen that the majority of the routes have higher percentages than 90%. However, if a value of 98% of audio correct subframes is set as threshold, the percentage of stretches with correct reception reduces drastically. Therefore, the power of the DRM signal of the Simulcast is not enough to have full coverage in the urban environment of Madrid in mobile reception, as in most of the stretches the objective quality does not reach the 98%.

In Table 13 the percentages of correct reception in East Radial and South Radial measurement routes are collected. In both cases many stretches where located at a long distance to the transmitter, which is even more important when taking into account that the Simulcast DRM signal transmitted power was only 0.25 kW.

TABLE 13

Summary of DMR Radial routes

Total stretches	**10**
Total Kilometers	**75**
% Stretches with AudioQ > 90%	**50**

The East Radial ran from the transmitter to the outskirts of Madrid, passing through the city center, across Gran Vía and Salamanca areas. The AudioQ measured in the substretches is depicted in Figure 6. Green points represent the 30-meter substretches with 100% correct audio frames, while red points are 30-meter substretches with lower AudioQ values. This way, any substretch that did not feature perfect reception is highlighted in red. This depicting procedure is very restrictive, as in many 30-meter stretches that featured some wrong audio frames the subjective perception was of correct reception.

FIGURE 6

DRM signal AudioQ every 30 meters along the East Radial route

The beginning of the stretch goes from Pozuelo de Alarcón to the West side of the center of Madrid, in a suburban environment where reception was almost perfect. In that part of the route high field strength and SNR (MER) values were measured. As soon as approaching to the dense urban surroundings of Madrid, the AudioQ of the substretches was not up to the established correct reception criterion. Only in wide streets with lower buildings in the center of Madrid (for instance, around the park) the AudioQ of the substretches recovers correct values. The simulcast DRM service mobile reception in urban environment is limited by the lack of signal level.

6.5 Results of the AM-DRM simulcast back off ratio

This subsection analyzes the compatibility of the AM and DRM simulcast components taking into account different back off ratios and receivers. The mutual interference between both signals and its influence for the incorrect reception cases are also studied.

Table 14 shows the percentages of locations with correct reception for both DRM and AM services in the four tested simulcast configurations. As for the AM service, each receiver used in any of the study phases is individually analyzed.

In general, DRM service quality was not very good. This incorrect reception is due to the path losses and the dense urban environments where all the locations (except one) were placed.

TABLE 14

Quality of the AM and DRM simulcast services with configurations MCS 10001, 10002, 10003 y 10004

Mean Distance to Tx= 8.8 km	MCS 10001 (D = 16 dB)	MCS 10002 (D = 11.8 dB)	MCS 10003 (D = 7.2 dB)	MCS 10004 (D = 1.5 dB)
Receiver	**% Reception OK**	**% Reception OK**	**% Reception OK**	**% Reception OK**
A (High-end)	100	100	60	100
B (High-end Mid-range)	100	50	0	0
C (Mid-range)	100	50	20	20
D (Mid-range)	100	50	0	0
E (Mid-range)	0	0	0	0
F (Mid-range)	20	0	0	0

With respect to the AM service, the high-end receiver installed into the mobile reception unit provided good results for each configuration, although the values corresponding to MCS 10003 and 10004 configurations are closed to the threshold. Similar results were obtained with receiver B (High end – Mid range).

The rest of mid-range receivers presented different behavior. The analog receiver D provided little worse behavior than B receiver, which gave very good results with the MCS 10001 configuration and results close to the threshold with MCS 10002 configuration. The C receiver presented a similar behavior than the two previous ones. No correct results were obtained with the mid-range receivers and the MCS 10003 and 10004 configurations. Finally, the results of the receivers E and F were poor with all the tested Simulcast configurations.

Table 15 includes the measured parameters for the AM Simulcast component. For each location and MCS configuration, the mean values of the back off ratios (Δ), field strength signal and carrier to noise ratio are provided. The last one is calculated as the difference between the median values of the field strength AM component and the measured radio electric noise at the corresponding location over an empty channel.

In all the locations, the AM signal decreased with the increase of the configuration. Also, it is clear the decrease of the measured back off ratio. However, the difference between the measured and the nominal back off ratios are higher than 2 dB. For the MCS 10001 and 10003 configurations, the measured back off ratio was higher than the nominal one Opposite result is obtained in most of the cases when considering the MCS 10002 configuration. Another remarkable issue is the high field strength levels of the AM component at six locations of the previous table for the MCS 10001, 10002 and 10003 configurations. Such values and the C/N ones should be enough to ensure the correct reception of the AM service with both tested receivers. However, the mid-range receivers provided incorrect reception with the MCS 10002 and 10003 configurations. This is consistent with the influence of the DRM Simulcast component over the AM service.

TABLE 15

Reception parameters of the AM signal with the MCS configurations

	MCS 10001 D = 16 dB			MCS 10002 D = 11.8 dB			MCS 10003 D = 7.2 dB			MCS 10004 D = 1.5 dB		
	Δ (dB)	E (dBµV/m)	C/N (dB)	Δ (dB)	E (dBµV/m)	C/N (dB)	Δ (dB)	E (dBµV/m)	C/N (dB)	Δ (dB)	E (dBµV/m)	C/N (dB)
mcsPp16f1	18.2	106.6	60.5	11.3	105.9	59.8	9.7	104.3	58.2	1.9	100.9	54.8
mcsGVp1f1	17.9	77.8	39.2	N.A.	N.A.	N.A.	10.7	74.7	36.1	2.6	52.6	14.0
mcsGVp10f1	17.0	81.1	41.6	10.1	79.8	40.3	8.4	78.6	39.0	0.9	75.3	35.8
mcsGVp3f1	17.1	87.7	54.5	10.3	86.6	53.5	8.2	84.8	51.6	0.9	81.9	48.7
mcsGVp2f1	18.8	61.6	N.A.	12.4	54.2	N.A.	11.0	53.0	N.A.	3.1	49.5	N.A.
mcsGVp1f2	17.9	95.4	56.1	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
mcsGVp2f2	16.4	62.7	N.A.	9.8	60.4	N.A.	5.4	59.4	N.A.	-1.7	55.9	N.A.
mcsGVp6f2	16.8	89.8	51	9.9	88.7	49.9	7.8	87.3	48.5	-0.1	83.7	44.9
mcsGVp3f2	15.7	69.3	35.2	8.2	68.3	34.2	7.9	68.0	33.9	0.9	65.4	31.3
mcsSp4f2	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
mcsSp5f2	15.6	68.2	37.9	9.0	67.1	36.8	7.0	65.5	35.2	-0.1	62.3	32

Finally, the MCS 10004 configuration presents so low nominal back off ratio that the value of the AM signal power is much lower than the levels of the rest configurations. In practice, the location variability of the signal causes a null of the measured back off ratio. In such cases, the AM service of the Simulcast mode has no protection margin against the DRM simulcast component. So, the mean values of the AM subjective audio quality evaluation using MCS 10004 mode are around "annoying degradation" that corresponds to a value of 2 in the scale.

6.6 Conclusions

Finally, as a conclusion, taking into account the static reception of **AM** part for simulcast configuration, the service coverage is good in the center-east Madrid and inside Pozuelo de Alarcón using a high end commercial receiver. For mobile reception, results using the high end commercial receiver are very good too, better than ones obtained for the DRM part of simulcast configuration.

On the other hand, considering the static reception of **DRM** part for simulcast configuration, the service coverage is good in the center-east Madrid and inside Pozuelo de Alarcon using a broadcasted power of only 0.25 kW for the experimental network. For mobile reception, the main impairment which caused a poor reception was the lack of field strength level that resulted insufficient. This factor was noteworthy determinant in Dense Urban environments and reinforced by the distance to the transmitter. Coverage radius would be considerably greater increasing the broadcasted power by 5 or 10 dB.

As regards to the AM-DRM interference analysis inside simulcast configuration, it can be concluded that the main cause of the DRM service unavailability was the lack of field strength level taking into account that the utilization of higher transmitted power configurations for the DRM part led to a quality of service increase. So it is important to say that the DRM service part of simulcast configuration was not interfered by the adjacent AM analog signal.

In the case of the AM part of the simulcast configuration, the DRM signal placed in the adjacent channel influences over the received AM subjective audio quality and its influence depends highly on the type of AM commercial receiver used for signal demodulation. The high-medium end receiver signal was not impaired or interfered by the DRM signal but some mid-range receivers begun to provide deficient audio quality with MCS 10002 configuration which uses 11.8 dB back-off ratio. The low end range AM commercial receivers never provided a good AM subjective audio quality. The DRM signal spectrum acts as an interferer noise in the adjacent channel for the AM signal and it is a critical factor for the worst receivers. Finally it is important to say that the type of tuning for the analog receivers did not result a critical factor, that is, a digital or analog tuning provided the same audio quality results.

7 Monocast DRM test (10 kW)

The second stage of the field trials consisted on broadcasting a DRM signal, without any analog signal associated (monocast). This way it was possible to make the most of the transmitter power performance without the restrictions of the analog signal protection rations that Simulcast mode requires.

The only characteristics which differ from the Simulcast tests are the DRM transmitted power, which increases from 0.25 kW to 10 kW in this case, and the DRM spectrum central frequency, 1260 kHz in this case. The DRM signal configuration parameters were the ones of Section 4.

In this section a summary of the outdoor monocast DRM trials description is included. Next, results are presented as follows. First, fixed locations results are explained, and then mobile reception ones. Thirdly, the study of the coverage and the necessary power to cover the city of Madrid is deployed. Finally, the results obtained in a comparative study of the propagation using two different frequencies, namely, 1 260 kHz and 810 kHz, are described.

7.1 Trial description

The measurements carried out in this phase of the project were planned in the city center of Madrid, in order to determine the behavior of the DRM system in a dense urban environment. Three measurement zones where set out and another one was added during the course of the project. The initial areas were: “Gran Vía” and the streets from the east to the center of the city of Madrid, which are narrow streets with quite high buildings; “Barrio de Salamanca” and some areas in the east of the M-30 auto route, with wider streets than the previous area; and “Barrio de Carabanchel” (South of Madrid), a representative environment of medium-size Spanish cities, which is characterized by irregular height housing (with 8-10 floors) and medium width streets. The fourth environment was the village of Vallecas, located in the South-West of the city center of Madrid, a kind of a combination between the first and third areas.

In Table 16 a summary of the points and mobile routes measured in the above-mentioned areas is presented. These measurements were the starting point for the studies included on each subsection of Outdoor Monocast DRM results. The measurement methodology used both in static and in mobile reception is the same one which has been described in the Simulcast measurements (Section 5).

TABLE 16

Measurements summary

ZONE	TYPE	NUMBER
Salamanca	Points	13
	Routes	2
Gran Vía	Points	16
	Routes	17
Carabanchel	Points	15
	Routes	16
Vallecas	Points	8
	Routes	4

The applied Quality of Service criteria for the coverage evaluation are the same that have been used in the Simulcast tests for the DRM signal both in static and in mobile reception (Section 6.3).

7.2 Static reception results

Static reception tests global results are shown in Table 17.

TABLE 17

DRM reception quality global results

Measured mode	**9 kHz/A/64/16/0.6/S**
Total number of measured locations	**52**
Number of locations with audio quality better than 98%	**51**
% of locations with correct reception	**98.08**

The total number of tested points is 52, which are distributed in the four areas previously mentioned. The reception has been very satisfactory in all the areas, even in those further away from the transmitter, so that 51 points featured AudioQ parameter values higher than the 98%, that is, correct reception.

Point 2 of Salamanca area was the only one that featured incorrect reception, with an AudioQ value near to 41.6%. As far as the situation of this point is concerned, Figure 7 shows that the reception environment is an area with quite narrow streets with regard to the height of the buildings.

FIGURE 7

Location 2 placed in Northwest-Center (Salamanca area and M30)

In spite of the high man-made radio electric noise levels of the city, signal to noise ratio values greater than 20 dB were obtained, except for the incorrect reception point.

7.3 Mobile reception results

In general, mobile reception provided very good results. Table 18 shows a summary with the percentage of correct audio stretches received in the measured areas.

TABLE 18

Routes summary

Routes (total)	**39**
Kilometers (total)	**133**
Audio better than 98% (total route)	**31**
Audio worse than 98% (total route)	**8**
% Right Routes	**79.49**

The results of the table refer to the percentages of correct audio in the total of the stretches and not by time interval. This clarification is important, as it can be seen that the majority of the routes have higher percentages than 98%.

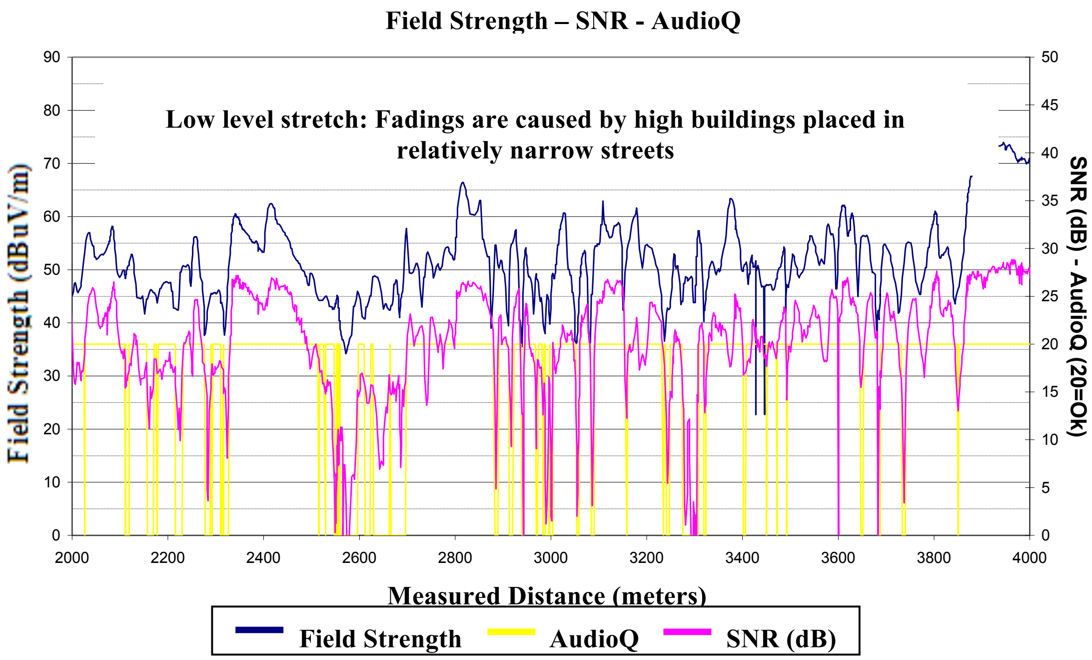
The obtained results are in agreement with the expected ones according to propagation in the medium wave band and depending on the distribution of the critical factors that affect the service, such as the width of the streets, the height of the buildings (with regard to the width of the street), man-made noise sources, urban elements that cause attenuation of the received signal (bridges, footbridges, tunnels...)…

The above-mentioned factors are aggravated by the signal level decrease as the distance to the transmitter increases, as it occurs in the route of Salamanca area shown in Figure 8. Graphic (a) shows the electric field strength, SNR (MER) and AudioQ versus the distance. Graphic (b) shows the reception quality calculated in 30-meters stretches.

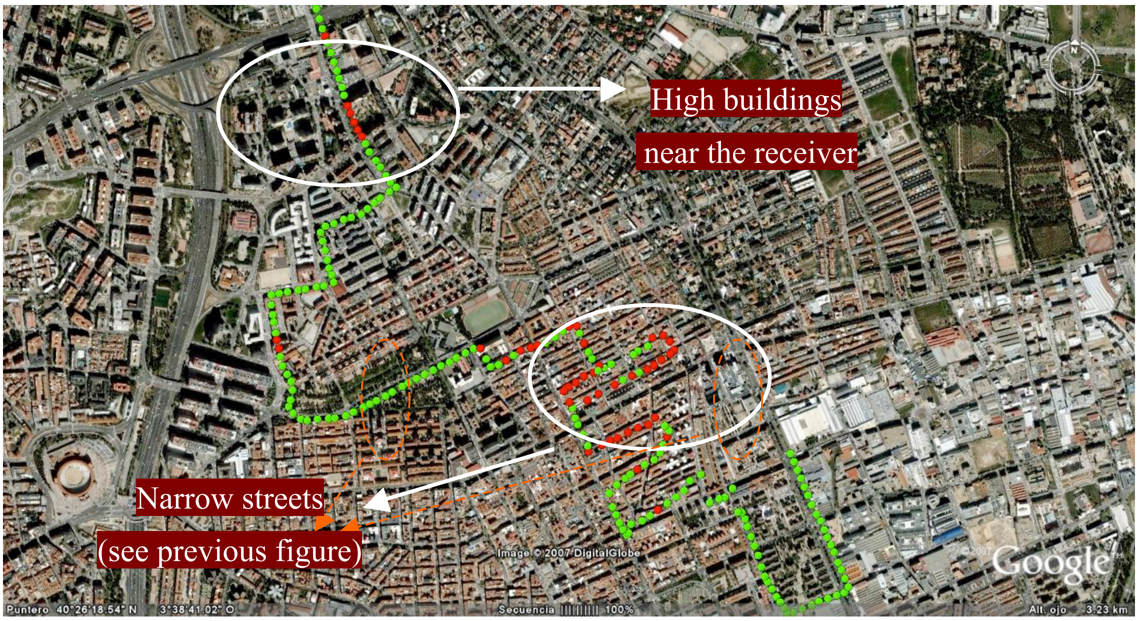
FIGURE 8

Mobile measurement routes: Salamanca district and East of the M-30

(a)



(b)



These graphics give an idea of the critical factors that affect the correct signal reception: attenuation along the first kilometers is due to high buildings, whereas the rest is due to narrow streets. In the same stretch some locations affected by man-made noise can be seen. In addition, Salamanca is the furthest zone from the transmitter.

Gran Vía presents more extreme cases of critical factors, as narrower streets and higher buildings with regard to the width of the street are the common rule. This is why the service listening carried out during the tests was characterized by the appearance of some audio dropouts basically due to field strength fast fading occurrences. These field strength fading occurrences appeared near high buildings and also along narrow streets. The increase of man-made noise level in this area must be also considered.

Carabanchel is just the opposite case to Gran Vía. Vallecas area is an intermediate case between the previous ones, because it includes narrow streets, although few high buildings can be found there. Moreover, it is located further away from the transmitter than Gran Vía and Carabanchel.

An increase of broadcasted power would slightly improve the signal reception in any of the analyzed cases. However, as shown in Figure 8a, most of the signal-fading occurrences are greater than a reasonable transmission power increase. These locations are problematic points due to the attenuation characteristics of the propagation and to man-made noise levels at these frequencies.

7.4 System thresholds and coverage

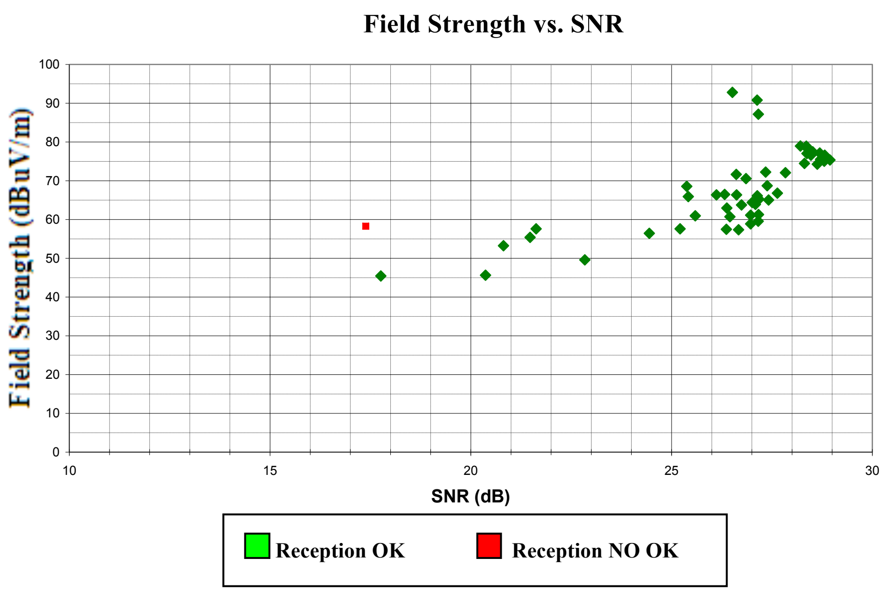
In this section system thresholds according to field strength measurements as well as coverage are discussed, both for fixed and for mobile reception.

SNR thresholds (MER)

The graphic in Figure 9 shows that only one point gave quality results below 98% of the correct audio frames. This point featured a slightly lower than 17.5 dB MER level. However, taking into account detailed results observed in each area, a more conservative value, such as **18 dB**, is recommended as a static reception MER threshold.

FIGURE 9

Electric field vs. MER at fixed points for DRM Monocast (10 kW)



On the other hand, if mobile reception stretches are analyzed, according to the results obtained in these tests, the threshold value for DRM network planning in urban areas should be **20 dB** if broadcasting 9kHz/A/64QAM/16QAM/0.6/S DRM configuration.

Both of the SNR (MER) thresholds obtained experimentally on these tests differ from the value of 15.1 dB (based on laboratory tests and simulations) proposed by Recommendation ITU-R BS.1615.

These SNR values do not have a clear equivalence as regards received electric field strength level, because of the considerable variability of the measured electric noise levels.

Radio electric noise values

As for man-made noise, higher levels than ITU reference [10] in urban environments have been measured in general terms. Table 19 shows average noise values in each measurement area.

TABLE 19

Average radio electric noise values

	Median value (dBµV/m)	Standard Deviation (dB)
Vallecas	27.6	4.0
Carabanchel	31.1	8.1
Gran Vía	32.2	3.9
Salamanca	21.8	4.9

Gran Vía and Carabanchel are the most affected areas. Both of them consist of office and company buildings and dense road traffic. In Carabanchel, noise values vary significantly between near locations.

Electric field variability

Another important factor is the attenuation level depending on different urban features along a route. Next table shows the different values that describe this variation.

TABLE 20

Differences between electric field intensity median value and percentiles (dB)

	Average (E50 - E99)	Standard Deviation (E50-E99)	Average (E50 – E90)	Standard Deviation (E50-E90)
Vallecas	20.1	3.8	9.7	4.4
Carabanchel	22.5	7.1	12.6	5.6
Gran Vía	23.7	7.6	11.4	6.6
Salamanca	22.0	1.1	11.9	1.4

Obtained data reflect an average estimate of 22 dB difference between the average value and the value exceeded by the 99% of the values in an urban route with a standard deviation near to 7 dB. This value decreases down to 11 dB if the 90% of the locations is considered instead of the 99%.

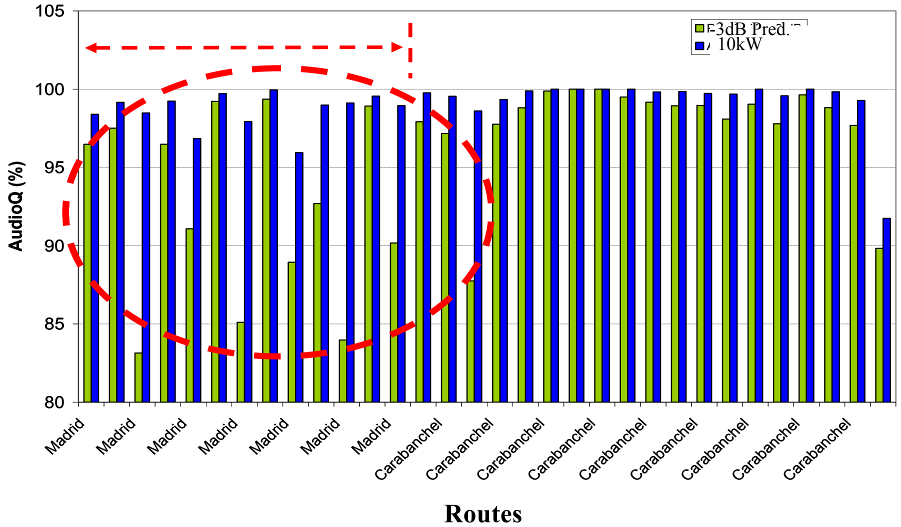
Study of the DRM signal optimum levels for urban coverage

The effect that a 3 dB increase on the transmitted power would cause in reception quality has been studied. It is important to remark that, at this frequency (1 260 kHz), signal fading occurrences in narrow streets are higher than 3 dB, thus incorrect reception locations will still be problematic points. That is, the global reception situation would not change excessively.

On the other hand, a reduction of 3 dB (5kW) in the transmission power would be negligible in fixed points. Signal to noise ratio values would keep above the threshold in most of the cases. However, the result varies noteworthy if the same analysis is carried out for mobile routes. The bars diagram in Figure 10 shows the "before" and "after" situation of a power decrease in the measurement routes along the city.

FIGURE 10

Comparative study of the mobile coverage for different transmission powers (5 kW and 10 kW) for a set of mobile routes



The worsening in Gran Vía and Salamanca areas is noteworthy when compared to the obtained results in the less dense routes of Carabanchel.

Comparative study of signal level for different transmission frequencies

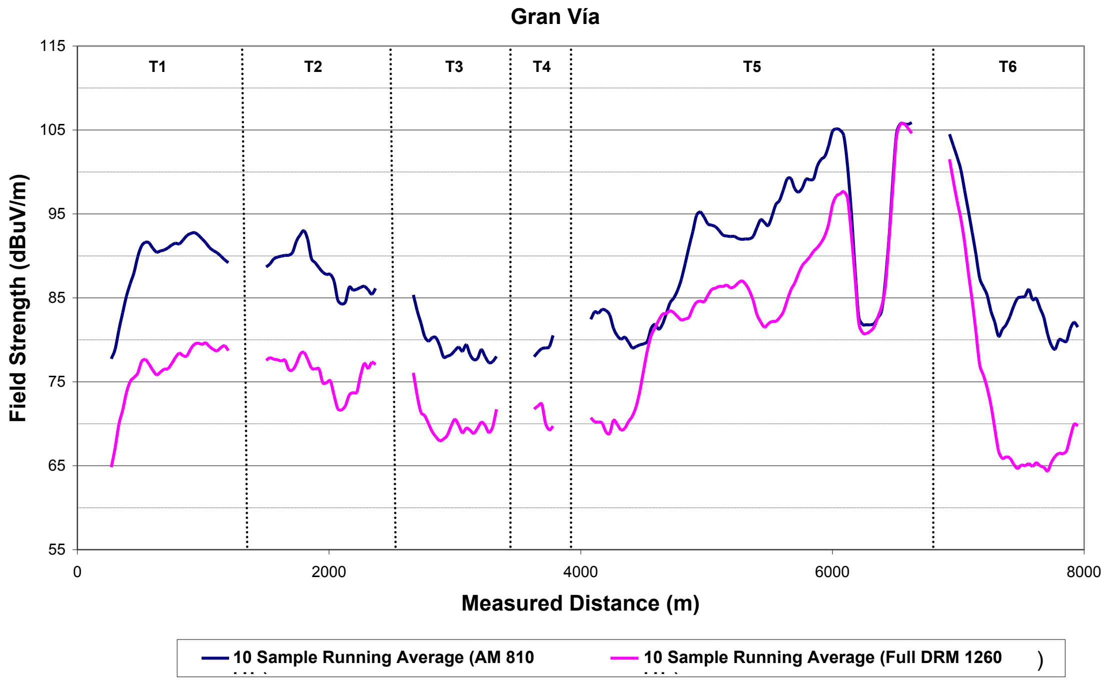
In order to determine the differences at different frequencies, a comparative study of the received electric field level has been carried out in this project. Two signals have been considered, both of them broadcasted according to the experimental network: a 50-kW AM signal in 810 kHz, and the Monocast DRM signal used in the tests. The same routes were measured for both of them and a received field strength level comparison has been made after normalizing data of both frequencies to the equivalent of a 50 kW transmission power.

By means of this procedure almost 40 km of comparable routes have been obtained in the areas considered: Gran Vía, Salamanca, Carabanchel and Vallecas.

Figure 11 shows the received field strength in the six stretches of Gran Vía area where both signals were measured. In order to make the comparison easier, a ten samples running mean has been applied, reducing the fluctuations of both signals. This way, and considering that one sample corresponds with a received field mean value every 30 meters, this figure shows the field level every 300 meters.

FIGURE 11

Gran Vía zone: Received field in 810 kHz and 1 260 kHz



It can be observed that both signals follow parallel tendencies with a difference level of 10 dB between them. The difference in the received field level for both of the study frequencies in the city of Madrid is set in Table 21 by means of averaging the global values obtained for all the described zones.

TABLE 21

Received field differences statistics between 810 kHz and 1 260 kHz in the 4 areas and for the city of Madrid

Area	Mean value (dB)	Standard deviation (dB)
Salamanca and West M-30	12.08	5.42
Gran Vía	10.00	5.95
Carabanchel	8.96	4.48
Vallecas	8.24	4.49
MADRID CITY	9.82	5.08

According to these results it can be concluded that received field level in 810 kHz in the city of Madrid is generally 10 dB higher than the one received in 1 260 kHz. However, this is not a constant difference, as it can fluctuate depending on the urban elements of the environment so that the difference between both signals increases when the height and density of buildings is higher, whereas the opposite effect takes place in less closed environments. Taking into account that the wavelength corresponding to 1 260 kHz is lower than the wavelength for 810 kHz, the first one is more affected by surrounding obstacles. It is worth pointing out that the distance between transmitter and reception area is not a decisive factor in that difference.

7.5 Conclusions

As a general conclusion for fixed reception, the Monocast DRM service coverage in the center of Madrid, with a power of 10 kW, is very good. It must be highlighted that the only point that presented wrong reception had MER values below the 18 dB threshold. In this point, the failure causes were a combination of a low field strength level as well as a considerable noise level.

In general and as a conclusion about the system failure causes, two error groups have been detected: Those caused by insufficient received signal levels (field strength level too low) and those caused by man-made noise sources (high noise level).

The SNR (MER) threshold is 18 dB for the static reception and 20 dB for the mobile reception.

The field strength thresholds are difficult to establish because they depend on the radio electric noise whose values are very variable spatially and significantly above the values recommended by ITU.

As to the field strength variability, the obtained result for 90% coverage involves a margin of at least 10 dB above the threshold.

The frequency comparative study concludes that those locations where reception is affected by urban critical factors, such as high buildings and narrow streets, could improve their coverage by means of a change to a lower transmitting frequency.

8 DRM Monocast indoor tests

In this section, the reliability of the same-as-above transmitted 10-kW DRM Monocast system configuration is analyzed in indoor portable reception conditions. The key characteristic that makes this test different from the previous one is the reception environment that will presumably be more hostile and critic. This happens because man-made noise is a very important impairing factor in medium wave propagation.

The range of this measurement campaign is summarized in the first part of this section. Results are provided afterwards, starting with a general summary. Then a division between commercial buildings and apartment buildings is made. This division has been made because in order to take into account the different characteristics of both types of building.

8.1 Trial description

The measurements of this stage of the project were planned for six buildings in the city center of Madrid and one in an industrial zone in Fuenlabrada, a village placed in the south of Madrid. With the aim of determining the performance of the DRM signal, different types of buildings were chosen in different environments.

Thus, seven different buildings were divided in two main groups: apartment buildings and commercial buildings, in which 113 locations were measured as summarized in Table 22.

TABLE 22

Measurements summary

Identifier	Type	Environment	Location	Distance to Tx (km)	Number of points
E1 Building	Appartment	Urban Non Dense Narrow streets 3 floors	Sol Naciente Street (East of Madrid)	13.8	15
E2 Building	Appartment	Urban Non Dense Narrow streets 3 floors	Clavellinas Street (North of Madrid)	10.2	9
E3 Building	Appartment	Urban Dense Wide streets 7 floors	Next to Princesa Street (Center of Madrid)	7.9	18
E4 Building	Appartment	Urban Dense Wide streets 10 floors	Badajoz Avenue (East of Madrid)	13.2	8
E5 Building	Commercial SER	Urban Dense Wide streets 10 floors	Gran Vía (Center of Madrid)	8.9	44
E6 Building	Commercial VIMESA	Industrial Wide streets 2 floors	Fuenlabrada	16.9	11
E7 Building	Commercial AXION	Urban Dense Wide streets 6 floors	Montalbán Street (Center of Madrid)	9.9	13

The preceding table shows the final data of the campaign field measurements, after removing those points in which, after being processed, measurement system errors were detected (e.g.: incomplete files).

8.2 Results summary

The general results of indoor measurement campaign are displayed in Table 23.

The seven buildings where locations have been measured have been divided into apartment buildings and companies' commercial buildings attending to the environments and the function they carry out.

TABLE 23

Summary of evaluated buildings (median values)

	APPARTMENT BUILDINGS				**COMMERCIAL BUILDINGS**		
	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**
Corrects (%)	80	100	56	0	25	64	62
E (dBµV/m)	78.95	93.79	74.31	68.08	79.51	70.8	83.99
MER (dB)	25.04	27.17	20.44	5.08	15.25	21.19	20.93
N (dBµV/m)	43.81	53.32	51.54	64.61	64.17	52.72	62.13
Dist. Tx (km)	13.8	10.2	7.9	13.2	8.9	16.3	9.9
Environment	Urban Non Dense	Urban Non Dense	Urban Dense	Urban Dense	Urban Dense	Industrial	Urban Dense

The required signal to noise ratio for a correct reception of the DRM signal is **17.5 dB.** With the previously specified transmission power **48 %** of locations are covered.

As a conclusion, this transmission power is not enough to cover the portable reception at Madrid City's indoor locations. However, according to the results, with an increase of 3 dB in the MER value, i.e., increasing transmission power in 3 dB (20 kW broadcasting power), a coverage of **82%** of locations can be reached.

Relating to the obtained main conclusions, it can be said that DRM reception in medium wave depends on the height of the buildings and its adjoining environment.

Looking at the previous table, following the preceding criteria, other considerations about noise can be obtained. In this type of Dense Urban environments, the noise is greater than in other types of environments. In this case, for example, noise values of 51, 64, 64 and 62 dBµV/m have been obtained in four buildings while the measured noise was not greater than 53 dBµV/m in other considered environments. For scheduling purposes, this parameter has to be considered as essential owing to the field level requirement which has to be 80 dBµV/m for correct reception in dense urban environments, while this value can be reduced in 10 dB in non dense urban environments. It must also be considered that the MER threshold is **17.5 dB**, which is the most important parameter for DRM digital service scheduling in indoor portable reception environments.

8.3 Detailed test results

The first analyzed measurements correspond with apartment buildings inside Madrid. This type of building presents special characteristics which makes it different from commercial buildings. The rooms tend to be smaller and the presence of different noise sources which could affect the received signal is less probable.

Field level results, DRM signal to noise ratio and measured man-made noise level data is set out below. Besides, an analysis of the effects on the analog signal field strength values as the height varies and as the location changes to inner positions inside a certain floor, is carried out.

Appartment buildings

In E1 building, 15 measurements were performed with an 80 % of correct reception locations.

TABLE 24

Summary of E1 Building parameters

E_{avg} (dBµV/m)	78.95
MER_{avg} (dB)	25.04
N_{avg} (dBµV/m)	43.81
Dev E_{avg} (dB)	0.45
Dev N_{avg} (dB)	1.23

In this case, the number of correct reception points is very high due to a very high received field level and a much low noise average value. As regards the time variability of field and noise levels, it can be noticed that signals are very stable and that the main impairing factor is the noise in this case, as it represents a bigger variability than signal level.

If the spatial variability of the signal is analyzed, that is, how much reception depends on a measurement made in a location or another inside a building, a very representative feature is the analysis of the best and worst reception point. In the table below it is shown that the worst measured point, which is situated in the stairs' landing of floor 0, is very near to the correct reception MER threshold.

TABLE 25

Spatial variability in E1 Building

	Best Point	Worst Point
E (dBµV/m)	85.00	66.86
MER (dB)	26.06	17.78
N (dBµV/m)	50.30	45.91
Dev E (dB)	0.06	0.16
Dev N (dB)	5.97	0.18
AudioQ (%)	99.65	60.99

It can also be observed that the signal can be attenuated as much as almost **20 dB** inside of the building depending on the exact location of the receiver.

Analyzing the result distribution within different floors, it can be observed that indoor received field levels increase as the measurement location is placed in higher floors. However, if outdoor measurements (on the street or outside a window) are analyzed, the opposite trend can be observed, that is, the field level loss due to the height is more or less 1 dB per floor.

Once height considerations have been analyzed, the indoor results within one floor can be observed. As shown in the table below, the field level decreases as the measurement reception is carried out in inner locations of the building.

TABLE 26

Locations in the inside of the building

	Outside	Living room	Landing
E_{avg} (dBµV/m)	85.74	80.28	72.91
MER_{avg} (dB)	29.23	29.02	23.49
N_{avg} (dBµV/m)	44.12	42.26	44.13
AudioQ (%)	100	100	100

It can be observed that 5 dB are lost from the outside to the inside point corresponding to the living room of the flat. Moreover, an additional 8-dB attenuation level is observed from the latter location to an inner one which is the stairs' landing.

In the table it can be observed as well, that noise levels do not depend on the location inside the building in terms of height and depth because the noise sources are given by the surrounding environment itself. The noise levels measured in E1 Building were above those recommend by the ITU in Recommendation ITU-R P.372, so the field level threshold will have to increase. Besides, noise levels varied as much as **12 dB** depending on the building location.

As for E2 building, the number of correct reception locations is 100%. Results are excellent due to the received field level which is high enough to cover the building even if the measured noise level were 10 dB higher than the E1 building average. The rest of the analyzed magnitudes followed a behavior similar to that which was observed in E1 building, although the differences in the field level between an outside and an inside point in the building were as high as 15 dB.

E3 Building had a 55.56 % of correct reception locations and the most part were measured between floors 4 and 6. These results are a consequence of the decrease of 20 dB in the field level average with respect to E2 building, but both have the same measured noise average. Both buildings had similar spatial variability values. The best reception point in E3 building was located in the highest floor of the building while the worst one was located in the bathroom. The field strength behavior with height in indoor points was checked by means of measurements in the stair landings, and an increasing trend was observed as the height was higher. That became more noticeable in the last building floors. The differences of field strength level between an outside and an indoor point in the building show a 22-dB of attenuation. Noise levels were similar to those of previous cases but its spatial variability was greater in this case and reached 27 dB.

E4 building is a 14-storey apartment building in which the most part of measurements were carried out in floor 8. In no location a correct quality of service was been obtained. This was due to low electric field strength values and higher radio electric noise values than in the previous cases.
The best point, which –as in previous cases– was located in the landing of the highest floor, featured field strength and noise values that were closed to the correct reception threshold.
The spatial variability inside the building showed the same behavior as E3 building. However, height spatial variability in previous outdoor measurements followed an opposite trend, as an increase in field level of as much as 40 dB can be observed from floor 0 to floor 8. This is due to the progressive avoidance of the surrounding buildings' shadows.

Commercial buildings

In E5 building, central office of *Cadena SER*, the most part of the measurements were carried out in floors 7 and 8. The nearby environment of the building is shown in Figure 12. In this type of environments, the existence of high level noise sources which interfere with the signal is very probable, thus increasing the necessary field strength level for correct reception.

FIGURE 12

E5 building environment

In this building, 44 measurements were performed, and 25% provided correct demodulation. It can be deduced from this percentage that the 10 kW broadcast power is not enough to cover this building. In principle, a measured field average of 80 dBµV/m should be enough for correct reception. However, commercial buildings feature very noisy environments, with about 35 dB higher noise values, in E5 building, than the recommended by the ITU [10].

As for spatial variability, signal varied as much as **30 dB** inside the building, so that it was masked by man-made noise in the worst cases. This value is greater than those obtained in the apartment buildings. Best and worst reception points are placed in the same floor of the building, floor 7. Therefore, it can be concluded that, in addition to the floor, the environment close to the reception location has also a very important influence.

TABLE 27

Indoor points in height

Indoors	Floor 2	Floor 3	Floor 4	Floor 6	Floor 7	Floor 8	Floor 9
Point 1: Shadow with adjoining buildings							
E (dBµV/m)	83.95	83.00	80.30	74.55			68.43
Floors	P2-P3	P3-P4	P4-P6	P6-P9			
Difference	–0.95	–2.70	–5.75	–6.12			
Point 2: Without Shadow of adjoining buildings							
E (dBµV/m)					88.78	78.06	
Floors					P7-P8		
Difference					–10.72		

In a floor analysis of the results of outdoor measurements, that is, the measurements carried out in the outside of the building windows, the field loss is more or less 1 dB as the height increases one floor in the building. However, in the case of line-of-sight reception, it can be observed that the maximum field strength loss is **4 dB**. Table 27 shows the results obtained for every point which was measured in the stairs' landing of every floor. Outdoor points follow the same trend but more abruptly, being **14 dB** the overall loss from ground level to the highest floor in this case.

As for indoor points, it can be observed that the difference of the field strength in similar locations of different floors can vary between **2** and **10 dB** in most cases. All the points are co-axial with respect to the building, that is, they have the same location inside the building but in different floors.

Results of field losses between outdoor points and their corresponding indoor measurements – i.e., penetration losses– are exposed in the table below.

TABLE 28

Penetration losses for E5 building

	Shadow with adjoining building			**Without Shadow of adjoining building**		
	Outdoor	**Indoor**		**Outdoor**	**Indoor**	
Floor	E (dBµV/m)	E (dBµV/m)	Dif. (dB)	E (dBµV/m)	E (dBµV/m))	Dif (dB)
P2	98.04	83.95	**14.10**			
P3	98.73	83.00	**15.73**			
P4	96.64	80.30	**16.34**			
P6	93.47	74.55	**18.92**			
P7				94.07	88.77	**5.29**
P8				90.21	78.06	**12.15**
P9	91.35	68.43	**22.92**			

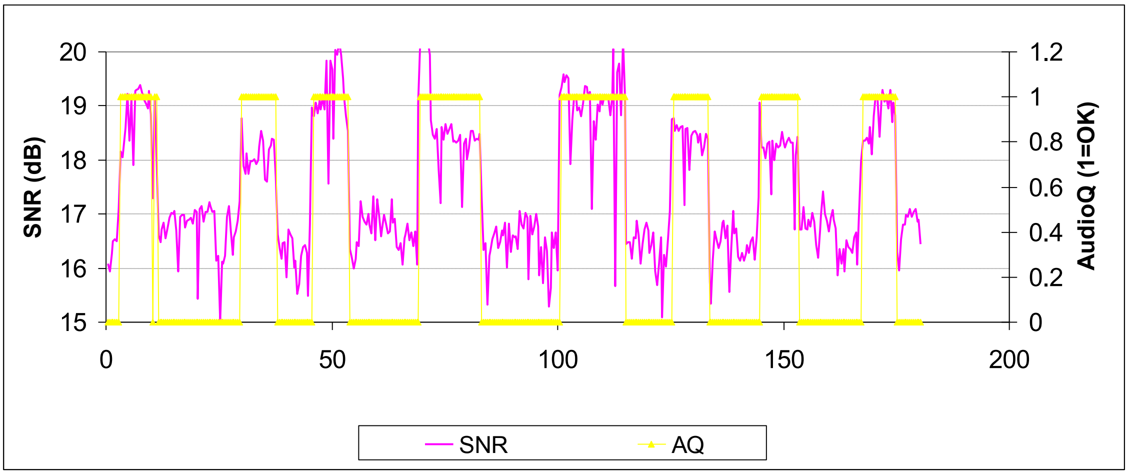
The penetration loss has a median value of **15.03 dB** and a standard deviation of 5.53 dB, that is, the most part of penetration loss cases in the building of *Cadena SER* were found to be between 9 and 21 dB, depending on the reception conditions.

Threshold levels for correct reception are determined by the signal to noise ratio of the transmission DRM configuration in use. To check them, a point which was very near to the correct reception threshold has been chosen and the objective audio quality AudioQ has been depicted along the received MER.

The depicted data in Figure 13 were measured at a point which was located on the stairs' landing of the second floor next to an elevator. It can be noticed that the MER threshold for a correct reception is **17.5 dB**. The abrupt increases of noise level (MER decrease) are a consequence of the operation of the elevator. Consequently, the higher the floor, the closer to the elevator room and the higher noise values were measured, thus increasing its effect on the reception.

FIGURE 13

Threshold levels in E5 building



The behavior of the other two office buildings was different. In E6 building, central office of *VIMESA*, there was a 63.64% of correct reception locations, being the field and noise behaviors similar to the apartments. In E7 building, central office of *AXION*, a 61.54% of DRM correct reception locations was recorded due to an electric field strength value above 80 dBμV/m. In spatial signal variability, the behavior was similar to the apartments, but man-made noise featured higher values with variations as high as 20 dB.

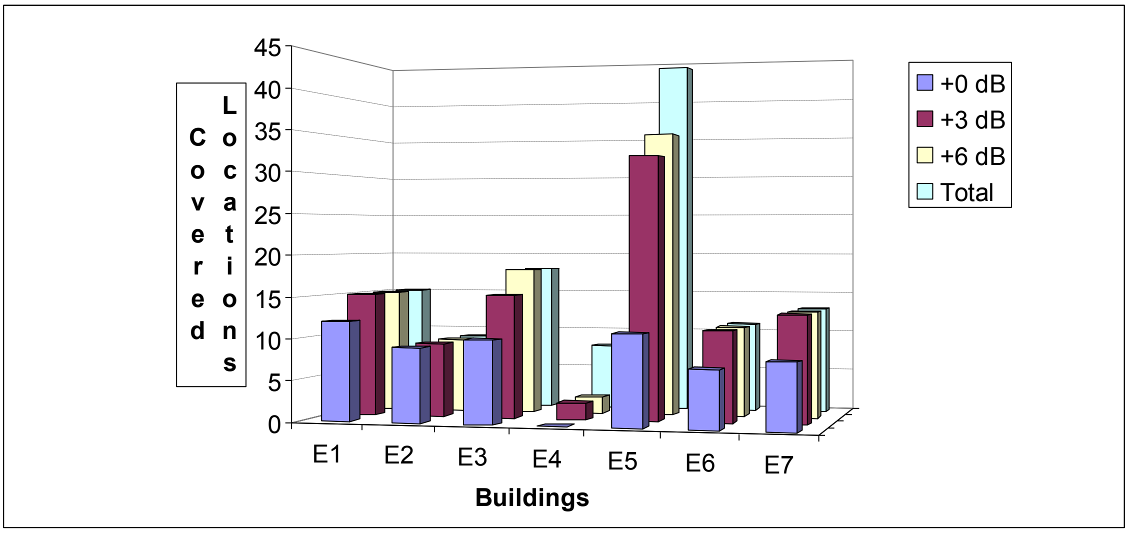
8.4 Coverage prediction

Field strength data discussed in the previous subsection let conclude that it is not possible to provide indoor portable reception with the current 10 kW broadcast power in Madrid. In order to determine the required power for this coverage, the effect of power increases has been extrapolated to reception. For this purpose, the MER parameter threshold has been used as a reference.

Different field strength predictions can be observed in Figure 14.

FIGURE 14

Coverage prediction



The first row (foreground) contains the points covered with the actual transmitted power, that is, 10 kW, within each building. The second row shows those which would be covered by increasing the transmission power in 3 dB, that is, 20 kW. The third level shows the hypothetic case of a 6-dB increase, and, at the last level, the total amount of points measured in each building are contained, that is, those which should be covered to get 100% coverage.

With the actual transmission (10 kW) only E2 building is totally covered. However, in a hypothetic case of a 3-dB increase of transmission power (20 kW), the coverage will considerably increase, covering this way 100% of E1, E2, E6 and E7 buildings and obtaining good coverage for E3 building (83%) and E5 building (73%).

In the case of a 6-dB increase of transmission power, the coverage will improve only a little in comparison with the previous prediction, though E3 building would be totally covered. E4 building and a low percentage of E5 building would not be covered even if the transmission power were increased due to propagation conditions, so correct reception of any type of analog or digital signal in the Medium Wave band could not be possible in these cases.

8.5 Conclusions

As a conclusion, different aspects of the analysis of the previous results can be emphasized:

1. Three out of seven analyzed buildings (E1, E2 y E6) offered correct reception, mainly in high locations.
2. In these cases, the buildings had 3 or 4 floors and were placed along wide streets and with similar buildings next to them. The industrial environment where VIMESA is located featured similar conditions. That is, **the best reception reliability has been found in non dense urban environments.**
3. The rest of the measured apartment buildings, E3 and E4, showed correct reception only near windows. These were very high buildings located in Dense Urban environment. Thus, it can be concluded that, **the worst reception reliability has been found in dense urban environments.**

4. At the headquarters of *Cadena SER* (E5), reception was not good in general terms, depending on the floor where the evaluation point was placed. MER values can present variations from 0 to 17 dB. As in the previous case, and because of being placed in a Dense Urban environment, reception near windows, mainly those oriented to the transmitter, was better. In this special case, the analog AM signal of *Cadena SER*, which is transmitted usually at 810 kHz, was also not correctly received**. The main reason for this bad reception in *Cadena SER* building was the high level of radio electric noise** which considerably rises the field strength threshold for correct reception.
5. In Non Dense Urban environments, values of **MER fluctuate between 12 and 29 dB.**
6. According to the measurement location, **electric field can vary up to 30 dB** inside the same building with a median variation of 16 dB. Moreover, the level of the received electric field increases as the height of the reception point increases, i.e., in the highest floors better levels of electric field and better reception reliability was obtained.
7. In the same **way, noise levels can fluctuate up to 40 dB,** with a median of 19 dB. The elevator was one of the most influential sources of the noise level found in the buildings. Specifically, they can cause 10-dB noise level fluctuations when they are running.
8. The DRM correct reception field threshold depends on the noise level measured in the indoor environments which is usually beyond 60 dBµV/m in Dense Urban environments and the MER **threshold for a correct reception is around 17.5 dBµV/m.**

Finally, it is remarkable that a broadcast power of 10kW is not enough for granting indoor reception in Madrid. However, with a **20 kW broadcast power,** that is, 3 dB more, the coverage is increased considerably, obtaining acceptable levels in **more than 80% of the analyzed locations.**

9 DRM reception trials using commercial receivers

The results of the DRM coverage subjective evaluation using home receivers are presented in this section. The evaluated signal was a DRM Monocast featuring a transmitted power of 10 kW at 1 260 kHz.

9.1 Reception infrastructure: Measurements

Three DRM home receivers were used for the trials. These receivers feature ferrite antennas as well as the possibility to connect an external antenna.

Two kinds of test were carried out, one using the ferrite antennas (home mode) and the other one using the external antennas featured by commercial vehicles, in order to simulate an on-board receiver (car mode).

In the so-called car mode, the reception antennas were those featured by two vehicles, one featuring a rod antenna, a rear window amplified antenna the other. The estimated antenna factors were 49 dB in the first one and 44 dB in the other. This estimation was obtained by means of measurements in which the antenna R&S HE010 (installed in the mobile unit of UPV/EHU) was taken as a reference.

Together with the subjective quality assessment trials, field strength measurements were carried out both at 1 260 kHz and 810 kHz. These comparative measurements were aimed at obtaining data with which the subjective evaluation results at 1 260 kHz could be transposed to the case of having used a frequency of 810 kHz.

The field strength measurements at 1 260 kHz and 810 kHz were performed by means of the Audemat AM_MC3 meter and its embedded antenna. This measurement system was comparatively characterized taking the UPV/EHU onboard measurement system as a reference.

9.2 QoS Criteria

For home mode, the subjective audio evaluation criterion was based upon the perception by a listener of a lossless audio service or perceptible audio faults. A medium wave ground wave propagated signal is very stable, so no variations have been considered in the signal behavior along the evaluation time interval.

For car mode, the coverage limit was reached when two continuous audio drop-outs longer than 3 seconds were perceived in a one-minute time interval (tunnels and locations close to high voltage distribution centers were excluded from the analysis).

9.3 Trial description

For the inside reception trials the so-called home mode was performed inside the same commercial buildings in which the professional equipment measurements of Section 8 were carried out.

For the urban outside trials (car mode), measurements were performed following circular and linear routes across downtown Madrid.

The coverage evaluation outside downtown Madrid was carried out following firstly two ring highways around the city, namely, M40 and M50, and secondly following six radial highways, A1 to A6, from the M40 on.

9.4 Car mode results

Routes inside Madrid

With the 10 kW power used at 1 260 kHz, coverage was considered deficient (there were continuous drop-outs). The best behavior was observed in the west area of Madrid (towards the transmitter) and along the wide street *Paseo de la Castellana*.

Ring routes around Madrid (M40 – M50)

With the 10 kW power used at 1 260 kHz, the coverage can be considered acceptable in this case. All along these routes drop-outs shorter than 2 seconds were perceived, except for a southeastern zone in M40, where reception was affected by high voltage power lines.

Radial routes

The behavior was not uniform in this case as it depended on the relative position of the reception location with respect to Madrid and to the transmitter. The results obtained in each of the radial highways under test were the following:

- **A1 Highway (north)**: acceptable coverage up to 75 km.
- **A2 Highway (northeast)**: acceptable coverage up to 105 km.
- **A3 Highway (east)**: acceptable coverage up to 85 km.
- **A4 Highway (south)**: acceptable coverage up to 90 km.
- **A5 Highway (southwest)**: acceptable coverage up to 110 km.
- **A6 Highway (northwest)**: acceptable coverage up to 45 km.

The 50 kW analog AM *Cadena SER* service at 810 kHz was simultaneously analyzed, reaching its coverage area 30 km further than the 1 260 kHz DRM service.

9.5 Results for commercial indoor receivers

QoS trials were carried out inside the same buildings of *section 8* using home commercial receivers. Measurements were carried out both at 810 kHz (50 kW AM) and at 1 260 kHz (10 kW DRM Monocast).

In two apartment buildings, namely, E1 and E2, reception and coverage were correct as their reception environment was non dense urban.

In addition, extensive trials were carried out in the *Cadena SER* headquarters (E5 building) with DRM service correct reception in none of the inside locations. The analog service at 810 kHz also featured a deficient overall QoS, being analog reception possible at certain locations with more or less degradation while the digital service was affected by continuous drop-outs.

9.6 Conclusions

Once the 1 260 kHz DRM subjective audio coverage results have been analyzed and the field strength values have been measured at the frequencies of 810 kHz (50 kW) and 1 260 kHz (10 kW), it is possible to make a transposition of the DRM coverage results to the frequency of 810 kHz:

For the home mode which was measured **inside buildings of Madrid** in order to obtain a coverage area similar to the one provided by the actual AM service at 810 kHz (50 kW), a required DRM transmitted power of 25-35 kW has been estimated. With this or with even higher power values, there will a considerable number of points inside buildings in which Medium Wave broadcasting services, either analog or digital, will not be available due to the extremely high man-made noise levels.

For **outside reception in downtown Madrid**, the so-called car mode, in order to obtain a coverage area similar to the one provided by the actual AM service at 810 kHz (50 kW), a required DRM transmitted power of 25 kW has been estimated.

In the surroundings of Madrid (M40 and M50 highways) in order to obtain a coverage area similar to the one provided by the actual AM service at 810 kHz (50 kW), a required DRM transmitted power between 15 and 20 kW has been estimated.

Finally, in the radial routes starting from M40 highway (A1 to A6 highways) in order to obtain a coverage area similar to the one provided by the actual AM service at 810 kHz (50 kW), a required DRM transmitted power of 15 kW has been estimated.

10 General conclusions

This document has summed up the results of the DRM transmission experimental trials project carried out in Simulcast mode in the Medium Wave band. The project arose from a proposal made by *Cadena SER* to the Spanish Ministry, and a subsequent collaborative agreement signed by Axion, Vimesa and the University of the Basque Country (UPV/EHU).

The project main objective has been the evaluation of several aspects of the performance of the digital radio system Digital Radio Mondiale (DRM) in the Medium Wave Band. The presented studies have been carried out on the basis of field trials that were performed from July to November of the year 2007.

The DRM Multi Channel Simulcast signal along with the AM analog service reception has been evaluated. The MCS configuration that has been extensively tested provided an AM-over-DRM power ratio of 16 dB. The transmitted power was 0.25 kW for the DRM signal and 10 kW for the AM signal. The trials were carried out in several urban reception environments of the streets of

Madrid and Pozuelo de Alarcón, as well as in rural environments. Reception points were located at distances up to 15 km from the transmitter. Mobile measurements range was of 90 km from the transmitter.

MCS configurations that provided AM-over-DRM power ratio values of 11.8 dB, 7.2 dB and 1.5 dB were only tested in static reception in downtown Madrid, at points located within the range from 5 to 11 km from the transmitter. Six receivers were used for AM reception assessment.

Also, DRM Monocast signal was evaluated in both static and mobile reception in locations outside downtown Madrid. These locations were representative of Madrid reception environments and they could be extrapolated to other Spanish and European cities. In this case, the transmitted power was 10 kW and the reception points were located within the range from 6 to 15 km from the transmitter.

DRM signal reception has been evaluated in more than 100 locations inside 7 buildings within Madrid metropolitan area, mainly in the city center. The farthest building was located at 13.6 km from the transmitter and the measured locations. Different features and reception environments have been tested.

Finally, DRM system reception has been evaluated by means of commercial receivers using both their own internal antenna and the antennas of several vehicles. This evaluation has been carried out both within and out of the city area of Madrid.

11 Acknowledgements

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