DRM field trials
— for urban coverage planning in Spain

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In 2007 the Spanish broadcaster *Sociedad Española de Radiodifusión* (SER) carried out DRM (Digital Radio Mondiale) experimental tests in close collaboration with other companies experienced in broadcasting: Vimesa Axión and the University of the Basque Country.

This article sums up the results obtained from these experimental tests. Firstly, an introductory section describes the transmission and reception infrastructures. Subsequently, the test results are summarized in three sections: *Simulcast, Monocast DRM* and *Monocast DRM Indoor Reception*.

Introduction

Various DRM field trials were carried out in the medium-wave band from July to November 2007, using an experimental network. The project focused on simultaneous broadcasting of the AM analogue and DRM digital signals using the configuration known as MCS (Multi-Channel Simulcast), as well as an evaluation of the DRM system in urban areas, considering both indoor and outdoor reception.

According to the DRM standard, there are two possible MCS configurations for ITU Region 1 [1], as shown in *Fig. 1*.

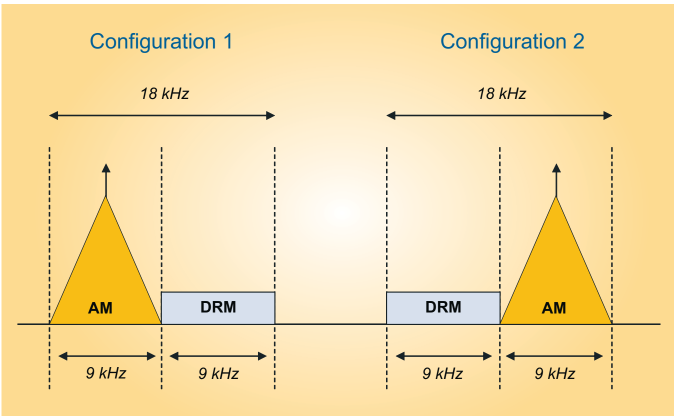

Figure 1
MCS configuration for ITU Region 1

Specifically, the objective of the tests was to find the system operating parameters for three planning scenarios:

1) ***Evaluation of the DRM-AM Simulcast System*** – to obtain the system operating parameters for planning an AM-DRM commercial service, such as the coverage area, threshold values and AM-DRM QoS by means of field measurements. The influence of the DRM signal over the AM

signal when using the Simulcast configuration would also be evaluated, as well as the optimum back-off ratio between both components of the simulcast signal: AM and DRM.

2) ***Evaluation of DRM reception in a city with dense urban areas*** – while transmitting the maximum power allowed by the experimental frequency licence, and without the power restrictions of the Simulcast configuration.

3) ***Evaluation of indoor DRM reception*** – to obtain the reception thresholds under various reception conditions inside different buildings in order to compare them with the corresponding ones for outdoor reception.

Transmission infrastructure: transmitted signals

The transmission infrastructure for the DRM tests was installed at Axion's transmitting station in Pozuelo de Alarcón, located about 9 km from downtown Madrid.

A Transradio Tram 25 transmitter with maximum peak power of 25 kW, a Fraunhofer content server, an 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 facilitate measurement of different DRM and Simulcast transmission modes. The transmission system is shown in *Fig. 2*.

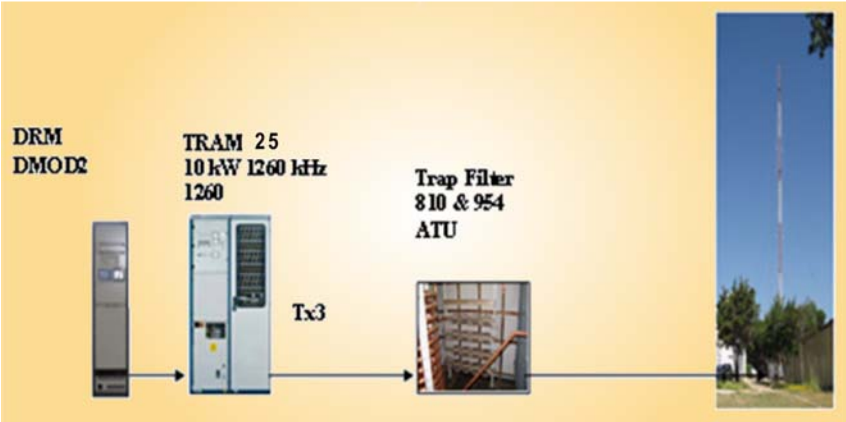

Figure 2
DRM transmission system installed in Pozuelo

The DRM-DMOD2 signal generator allows both Multi-Channel Simulcast and DRM Monocast modes. When using the Simulcast mode, the DRM signal was transmitted with a central frequency of 1251 kHz and the AM signal was centred on 1260 kHz.

The multicarrier digital signal is a potential interferer for the adjacent analogue channel. So far, the recommended back-off ratio between the AM carrier and the DRM signal has been 16 dB. This value was obtained from different laboratory tests, as well as the field trials that were carried out in Mexico City [2] and it has also been tested during the trials described in this article. In order to evaluate experimentally the possibility of decreasing this ratio, other three values have been analyzed. *Table 1* summarizes the transmitter configurations that were tested.

Table 1
MCSC transmission configurations

Power Ratio (dB)	Signal Modulation Type	DRM Power (rms) [kW]	Carrier Power (AM) [kW]	Frequency [kHz]
16	MCS	0.25	10	1251
11.8	MCS	0.5	7.5	1251
7.2	MCS	0.75	4	1251
1.5	MCS	0.9	1.25	1251

A second test phase involved measurements of DRM Monocast transmissions; i.e., only a DRM signal inside the channel. During this phase, the output transmission power was 10 kW and the digital signal was centred at 1260 kHz with a bandwidth of 9 kHz. Using this configuration, both outdoor static and mobile reception, as well as indoor reception, were evaluated.

Table 2 shows the transmission DRM mode that was selected for both the Simulcast and Monocast configurations [3]. In general, it is a robust configuration for ground-wave propagation, the only propagation mode that existed during the tests.

Table 2
DRM transmission configuration

OFDM Mode	Data Channel Constellation	Redundancy	Interleaving	Bitrate (kbit/s)	Min. SNR ITU-R BR 1615 [4] (dB)
A	64-QAM	40%	Short (0.4 s)	23.6	15.1

Reception infrastructure

The University of the Basque Country (UPV/EHU) installed a measurement system in a vehicle, specifically designed to carry out extensive measurement campaigns. *Fig. 3* shows a block diagram of the measurement system situated in the mobile unit.

The measurement system was divided into three sections: the acquisition and distribution section, the measurement equipment section and the control section. The first one consisted of a short monopole active antenna, R&S HE010, placed on top of the vehicle over a specific ground plane. The signal was distributed to various measurement devices: the R&S ESPI3 field-strength meter, the DRM professional receiver which comprised an AOR7030 front-end, a Presonus Firefox digitizer card and the Fraunhofer SW DRM Demodulator. The control system was based on a laptop

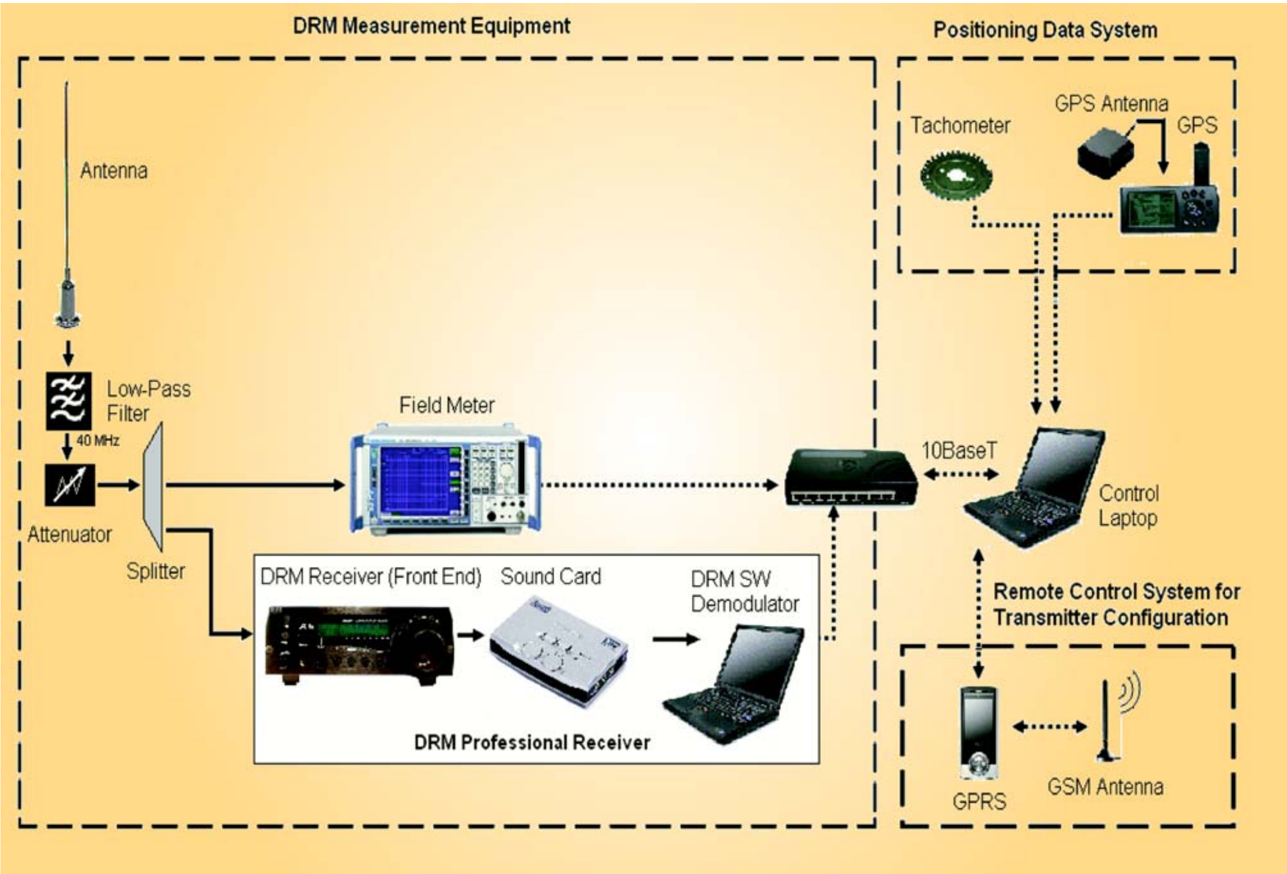

Figure 3
Block diagram of measurement system situated in the mobile unit

computer running a software control tool installed on a GNU/Linux platform in order to configure and control the rest of the equipment. In addition, a GPS receiver and a tachometer provided ancillary data such as time, position and trip data. These parameters and a set of DRM or AM signal parameters were automatically recorded by the measurement system and stored for any subsequent processing.

Regarding the indoor measurement system, a similar schema was used. The most relevant difference with respect to the outdoor system was the antenna, which was an active directional magnetic loop: a *Wellbrook Communications ALA 100*.

Simulcast tests

The so-called MCS 10001 configuration, which specifies a 16 dB of AM-over-DRM power ratio, was extensively evaluated. Overall, such a configuration was measured at more than 42 locations and along more than 210 km of roads. Radial routes or coverage routes were set up in order to assess the system coverage limits in areas further than the city of Madrid. Also, the urban routes began at the closest location to the transmitter, Pozuelo de Alarcón, but they were mainly focused on Madrid.

A second analysis – the AM/DRM mutual interference and power ratio study – involved an AM audio quality assessment using different AM receivers. In order to perform it rigorously, exhaustively and quantitatively, static reception was mandatory. Out of the 42 first locations, a subgroup of 11 reception-impaired locations was selected for measuring all four of the MCS configurations proposed for this study.

QoS has also been studied on the basis of RF measured parameters of the signal (field strength and SNR) and received audio quality parameters. The former ones were collected every 400 ms, but median values were considered for the static reception analysis. The latter ones were used to assess the availability of the analogue and digital Simulcast services.

The availability of the analogue service was assessed by the evaluation of the audio demodulated by commercial receivers. Subjective AM audio quality assessment was carried out in accordance with the audio quality degradation criteria of ITU-R Rec. BS.1284 [5]. Hence, each evaluator assessed an audio sample according to this degradation scale. On this scale, values of “4” (the degradation is perceptible but not annoying) and “5” (imperceptible degradation) were considered as “satisfactory”, meaning that correct reception was obtained.

Taking into account the previous procedure, an audio sample has been considered to show satisfactory 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 each location, every listener evaluated the AM service using all the proposed receivers, so that there was a mean evaluation score for each receiver.

Abbreviations

16QAM	16-state Quadrature Amplitude Modulation
64QAM	64-state Quadrature Amplitude Modulation
AM	Amplitude Modulation
DRM	Digital Radio Mondiale **http://www.drm.org/**
ETSI	European Telecommunication Standards Institute **http://pda.etsi.org/pda/queryform.asp**
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile communications
ITU	International Telecommunication Union **http://www.itu.int**
ITU-R	ITU - Radiocommunication Sector **http://www.itu.int/publications/sector.aspx?lang=en&sector=1**
MCS	Multi-Channel Simulcast
MER	Modulation Error Ratio
MW	Medium-Wave
QoS	Quality of Service
SNR	Signal-to-Noise Ratio
SW	SoftWare
Tx	Transmitter

In the Simulcast trials, six AM receivers were used in order to obtain AM-quality quantitative evaluations. From now on, these receivers will be referred to as 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. 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.

The subjective audio quality for a certain DRM service depends on the bitrate provided by the transmitted DRM configuration. However, only if the DRM signal is correctly decoded in the receiver will the intended audio quality be enjoyed by the listener. 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 for the DRM service as a function of the correctly decoded audio frames at the receiver by means of the so-called AudioQ (AQ) parameter, as follows:

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

Given this objective parameter, a value of 98% is found to be the minimum for static reception, below which the average listener begins to detect audible degradation of the subjective audio quality. This threshold has been taken as a reference value for satisfactorily received audio quality and it has been used in many trials within the DRM Consortium. According to the time statistical error distribution, this value is a very conservative criterion for time intervals of several minutes.

AudioQ has also been considered for DRM mobile quality assessment. However, in this case, instead of calculating it every three minutes, it has been obtained every 400 ms – the duration of one DRM frame containing 10 audio subframes. With this AudioQ figure, one erroneous audio subframe within a DRM frame was accepted as still providing satisfactory reception, thus it is a bit less restrictive than the 98% figure.

MCS 10001 results (16-dB power ratio)

The global results obtained from the static reception trials of the analogue part of the MCS 10001 configuration are shown in *Table 3*. On an area by area basis, the AM service coverage near the transmitter is rather good using the high-end receiver and acceptable for the mid-range receiver. On the other hand, reception in downtown Madrid was very good using the high-end receiver but unsatisfactory with the mid-range receiver at half of the locations (which were usually located in narrow streets). Nevertheless, the AM service degradation was not very great.

Table 3
MCS 10001 AM quality global results

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

A subjective evaluation of the received audio quality with two receivers simultaneously was not possible for mobile measurements. However, along those stretches where DRM measurements were also carried out, an estimated comparison between the qualities of the DRM and AM services was done using the high-end receiver. Overall, the AM reception results for the high-end receiver were very good; better than the DRM results. Following the East Radial route, starting from the transmitter and crossing the centre of Madrid, satisfactory audio quality was obtained up to distances of 13 km away from the transmitter. In the case of the South Radial, also from the transmitter but not across Madrid, the maximum distance where the AM service was received satisfactorily exceeded 80 km in rural areas.

Fig. 4 shows the received DRM field strength at fixed locations versus the distance to the transmitter, in order to check the coverage range. The values of the locations where satisfactory reception was obtained are green coloured while the remaining ones are coloured red. Thus, a Simulcast DRM service coverage radius of 9.5 km from the transmitter can be observed for static reception, when transmitting only 0.25 kW.

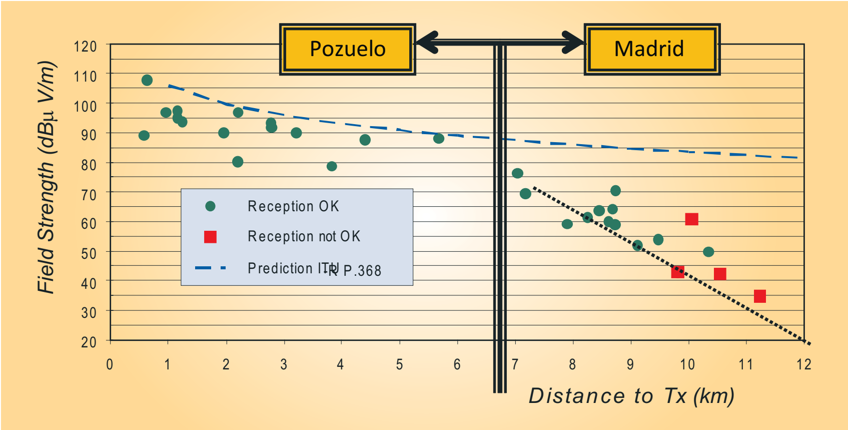

Figure 4
DRM Electric field strength marking points with correct and incorrect reception

In addition, the predicted field strength level according to ITU-R Recommendation P.368-9 [6] for ground-wave propagation is depicted using a discontinuous blue line. The parameter values for the prediction were 16 mS/m for conductivity (average value in centre of Spain) and 6 for the relative permittivity.

When locations measured in Pozuelo de Alarcón are compared with Madrid locations, unequal attenuation values caused by the different urban densities of the two environments are confirmed. The difference between the measured field-strength levels at Madrid locations and the ITU-R predictions can be up to 40 dB against the 15 dB of Pozuelo. The main causes of reception failure were low field-strength values due to the urban reception environment and the distance to the transmitter. Man-made noise was an additional factor.

With regard to mobile reception, overall results are shown in *Table 4*. The percentages of correct audio included have been calculated from the total number of road stretches and not by time interval. This clarification is important, since it can be seen that the majority of the routes have higher percentages than 90%. However, if a value of 98% for correct audio subframes is set as the threshold, the percentage of stretches with satisfactory reception decreases significantly. Therefore, the power of the DRM Simulcast component is not enough to provide full mobile coverage in Madrid.

Table 4
Summary of routes of DRM in urban environment

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

The East Radial runs from the transmitter to the outskirts of Madrid across the city centre. The measured AudioQ of its sub-stretches is depicted in *Fig. 5*. Green points represent 30-meter sub-stretches with 100% correct audio frames, while red points are 30-meter sub-stretches with lower AudioQ values. In this way, any sub-stretch that did not feature perfect reception is highlighted in red. This depicting procedure is very restrictive since correct reception was subjectively perceived along many red 30-meter sub-stretches.

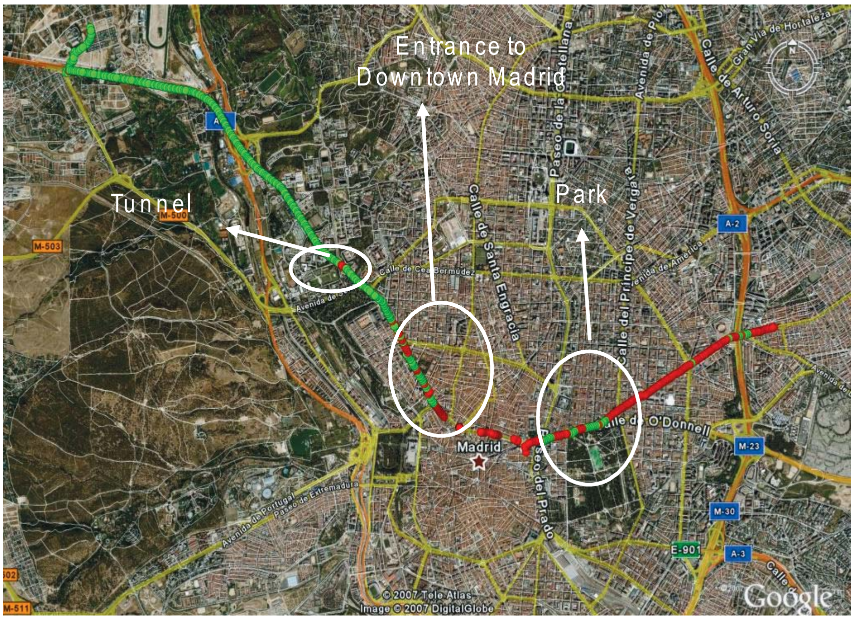

Figure 5
DRM signal AudioQ every 30 meters along the East Radial route

The beginning of the route goes from Pozuelo de Alarcón to the western side of Madrid centre. It is a suburban environment where reception was almost perfect: high field-strengths and SNR (MER) values were measured. However, as soon as the dense urban surroundings of Madrid were approached, the AudioQ of the sub-stretches did not fulfil the established criterion for correct reception. Only along wide streets with low buildings in the centre of Madrid (for instance, around the park) did the AudioQ return correct values. Mobile reception of the Simulcast DRM service in urban environments is limited by the lack of signal level.

AM-DRM mutual influence

This section analyzes the compatibility of the AM and DRM Simulcast components, taking into account different back-off ratios and receivers. *Table 5* shows the percentages of locations providing correct reception of the AM service and the four Simulcast configurations that were tested. Each receiver was individually analyzed.

Table 5
Quality of the AM Simulcast service with configurations MCS 10001, 10002, 10003, 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

The high-end receiver provided good results for each configuration, although the values corresponding to the MCS 10003 and 10004 configurations are close to the threshold. Similar results were obtained with receiver B.

The remaining mid-range receivers presented different behaviours. Receiver D provided little worse behaviour than Receiver B, which gave very good results with the MCS 10001 configuration, and results that were close to the threshold with the MCS 10002 configuration. Receiver C presented a similar behaviour to the two previous ones. In the case of the MCS 10003 and 10004 configurations, no satisfactory results were obtained with the mid-range receivers. Finally, the results for Receivers E and F were poor for all the MCS configurations.

Some of the worst results for the MCS 10001 configuration AM service were recorded at one particular location with very high and constant back-off ratios and AM signal values. This result proves that incorrect reception of the AM Simulcast component was not due to the lack of signal power or the environment. Therefore, the conclusion is that this mid-range digital receiver had problems with the AM service because of the DRM Simulcast component.

Monocast DRM tests

The second stage of the field trials was carried out while broadcasting only the DRM signal, without any analogue signal. This mode will be referred as Monocast in this article. In this case the DRM signal power was increased to 10 kW and the central frequency was 1260 kHz.

The measurements carried out in this campaign were planned in the city centre of Madrid, in order to determine the behaviour of the DRM system in a dense urban environment. Four areas were chosen for the measurements:

1) the *East of the city* with wider streets than the city centre;
2) the *centre of downtown Madrid* which comprises narrow streets with quite high buildings;
3) the *South of Madrid*, a representative environment for Spanish cities in general, characterized by irregular building heights (8-10 floors) and medium width streets;
4) Finally, the fourth environment was a *village located in the South-West of the city*, showing some common characteristics of types 1 and 3.

Table 6 summarizes the measured locations and mobile routes.

Table 6
Measurement summary

Zone	Type	Quantity
1. Salamanca	Points	13
	Routes	2
2. Gran Vía	Points	16
	Routes	17
3. Carabanchel	Points	15
	Routes	16
4. Vallecas	Points	8
	Routes	4

Global results for the static reception tests are shown in *Table 7*. Only one measured static location provided incorrect reception with an AudioQ value near 41.6%. The remaining 51 locations fulfilled the 98% quasi-error-free reception criterion.

Table 7
DRM reception quality – global results

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

In spite of the high man-made radioelectric noise levels typical in a big city, signal-to-noise ratio values greater than 20 dB were obtained, except for the problematic reception point mentioned above.

Table 8
Routes summary – mobile reception

Routes (Total)	39
Kilometres (Total)	133
% Routes with AudioQ > 98% (total route)	79.49

The results in *Table 8* refer to mobile reception. The majority of the routes had higher AudioQ values than 98%. The results obtained agree with the expected ones according to propagation in the medium-wave band. The results were influenced by critical factors that affect services in this waveband, such as the width of the streets, the height of the buildings (with regard to the width of the

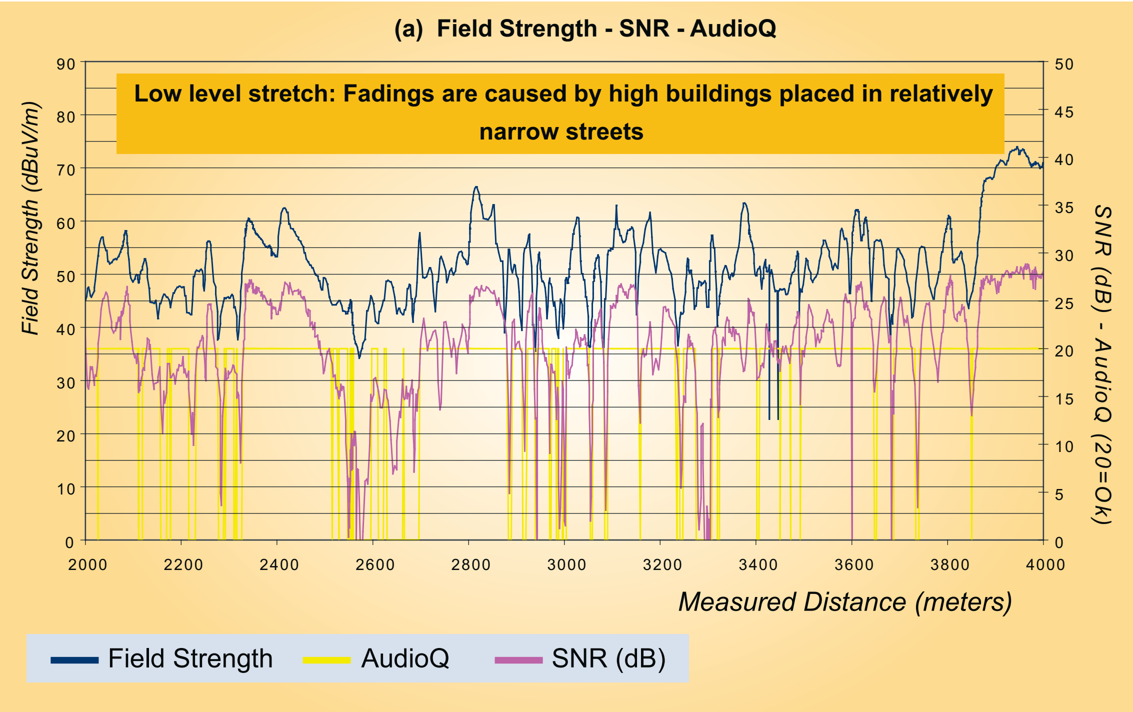

Figure 6
Salamanca district, east of the M-30: Field strength – SNR – AudioQ vs distance

corresponding street), man-made noise sources and urban elements that cause attenuation of the received signal (bridges, footbridges, tunnels....). These factors become critical as the signal level decreases with increasing distance from the transmitter. It occurs in the Salamanca zone shown in *Fig. 6*.

Fig. 6a (on the previous page) shows the electric field-strength level, SNR (MER) and AudioQ versus distance while *Fig. 6b* shows the reception quality calculated for 30-meter sub-stretches.

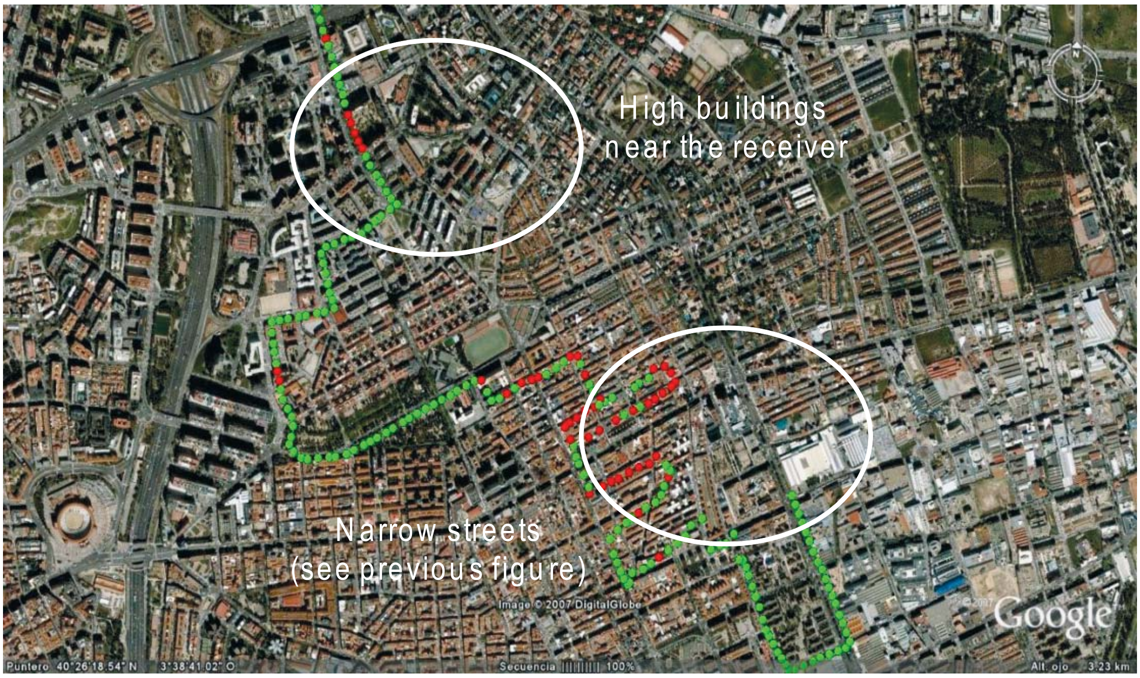

Figure 6b
Salamanca district, east of the M-30: reception quality over 30-meter sub-stretches

An increase in the broadcast power would slightly improve the signal reception in any of the analyzed cases. However, as shown in *Fig. 7*, most of the signal fading occurrences are too great to be rectified by a reasonable increase in the transmission power. The graphic shows that only one point returned an AudioQ value below 98%. This point is located slightly lower than the 17.5 dB SNR level. However, taking into account detailed results observed in each zone, a more conservative value of 18 dB is recommended for the SNR threshold in the case of static reception.

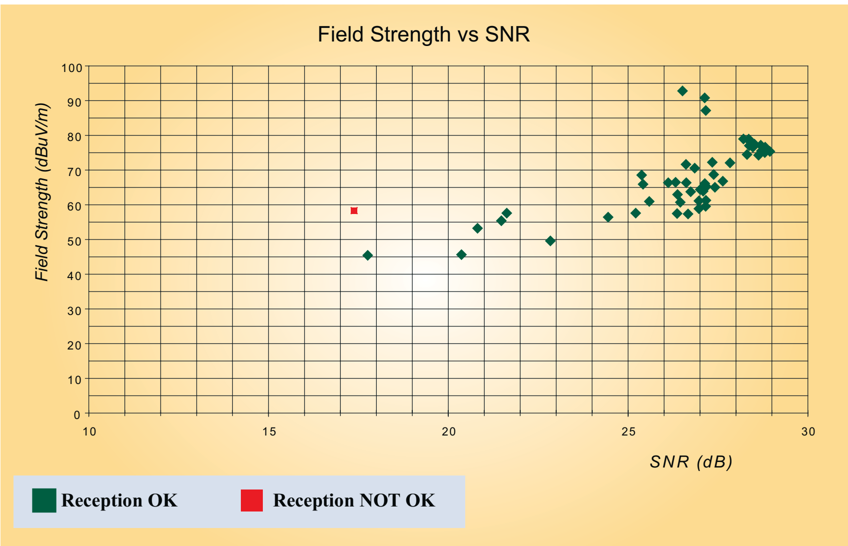

Figure 7
Electric field vs. SNR at fixed points for DRM monocast (10 kW)

In the case of mobile reception, the threshold value for DRM network planning in urban areas, broadcasting in the 9kHz / A / 64QAM / 16QAM / 0.6 / S mode, should be **20 dB**.

Both of the SNR thresholds obtained experimentally during these tests differ from the value of 15.1 dB proposed by ITU-R Recommendation BS.1615 [4] (which is based on laboratory tests and simulations).

These SNR values do not have a clear equivalence to the received electric field strength, because the electric noise levels measured during these tests were very variable. As for man-made noise, higher levels than the ITU reference [7] for urban environments were generally measured. Noise levels of around 30 dBµV/m were measured, showing a variability of up to 8 dB in some areas.

Another important factor is the level of attenuation along a route, which depends on different local urban factors. The median variation between the average value and the value which was exceeded at 99% of locations was 22 dB (standard deviation = 7 dB).

Finally, a study to determine the field strength spatial distribution at a lower frequency in urban environments was performed. For this purpose, a 50 kW radiated AM signal was broadcast on 810 kHz from the same transmitting site used for the DRM experimental network. The same routes were measured for both signals (810 kHz and 1260 kHz) and a received field-strength comparison was made after normalizing the levels measured at both frequencies.

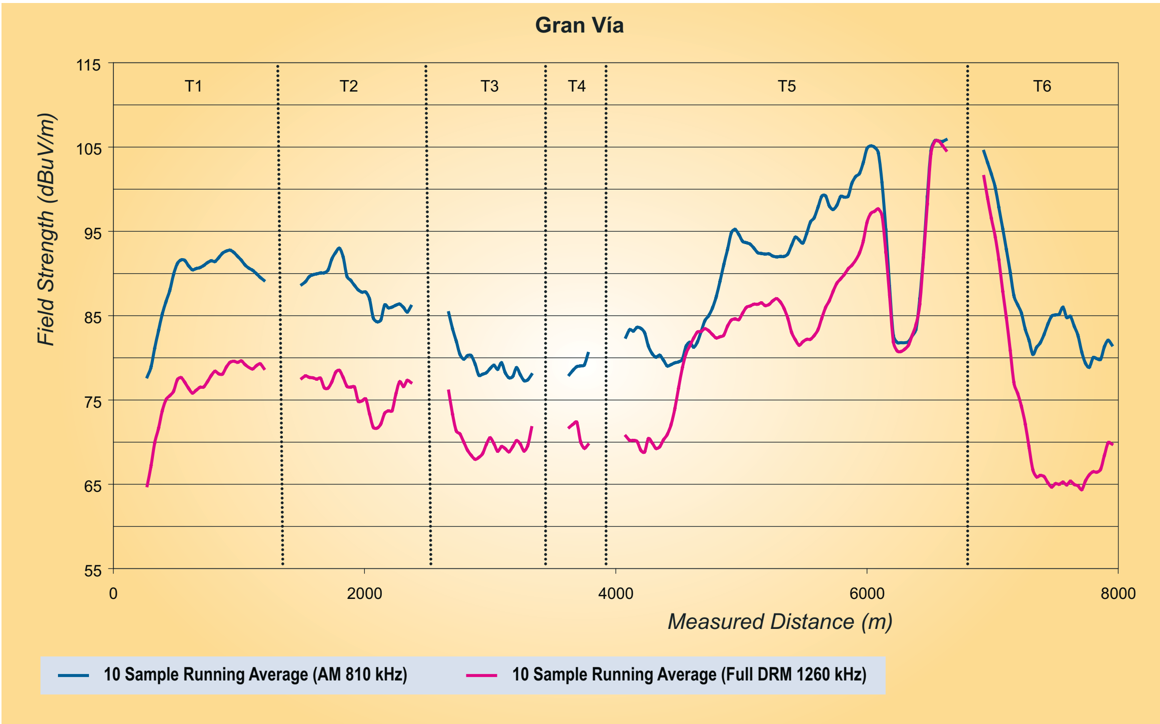

Figure 8
Gran Vía zone. Received field in 810 kHz and 1260 kHz

By means of this procedure, almost 40 km of routes were assessed in the different zones covered by these tests. *Fig. 8* shows the received field strength for six sections analyzed in the Gran Vía zone. In order to make the comparison easier, a ten-samples running mean was applied, reducing the fluctuations of both signals.

It can be observed that both of the signals vary in a similar way with a 10 dB level difference. The difference in the received field-strength level for both of the studied frequencies in the whole city of Madrid is determined by averaging the global values obtained for all areas as shown in *Table 9*.

According to these results, it can be concluded that the received field strength levels on 810 kHz in the city of Madrid are generally 10 dB higher than the ones received on 1260 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 the two signals increases when the height and density of buildings is higher, whereas the opposite effect takes place in less dense environments. Taking into account that the wavelength corresponding to 1260 kHz is shorter than the wavelength for 810 kHz, the former frequency is more affected by surrounding obstacles. It is worth pointing out that the distance between the transmitter and reception location is not a decisive factor in that difference.

Table 9
FS differences between 810 kHz and 1260 kHz statistics

Zone	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

DRM Monocast indoor tests

During the last 5 years, several studies have been carried out based upon field measurements in the medium-wave band. Different modes and configurations, correct reception thresholds, interference and environments have been assessed but this is the first time that an extensive specific field trial has been carried out for portable indoor reception analysis in the MW band. This environment was assumed to be more hostile and critical, mainly due to an increase in man-made noise levels.

The measurements for this stage of the field trials were planned for 6 buildings in the city of Madrid and one in an industrial area in a suburb to the south. With the aim of determining the performance of the DRM signal, different types of buildings were chosen, in different environments and serving different purposes. A total of 113 indoor locations in seven buildings were measured as summarized in *Table 10*.

Table 10
Measurements summary

Identifier	Type	Streets	Height (floors)	Environment	Distance to Tx (km)	Number of meas. points
E1 Building	Private	Narrow	3	Urban Non Dense	13.8	15
E2 Building	Private	Narrow	3	Urban Non Dense	10.2	9
E3 Building	Private	Wide	7	Urban Dense	7.9	18
E4 Building	Private	Wide	10	Urban Dense	13.2	8
E5 Building	Commercial	Wide	10	Urban Dense	8.9	44
E6 Building	Commercial	Wide	2	Industrial	16.9	11
E7 Building	Commercial	Wide	6	Urban Dense	9.9	13

The overall results for indoor reception are displayed in *Table 11*. These results have been divided according to the environment where the building is placed and the type of building. DRM reception in the medium-wave band depended on the height of the buildings and its adjoining environment. Noise values of 51, 64, 64 and 62 dBµV/m were obtained in four different dense urban environments. For planning purposes, this parameter has to be considered as essential owing to the field level requirement. This value should be as high as 80 dBµV/m for satisfactory reception in dense urban environments, while it can be reduced by more than 10 dB in non-dense urban environments.

Table 11
Summary of evaluated buildings (median values)

	PRIVATE 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
SNR (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

As for the noise behaviour, for instance, *Fig. 9* shows the effect of an elevator on the noise level and therefore over the received SNR value which, in this case, is near the correct reception threshold value.

As a conclusion, 3 out of 7 buildings offered acceptable indoor reception. Good reception could be obtained in the higher part of the building, that is, on the second or third floor of a three- or four-storey building. The best reception reliability was found in non-dense urban environments. Inside the remaining measured private homes, E3 and E4 only showed good reception near the windows. That is because they are very tall buildings located in dense urban environments.

At the headquarters of *Cadena SER* (E5), reception was not good in general terms, and depended on the floor where the evaluation point was placed. SNR values showed variations from 0 to 17 dB. As in the previous case, and because of being placed in a dense urban environment, the reception close to the windows was better. In this special case, the analogue services transmitted on 810 kHz, were also not correctly received**.** The main reason for bad reception in this building is man-made noise. Noise levels can fluctuate up to 40 dB, with a median value of 19 dB.

What is also remarkable is the variation of the received electric field strength inside the buildings: they can vary by up to 30 dB inside the same building. The median value of the measured variation was 16 dB. Moreover, this value increases with the height of the reception point.

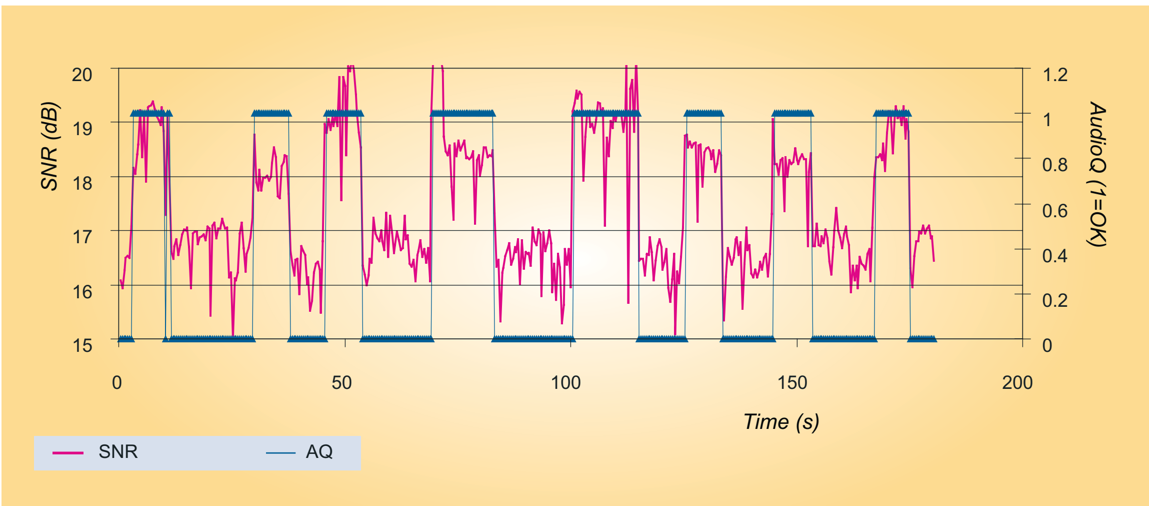

Figure 9
Threshold levels in E5 building

The required signal-to-noise ratio for a correct reception of the DRM signal using the mode mentioned above was 17.5 dB. Using 10 kW transmitted power, around 48% of the measured locations were covered. As a conclusion, this transmission power is not enough to provide reasonable indoor reception in a big city like Madrid. However, according to the results, with an increase of 3dB in the SNR value; i.e. increasing the transmitted power by 3 dB (equivalent to a 20 kW transmitted power), a coverage of 82% of locations can be achieved. *Fig. 10* shows the evolution of the predicted coverage when a transmitted power increase is considered. The 0 dB bars correspond to the actual coverage measured in these trials with 10 kW, so +3 dB would be 20 kW and +6 dB would be 40 kW. Each row represents each building tested in these trials (E1 to E7)

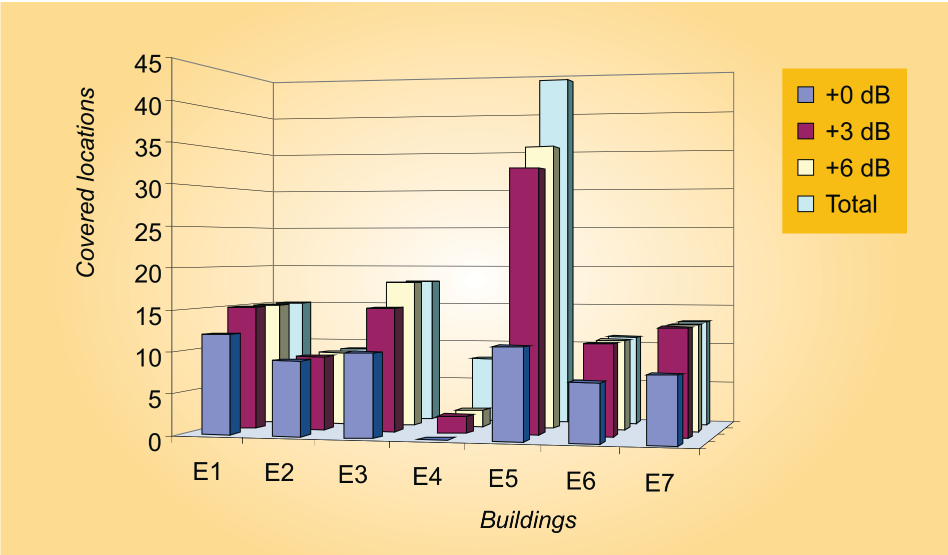

Figure 10
Coverage prediction

The first row (foreground from left to right) represents the number of indoor locations with good coverage (AQ>98%) inside each building. The second row shows those which would be covered by increasing the transmission power 3 dB, that is, to 20 kW. The third row shows the hypothetical case of a 6 dB increase (to 40 kW) and, in the last row, the total number of points measured in each building is shown.

The actual test transmission, featuring 10 kW transmitted power, only covered the E2 building in its entirety. However, in a hypothetical case of a 3 dB increase in transmission power (to 20 kW), the coverage would considerably increase to 100% in the E1, E2, E6 and E7 buildings. Good coverage within the E3 building (83%) and E5 building (73%) would also be obtained.

In the case of a 6 dB increase in transmission power, the coverage will improve only a little in comparison with the previous prediction, with the E3 building being totally covered. The E4 building and a low percentage of the E5 building would not be covered, due to local propagation conditions. Even if the transmission power were increased, it would not enable correct reception of any type of analogue or digital signal in the medium-wave band.

Conclusions

A DRM experimental network was set up in Madrid during 2007 to evaluate the AM-DRM Simulcast configuration for outdoor environments and the DRM Monocast configuration (in both urban outdoor and indoor reception environments).

The coverage area when broadcasting in the ***Simulcast configuration*** resulted in around 7 km with 16 dB power ratio and 0.25 kW transmitted power for the digital signal. This back-off ratio value is mandatory for the worst performing receivers. On the other hand, the analogue signal should be given a minimum of 12 dB margin over DRM in order to get acceptable reception with most mid-range receivers.

In the case of ***DRM Monocast reception in urban outdoor areas***, the transmitted power of 10 kW provided an excellent static coverage. Nevertheless, a transmitted power of 20 kW would be needed to achieve fair mobile coverage. Also, low frequencies within the medium-wave band ensure lower attenuation values in these environments, thus extending coverage significantly.

Finally, the results for ***DRM Monocast indoor reception*** depend highly on the type of building. Reception is generally better in the upper part of such buildings and Non-Dense urban environments. Since high noise levels were found at many locations, the transmitted power should be increased to 25-35 kW to cover Madrid properly.

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