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DRM

DIGITAL RADIO MONDIALE (DRM):

MW SIMULCAST TESTS IN MEXICO D.F.

Abstract

This report presents the study on the performance and related propagation aspects of the DRM system in Simulcast configuration developed after an extensive measurement campaign in the coverage area of an experimental network installed in México City (México). The study analyzes the quality of analogue and digital services based on a set of static and mobile measurements done during the year 2006. This report contains information regarding, received audio quality statistics and minimum usable field strength thresholds. Also the potential interferences between analogue and digital signals are studied. Finally, the ITU-R recommendations that have been traditionally used to predict field strength values for both the analogue and the new digital service are evaluated.

CONTENTS

1 Motivation

The DRM system is a digital radio system that is currently standardized for applications in the broadcasting bands below 30 MHz (long-wave, medium wave, and short-wave).

During the last few years several studies have been carried out in some European countries in order to evaluate the Digital Radio Mondiale (DRM) **[1]** simulcast performance in the medium wave band. Many of the available results have been based on laboratory measurements and few measurement campaigns have been carried out. This report aims at providing information about the system behaviour based on a carefully designed extensive field measurement campaign. This measurement campaign has been carried out as a collaborative effort between Radio Educación from México and DRM Consortium members (University of the Basque Country, Continental, Transradio, Fraunhofer IIS, RNW, and TDF).

This report and the analyses contained, have been carried out by the TSR (Signal Processing and Radiocommunications) Research Group from the University of the Basque Country (UPV/EHU).

2 Evaluation criteria

Several criteria were employed to assist in the evaluation of the DRM system for the medium wave applications. These criteria are listed in this section. Then the conclusions will be performed using these criteria:

Criteria related to existing AM analogue broadcast

- AM Audio quality
- Coverage area
- Interferences into N+2 channel (the channel of a broadcast "2 channels" from the Radio Educación one)
- Compatibility with existing broadcasters

Criteria related to DRM digital broadcast

- DRM Audio quality
- DRM Transmission circuit reliability
- Coverage Area
- Multiple languages within the same broadcasting channel
- Spectrum efficiency
- Data broadcasting
- Single standard and openness
- Cost and complexity of the transmitter and receiver
- Social, cultural and business considerations

More details of the tested DRM system, planning, equipment, procedures and results of the tests are given in subsequent sections.

3 DRM system description

The DRM signal was broadcast from the transmitter station that Radio Educación has in Iztapalapa. *Figure 1* shows Radio Educación's transmitter location that is at about 13 kilometers away from the centre of the City of Mexico.

FIGURE 1

Transmission Centre Location

A summary of the transmission centre features can be found in *table 1*. *Figure 2* shows the antenna, the transmitter and DRM exciter pictures.

TABLE 1

Transmission Centre Features

Transmission Centre	**Radio Educación (Iztapalapa, Mexico DF)**
Broadcaster	Radio Educación
Transmission centre coordinates	19º 21' 50.40'' N 99º 01' 37.75'' W
Frequency	1060 kHz
Bandwidth	10 kHz
Radiating System	134.1 m high tower braced antenna

FIGURE 2

Transmission Centre Features

The radiating infrastructure is based on 134.1 m height tower braced antenna, which is a little smaller than half a wavelength at the transmitting frequency. The broadcast of AM and DRM simulcast signal was carried out by making a change in Radio Educación's transmitting infrastructure. The transmitter that Radio Educación has in the centre of Iztapalapa usually transmits an analogue AM power of 100 kWatt. That equipment consists of two *Harris DX50* transmitters combined so that it can offer the total power of 100 kW. During these tests, AM-DRM simulcast equipment was installed in one of the Harris DX50 transmitters, while the second DX50 unit was shut down. The AM-DRM exciter is manufactured by Continental Electronics and Transradio (former Telefunken). The installation of DMOD 2 exciter and the adaptation of power distribution elements and the radiating system feeding were made in a few hours. This short period of time shows that the adaptation of an AM centre to transform into a simulcast broadcast centre is an easy task.

The transmitter output AM DRM simulcast signal was produced according to one of the possibilities, described in recommendation ITU-R BS.1615 ITU Annexes **[1]**. The DRM signal is located in the upper or lower side of the AM signal with its central frequency at 10 kHz away from AM carrier. The relative levels between the analogue and the digital signal powers were adjusted to 16 dB (being the digital part 16 dB lower than the analogue). This ratio was established to have a balance between digital signal broadcast power –and therefore coverage- and to maintain at the same time a negligible perturbation of the analogue signal.

This way the following power levels were delivered to the radiating system.

TABLE 2

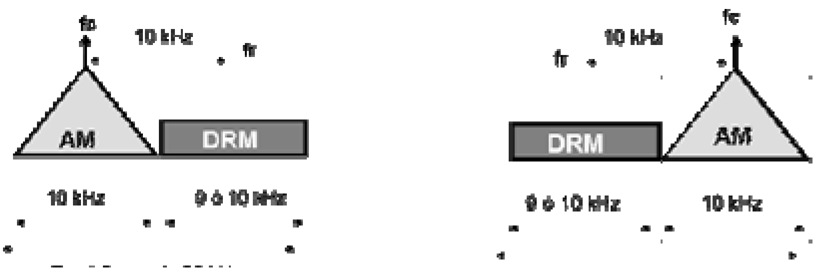
Simulcast signal transmitting powers

Signal	Power (dBkW)	Power (kW)
AM	16.98	50
DRM	0.98	1.25

The choice of using the upper ($f_{Carrier\ AM}$ + 10 kHz) or lower frequencies ($f_{Carrier\ AM}$ − 10 kHz) from the AM signal carrier to locate the digital signal is a broadcaster decision. It can choose the configuration that better fits its service and minimizes interference potential according to the frequency allocations in the coverage area. In these tests measurements were taken using both configurations. This way, it was demonstrated by measurements that in the installation in Radio Educación center, results were similar for both, being slightly better for the configuration on upper frequency ($f_{Carrier\ AM}$ + 10 kHz).

FIGURE 3

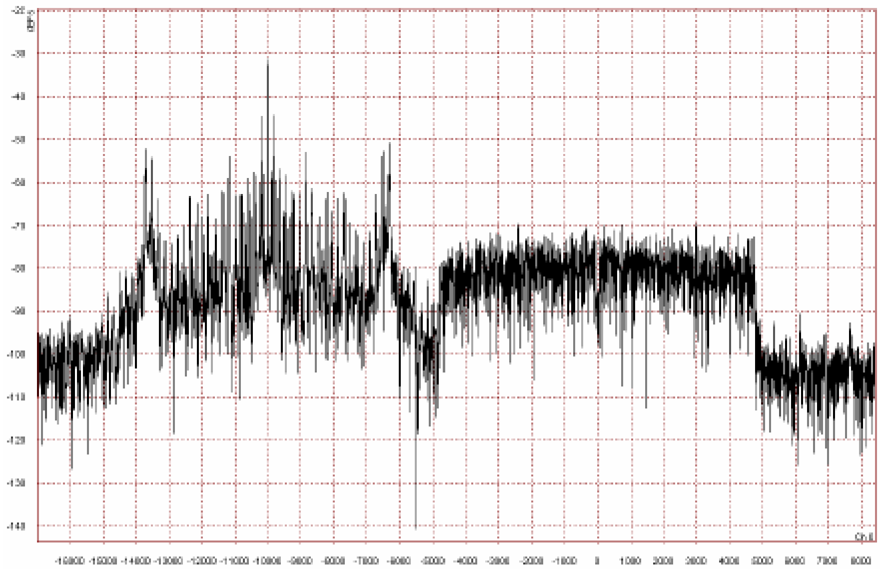
Mexico D.F. field tests. Simulcast configurations.



A graph of the simulcast signal spectrum appears in the following figure. In *figure 4* the horizontal axis represents the spectrum of the Medium Wave band with a 24 kHz span and central frequency of AM-DRM simulcast signal. The disposition of AM signal and DRM signal located in the upper side of the spectrum ($f_{Carrier\ AM}$ + 10 KHz) is shown in the figure.

FIGURE 4

Spectrum of simulcast signal in Mexico D.F.



The DRM standard **[2]** provides several configurable transmission parameters that allow many different DRM transmission modes, with different robustness against noise, multipath or interference. The more robust the mode is, the less maximum subjective audio quality can be achieved due to a lower useful bit rate available. In order to evaluate the influence of each parameter, the modes in *Table 3* were chosen for the tests.

TABLE 3

DRM tested configurations

NAME IN DOCUMENT	Bandwidth (kHz)	OFDM	MSC	SDC	Code rate	Interleaver	Bite rate (kbps)
10K_A/64/16/0,6	10	A	64QAM	16QAM	0,6	L (Long)	26.6
10K_A/64/16/0,5	10	A	64QAM	16QAM	0,5	L	22.1
9K_A/64/16/0,5	9	A	64QAM	16QAM	0,5	L	19.7
10K_B/16/4/0,5	10	B	16QAM	4QAM	0,6	L	11.7

The first column of *Table 3* is a reference code included for the sake of briefness when referring to a combination of parameters in the rest of this document. The DRM modes in *table 3* are ordered from less to more robust as can be deduced from the corresponding useful bit rate, which decreases from the top to the bottom of the table. A broader explanation of the number of carriers, OFDM guard interval, protection level and interleaving algorithms, as well as the Main Service Channel (MSC) and the Service Description Channel (SDC) modulations is out of the scope of this document and can be found in detail in the DRM Standard **[2]**.

The base band source audio information used in these tests was the same for both analogue and digital signal. However DRM simulcast configurations allow the broadcast contents for AM signal and DRM signal to be independent. In these tests audio content was Radio Educación regular AM programming. As both analogue and digital signal transmitted the same contents analogue and digital system, final qualities could be compared in a subjective way. The possible degradation of subjective quality of analogue signal due to the interference of the digital signal was also tested.

4 Performed Tests and objectives

The tests carried out in Mexico D.F. on Medium Wave simulcast were planned in three main groups:

- AM-DRM simulcast behaviour in different environments.
- Tests under specific transmission and reception conditions
- Noise level evaluation at Medium Wave.

4.1 DRM simulcast behaviour evaluation in different environments

The first test group consisted on data collection for several reception environments with different DRM signal configurations. The objective of this measurement block was to obtain the threshold levels for the digital system to work properly at a set of representative reception conditions. The subjective quality of the received AM signal using a sample of the analogue receivers currently available at the Mexican market was also analyzed. Most of the measurement campaign time was spent in measuring at these pre-selected routes at different environments. Two kinds of measurements have been performed at each route: fixed reception at some locations and mobile reception. The objective of these routes (Route 1 to 7 on *table 4*) was to determine the characteristics of the simulcast signal propagation at each of the considered environments that have been named “Urban”, “Open-Residential”, “Industrial”, “Typical Mexican Dense”, and “Typical Mexican non Dense”.

TABLE 4

Measurement Routes

Name	Main Environment	Zone	Approximate Distance to the Transmitter
Route 1	Typical Mexican Dense	Benito Juárez	12 km
Route 2	Urban	Reforma	15 km
Route 3	Industrial	Azcapotzalco	18 km
Route 4	Typical Mexican Non Dense	Coyoacan	16 km
Route 5	Typical Mexican Non Dense	Ecatepec	17 km
Route 6	Typical Mexican Non Dense	Venustiano Carranza	10 km
Route 7	Typical Mexican Non Dense	Xochimilco	13 km

The environments are mainly defined by the following characteristics:

- "Typical Mexican Non Dense". Urban environment with wide streets and low houses, usually two floors.
- "Typical Mexican Dense". Environment with 3 to 7 floors houses and a bit narrower streets than the Mexican Non Dense environment.
- "Urban". An area with very high buildings, usually more than 8 floors.
- "Open Residential" Areas with few buildings like parks, or open areas. Two different areas have been chosen, "El bosque de Aragón" and "La Ciudad Deportiva" very far from each other.
- "Industrial". Industrial park like, with no heavy industry.

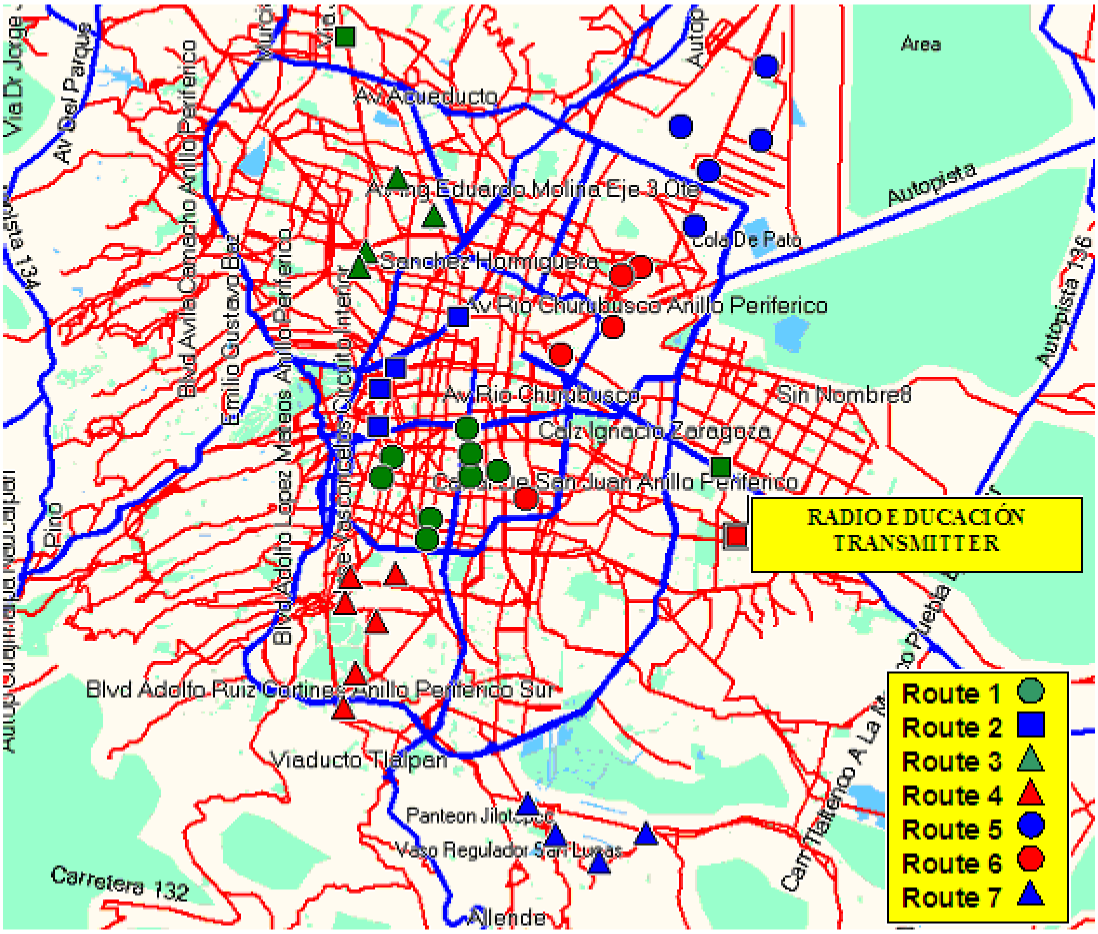
The initial planning was made to have routes with only one environment type; but in the Open Residential environment case this was not possible because the chosen locations for such environment are very disperse, and the measurements are associated with driving through a mixture of several environments.

Although in each route one of the selected reception environments is predominant that does not mean that all the measured locations within the route correspond necessary to such an environment. That is why all the measured locations were later classified independently of the route where they have been measured.

More that 40 fixed points were measured altogether and the corresponding mobile measurement routes between two consecutive locations. Both, the points and the routes are represented on *figure 5*. Two locations can also be observed, marked with green squares, that do not belong to any of the routes planned. They were measured when testing the coverage area in a radial route beginning near the transmitter towards northwest of Mexico City.

FIGURE 5

Measurement Routes in Mexico D.F.



4.2 Specific Tests

The second set of measurements consisted of evaluating very specific aspects of the system behaviour. The following tests were made:

1 Variation of the power ratio between the analogue and the digital signal.

2 Variation of the DRM signal bandwidth between 10 kHz and 9 kHz inside the simulcast

3 Variation of the transmitted modes and bit rates

4 Adjacent channel interference test

5 Tests near high voltage power towers

6 Tests under wires at typical Mexican environment

7 Measurements in presence of trolley buses

8 Indoor AM subjective audio quality evaluation

4.3 Radio electric noise

The man-made radioelectric noise (power lines, car engines, transformer stations, and general electronic equipment) is becoming larger every day.

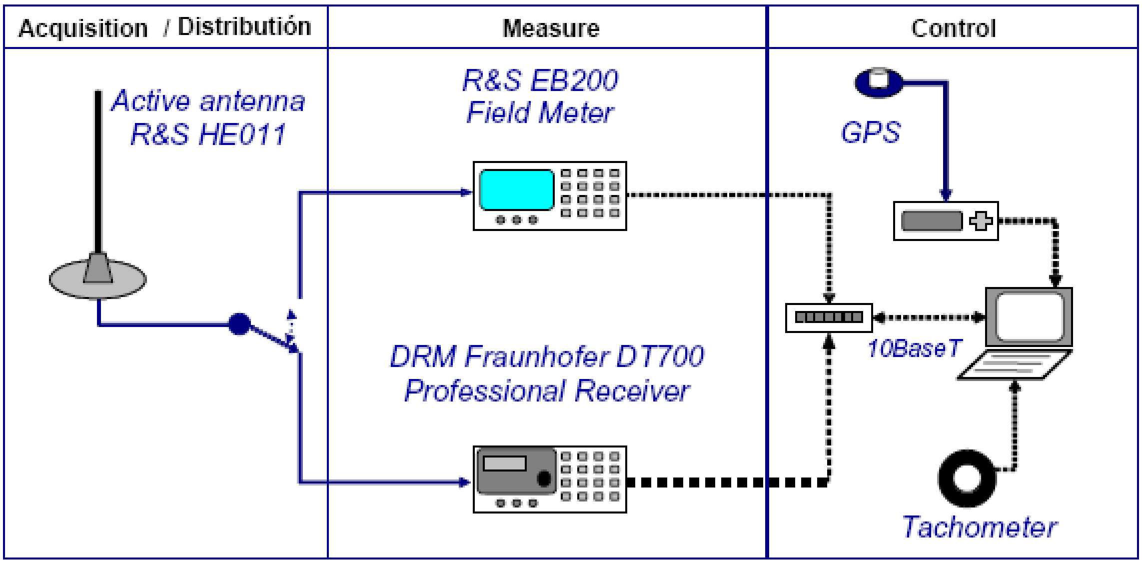
To characterize the radioelectric noise level present at Mexico D.F some measurements were taken at the fixed locations and through the predefined routes for the transmitted signal analysis.

5 Measurement system

The measurement vehicle was equipped as shown in *figure 6*. A set of three modules are in the measurement system: signal acquisition and distribution, measurement and control module.

FIGURE 6

Measurement system



The acquisition system was formed by a fully characterized short monopole active antenna R&S HE011 [3], placed on the top of the measurement vehicle over a specified ground plane. Received signal was properly distributed to the Fraunhofer DRM DT700 professional receiver front end or to R&S EB200 field meter depending on the type of measurement. Antenna connection was carried out with one switch as shown in the figure to be able to make two secuential measurements, first with the EB200 and later with the DT700.

The reception system was formed mainly by the previously mentioned devices. R&S EB200 Field meter [4] was used for noise and DRM signal field strength measurements with 1 dB accuracy and on the other hand the Fraunhofer DRM DT700 professional receiver [5] was used, which is capable to capture all the required DRM parameters and the analogue AM signal field strength. Moreover DT700 saves intermediate frequency signals and demodulated audio signals.

Finally, a module, called the reception module, (not shown in the figure) is formed by different medium wave commercial receivers which were used to assess the AM signal subjective audio quality in different reception locations.

The control module is based on a laptop running specific software over GNU/Linux platform. This software configures and controls the other equipment and calculates some statistics of the measured parameters during the measurements. Furthermore, a GPS receiver and a tachometer provided auxiliary data such as time, position and route data.

The measurement system captured a set of DRM or AM signal parameters and auxiliary data and they were properly stored in plaintext format files. These basic parameters were stored for each measured signal over a complete route in the case of mobile reception and during 3 minutes interval in the case of fixed reception. For this last type of measurement one minute statistical analyses were carried out, storing them in each measurement plane text files. *Table 5* and *table 6* show measured parameters by each module of the system for both, analogue AM signal and DRM signal.

TABLE 5

AM signal measured parameters.

Supplier	Type	Parameter	Fs
DT700 Receiver	RF	Field Strength	400 ms
	IF	IQ Signal	
Comercial receivers	Base Band	Audio subjective quality	3 min
Field Meter R&S	RF	Field Strength	400 ms

It is very important to emphasize the utilization of different AM commercial receivers to the audio subjective quality assessing. This means that each receiver will use its own antenna for the reception which is obviously different in all cases to the antenna used by the measurement system. So the obtained subjective quality results could not match with the results obtained with used professional measurement system. However, these results will be useful to assess the Simulcast system introduction in México City taking into account the user impressions with a commercial AM receiver.

TABLE 6

DRM signal measured parameters.

Supplier	Type	Parameter	Fs
DRM DT700 Receiver	RF	Field Strength	400 ms
		SNR	
		Delay Spread	
		Doppler Spread	
	IF	IQ Signal	
	Base Band	Error audio frames distribution	
Field Meter R&S	RF	Field Strength	400 ms

Auxiliary data provide spatial and time references as shows *table 7*. Tachometer module provides for each measurement the distance and instantaneous speed counting each wheel turn and knowing its diameter. The measurement system allows a trigger configuration to calculate some statistics in a specified distance interval.

TABLE 7

Auxiliary data

Supplier	Type	Parameter	Fs
Auxiliary Data	Tachometer	Distance	Every 2.2 meter
		Trigger	
		Speed	
	GPS receiver	Time	1 s
		GPS position	
		Speed	

Apart from the basic parameters and calculated statistics, sampled input at intermediate frequency signal and DRM parameters specified in RSCI standard **[6]** were stored in binary format files. So, IQ samples of measured AM, DRM and noise signals during the whole field trials were stored for a possible post processing after the tests.

In order to complete all the measured information stored by the equipment, a detailed description and some photos in the reception location were carried out to ensure a correct classification of existing environments. In the location description, the presence of power lines, buildings, traffic or lorries shadowing the reception antenna and possible presence of noise sources were annotated.

6 Test results

6.1 Introduction

Test results have been divided into two different parts. The first one shows the major conclusions obtained for the analogue AM signal (*section 6.2.*). In this section, the AM signal subjective audio quality in measured reception locations is exposed first, then analogue coverage for the transmission centre with simulcast configuration, and finally the AM-DRM compatibility is analyzed studying the possible interference between analogue and digital signals.

The second part of this section analyzes reception quality and obtained reception thresholds for the DRM digital signal in México City. In this second part the results are summarized in different sections. The first one studies obtained service availability for DRM signal. The second part shows the system reliability results. This second part analyzes the system thresholds for a proper operation configuring DRM signal in different ways as described in *section 3*.Then, DRM coverage will be analyzed and finally there will be a subsection studying DRM and AM signal compatibility but in this case taking into account the possible interference of analogue signal over DRM signal.

6.2 Radio Educación AM service evaluation.

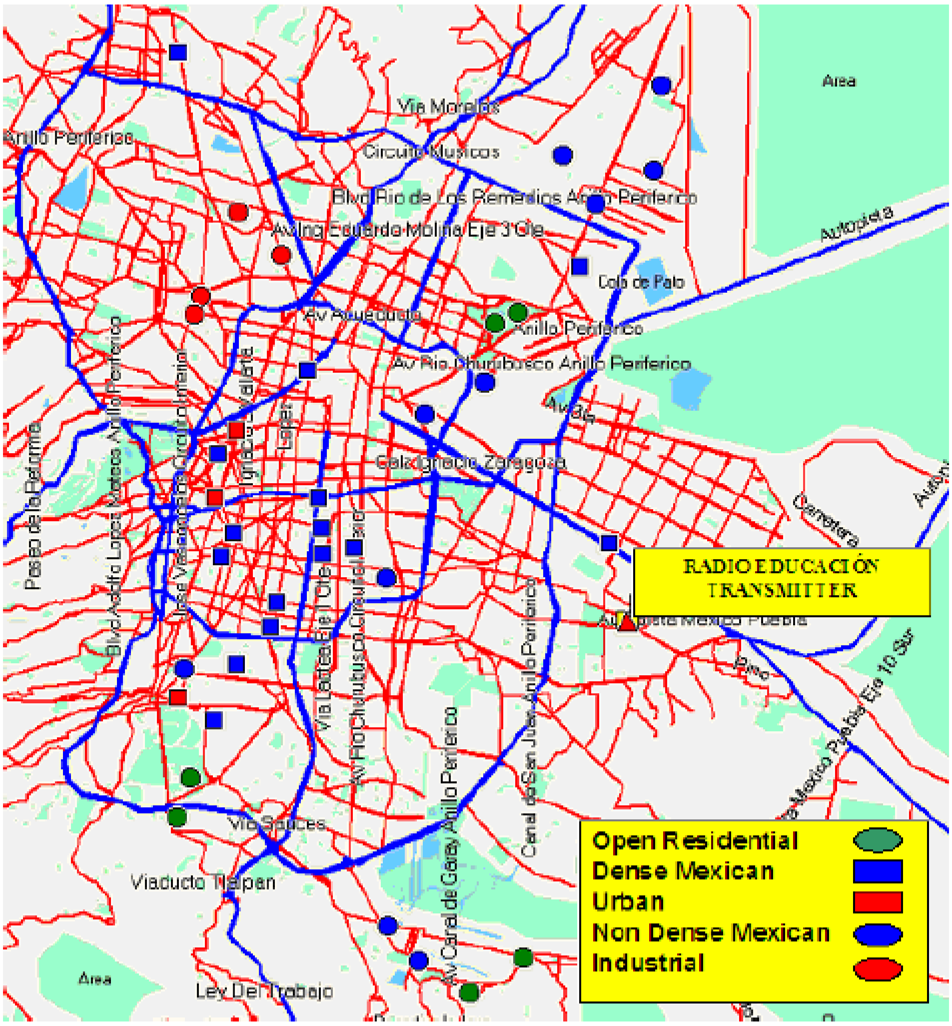
6.2.1 Reception quality of AM signal.

Subjective audio quality reception of AM signal was assessed in different measurement locations specified by planning described in *4.1. subsection*. *Figure 7* shows over a Mexico City map measurement locations where subjective audio quality was analyzed distinguishing between different environment types.

The analogue AM signal quality evaluation was mainly based in two different parameters, on the one hand **subjective audio quality** was assessed and on the other hand received field strength in each location was analyzed.

FIGURE 7

AM measurement locations



Both audio quality and field strength were evaluated during a time period no shorter than three minutes in each measurement location. In the next table a summary of locations where the AM signal data were stored is shown. In *table 8* locations are classified by type of reception environment.

TABLE 8

Locations where AM was measured

Environment	Locations
Industrial	4
Open residential	6
Dense Typical Mexican.	12
Non Dense Typical Mexican.	6
Urban	3
TOTAL	35

AM subjective audio quality depends highly on the used receiver features to demodulate the received signal. Features of intermediate frequency filters have a direct effect in the signal to noise ratio (SNR) over a base band audio signal. On the other hand, those filters are different in different commercial manufacturers and between different models of the same manufacturer. In order to obtain realistic results of the quality that users will perceive from Radio Educación's broadcasting service in Mexico D.F., subjective tests were carried out with a set of four commercial receivers which represents a big range of receivers for the Mexican market.

FIGURE 8

Used AM commercial receivers

- The first of receivers used is a Sony ICF SW10. This type of receiver can be considered as a medium price receiver and it has the possibility of short wave tuning.
- The second one is a Sony CFDS400. This receiver is an inside multifunctional device with CD. This is not such a portable receiver like the others but is a high price receiver.
- Grundig MiniWorld PE receiver is the third one; it is the smallest one and it offers the possibility of short wave tuning. In the same way as the first receiver, this is a medium price receiver.
- The last receiver used in these tests is a Panasonic RQ-CR07V whose features are integrated in a walkman device which can be considered as a low price receiver.

The subjective audio quality and degradation was analyzed using the ITU-R BS.1284 [7] criterion.

TABLE 9

AM subjective audio quality criteria

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

Subjective audio quality annotations were made by the engineers who carried out the field trials. They are expert listeners as it is said in the mentioned recommendation. Since the type of listeners will affect subjective audio quality results, the assessments from expert listeners will be conservative because an average listener would perceive less critical subjective audio quality than an expert listener.

Audio contents for evaluation of subjective audio quality were broadcast by Radio Educación all the time and, as we have mentioned in previous sections, the tests were carried out using the regular broadcast service of this Mexican public broadcaster.

The Tables below show obtained values for quality in locations where the subjective audio quality was evaluated. This evaluation has been carried out taking into account different reception environments.

TABLE 10

AM subjective quality in Industrial areas

Location	Distance to Tx (km)	Subjective quality (AM)	AM Field (dBµV/m)	DRM Field (dBµV/m)	Difference (dB)
R3P1	18,9	5	100.63	83,65	16,97
R3P2	17,9	5	94,34	79,54	14,8
R3P3	20	4	99,78	82,7	17,07
R3P44	18,7	4	98,57	79,76	18,81

The first column shows the name of the measured location whose results are shown in the subsequent columns. The number after the ‘R’ indicates the number of the route and one after the ‘P’ is the order of the location in that route. The second column references the distance between location and transmitter in Iztapalapa in kilometres. In the next column measured audio qualities are shown using a range of 1-5 and only with Sony ICF SW10 receiver. Although the evaluation of the subjective audio quality has been made using 4 different receivers, obtained results are very similar for all so, in this document only the results of mentioned receiver will we shown. The last three columns show measured field strength levels for both the AM and DRM signals in the simulcast configuration and measured difference of power levels between them.

The following tables show obtained results for the other reception environments.

TABLE 11

AM subjective quality in Open-Residential areas

Location	Distance to Tx (km)	Subjective quality(AM)	AM Field (dBµV/m)	DRM Field (dBµV/m)	Difference (dB)
R7P3	14,4	5	107,12	90,45	16,67
R7P4	12,56	5	110,83	92,05	18,78
R4P1	17,3	5	108,66	91,26	17,39
R4P2	16,2	5	101,72	88,12	13,6
R6P4	11,6	5	110,99	94,11	16,88
R6P5	11,7	5	109,83	92,01	17,88

TABLE 12

AM subjective quality in Dense Typical Mexican areas

Location	Distance to Tx (km)	Subjective quality(AM)	AM Field (dBµV/m)	DRM Field (dBµV/m)	Difference (dB)
C1	25,6	5	102,8	85,94	16,82
R4P3	15,1	5	99,25	81,88	17,37
R4P4	13,8	5	109,86	92,11	17,75
R1P1	11,8	3	100,44	84,64	15,8
R1P2	14,3	5	110,99	93,69	17,3
R1P3	12,5	4	98,74	82,99	15,75
R1P4	10,9	4	103,15	88,09	15,06
R1P5	11,3	4	103,31	84,9	18,4
C2	2,9	4	117,31	99,97	17,35
R5P1	9,95	5	107,44	88,65	18,69
R2P3	14,2	4	109,42	93,74	16,68
R2P4	15,5	3	100,75	83,54	17,21

Locations named as C1 and C2 are not included in a defined route because they were measured during the coverage test of the simulcast signal.

TABLE 13

AM subjective quality in Non Dense Typical Mexican areas

Location	Distance to Tx	Subjective quality(AM)	AM Field (dBµV/m)	DRM Field (dBµV/m)	Difference (dB)
R7P1	13,76	5	105,24	87,88	17,35
R7P2	14,13	5	100,24	84,28	15,96
R5P2	15	4	106,29	88,62	17,66
R5P3	16,2	2	100,8	83,07	17,73
R5P4	19,1	4	95,8	78	17,8
R5P5	17,1	4	103,51	88,19	15,31

TABLE 14

AM subjective quality in Urban areas

Location	Distance to Tx	Subjective quality(AM)	AM Field (dBµV/m)	DRM Field (dBµV/m)	Difference (dB)
R4P5	14,9	4	103,13	85,76	19,14
R2P1	15	4	105,23	88,19	19,73
R2P2	15,3	4	101,79	88,31	18,92

The previous table data show that AM subjective audio quality is excellent and it is not influenced by the presence of the DRM signal at a distance of 10 kHz of the AM carrier (DRM central frequency of 1070 kHz) and with 10 kHz bandwidth. So, it can be said that digital signal has no effect on analogue signal regularly transmitted by Radio Educación.

FIGURE 9

AM subjective quality measured in Mexico DF

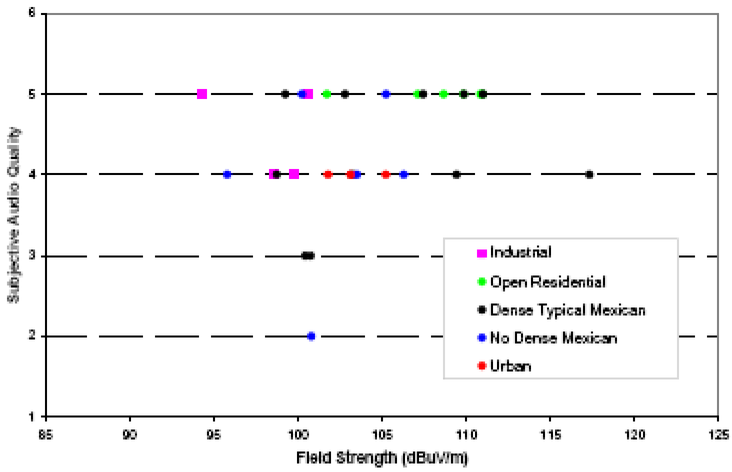


Figure 9 shows that the AM subjective audio quality has no dependence with the received field strength level in an urban environment inside the coverage area. Moreover, inside México City this audio quality is not dependent on the environment. This means that the subjective audio quality depended only on the ratio between signal strength and noise level at each measured location.

TABLE 15

Subjective Audio quality results

	Number of locations	Correct Reception	Incorrect Reception	% of incorrect
Number of measured locations	31	28	3	9,67%

Following ITU subjective grading, out from a **total of 31 measured locations** where the subjective audio has been assessed, there are only three cases where listeners experienced a perceptible audio degradation and minimum slightly annoying degradation. After analyzing obtained results the conclusion is that DRM digital signal does not affect the AM signal audio. The degradation is negligible then when the power ratio between the analogue and the digital signal is 16 dB. If this statement were not true, audio degradations in the AM analogue signal would appear even if the signal to noise ratio in AM was higher.

AM field strength level reception

The second AM signal reception parameter analyzed is the received field strength every 400 ms in the 10 kHz bandwidth channel occupied by the analogue signal. In that way, measured values included carrier and side band power. Considering a maximum modulation index of 100%, the carrier power level is the same as that level contained in the two side bands. This means that in overall bandwidth of the signal there is two times the carrier power level, that is, 3 dB more.

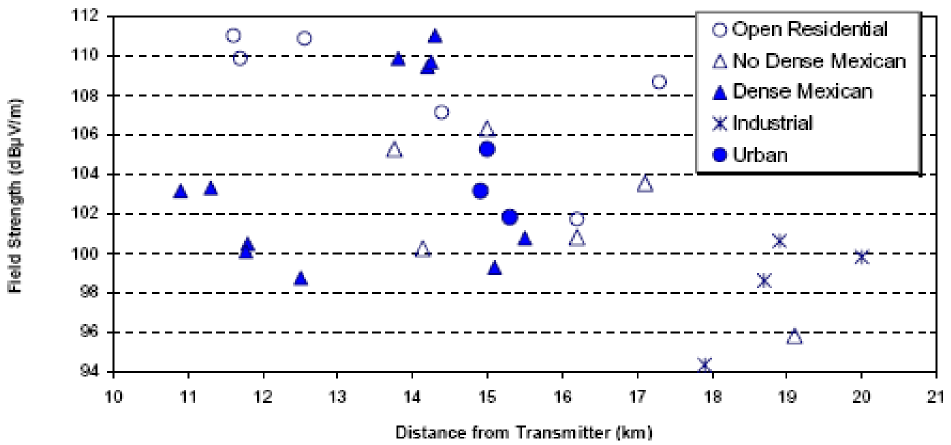
The field strength values were obtained by adding the antenna K factor to the measured power level. The antenna K factor is the relationship between the power provided by the antenna and the field strength in reception location. So, it has been obtained a field strength value every 400 ms.

Measurements were carried out during a minimum of 3 minute interval in each location so there are more than 450 field strength values in each location. Median value of field strength measurements was taken as a nominal value to analyze coverage and audio quality. Nominal field strength values are shown in *tables 10 to 14*.

Figure 10 shows the nominal value of measured field strength over the distance to the transmitter with different characteristic environment of each reception location.

FIGURE 10

Measured field strength over distance to the transmitter in different environment locations.



The graph shows that the field strength average level received in Open-Residential areas is higher than in the rest of defined environments. This conclusion is in accordance with the fact of the lack of buildings in Open Residential environment which reduces the possible causes of signal attenuation in the received signal.

6.2.2 Coverage Data

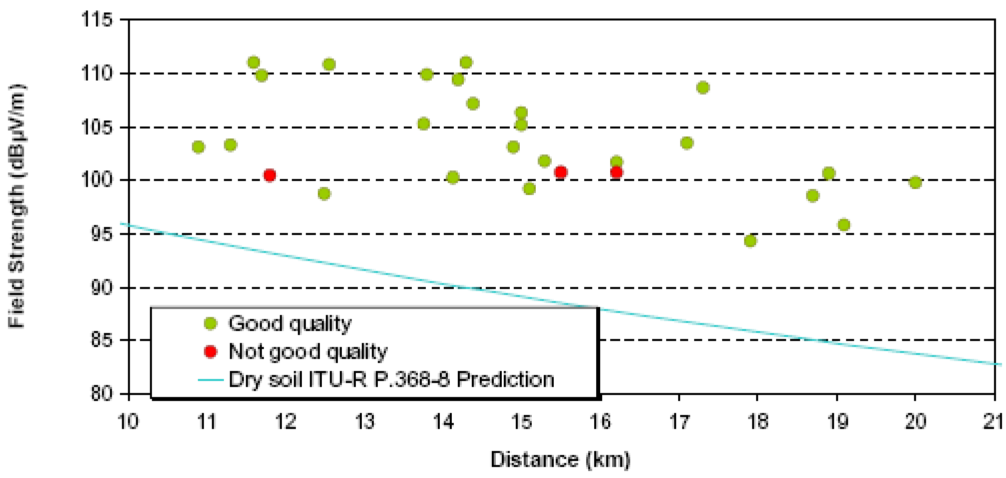
AM signal coverage is analyzed in *figure 11* where there is represented nominal field strength over distance to the transmitter in each measured location.

The classification of measured locations into "covered" and "not covered" was done on the basis of the subjective audio quality perceived at each point. Locations where the subjective rating was either 4 or 5 were considered as covered locations. Locations with subjective scores corresponding to 3, 2 and 1 levels where considered "not covered" locations. Locations with a correct reception corresponding to the first set of points have been coloured with green in *figure 11* and locations inside the second set are in red.

That figure shows field strength values obtained using the prediction method recommended by the ITU **[8]** for daytime medium wave band propagation. These analyzed transmission features involve the presence of ground wave propagation without any important presence of line of sight or sky wave propagation. Simulation and prediction has been carried out for the type of terrain of Mexico D.F. considering a 3 mS/m conductivity **[9]** and a relative permittivity of 6 obtained from tabulated values in common use references for "dry terrain" εr = 4 and "rocky terrain" εr = 7 **[10]**. Transmitter height is detailed in *table 1*.Used prediction method provide values for 1kW transmission power. In DRM-AM simulcast mode transmitted in these field trials AM transmitted power was of 50 kW and in a logarithmic scale the DRM power was 16 dB lower than analogue signal. These values have been taken into account for the prediction field strength obtained values in the figure.

FIGURE 11

AM coverage of simulcast service with DRM. Predicted field strength for "dry terrain".



First of all, it is observed that the subjective audio quality of the AM service in simulcast with DRM was in a correct reception in most of measured locations, specifically in 90.32 % of locations. Measured field strength value in incorrect reception locations is higher than some of them with correct reception; so the reception problems were not due to the lack of field strength level.

On the other hand, locations receiving a nominal field strength value higher than 101 dBµV/m, threshold value, had a correct reception. This threshold value is considerable higher than the value of 60 dBµV/m recommended by the ITU for medium wave band **[11]** in order to obtain an audio signal to noise ratio of 26 dB.

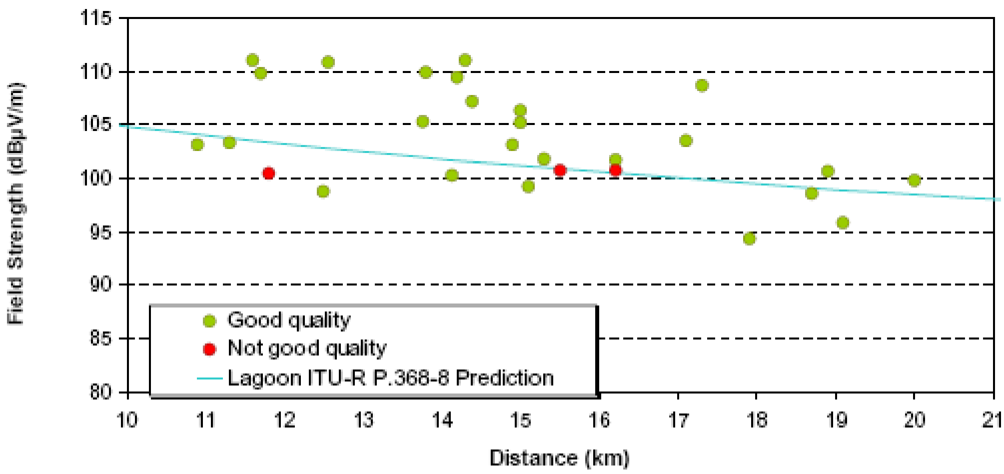
Field strength general tendency line decreases as the distance to the transmitter increases. Nevertheless, there is an influence of additional propagation factors. For measured field strength values, locations at a similar distance to the transmitter registered values that differ up to 10 dB. These differences were due to the attenuation caused by the characteristics of urban areas where buildings represent wavelength magnitude obstacles **[12]**. There were other kind of smaller obstacles like buses, lorries and trolley buses which cause signal attenuation if they were near the reception antenna.

Comparison between measured and predicted field strength values shows remarkable differences (5 to 25 dB). The results of the predictions are very pessimistic, when the input model parameters are a conductivity value of 3 mS/m and a relative permittivity of 6. Using these parameters at the working frequency, penetration depth of the resulting ground wave is around 10 meters approximately. In this way, an important part of the propagated wave is in contact with a terrain of the small lake over México D.F. was constructed and the real conductivity values should be higher than the ones supposed in the first approach.

If a value of 50 mS/m is considered, and conductivity and a relative permittivity of 80, typical values for fresh water **[10]**, the prediction results as shown in *figure 12*.

FIGURE 12

AM coverage of simulcast service. Predicted field strength for "small lake"



Although predicted field strength value is pessimistic in this case too, the difference between predicted and measured field strength is lower than 10 dB all the time. Conductivity and permittivity of small lake terrain are better adjusted to values registered in Mexican field trials.

6.2.3 Compatibility in simulcast mode between AM and DRM signals

Locations with an incorrect reception of the AM service, with a quality level lower than 4 with DRM in the simulcast signal, are detailed in *table 16*. It is explained by the reception environment in those locations. Moreover, there are included nominal values of field strength relationship Δ between AM and DRM parts of simulcast signal.

A brief summary of the maximum and minimum power relationship of each location with correct and incorrect reception where AM measurements were made as a reference has been included.

TABLE 16

Incorrect AM reception location analysis.

Location	Type of environment	Observations	Δ (dB)
R5P3	Non Dense Typical Mexican	Near a building and power lines	17.73
R1P1	Dense Typical Mexican	In a highway and near the train station.	15.80
R2P4	Dense Typical Mexican	Near a lot of power lines	17.22
Mexico D.F.	Summary	Rest of AM summary	from 13.49 to 18.81

The values of power relationship obtained in locations with incorrect reception were near the maximum registered value and near of 16 dB obtained in DRM consortium trials **[13]**. The reception area is not urban in any of the three locations, but it can be found the presence of possible strong noise sources in the first two locations which could cause reception degradation of AM service. In figures below there are some examples of possible noise sources in those mentioned locations of *table 16*.

FIGURE 13

AM incorrect reception locations

To sum up, obtained values for power relationship between AM and DRM signals were not the cause of AM signal quality degradation on any of the three mentioned locations. The digital part of the simulcast signal did not have an effect over the subjective audio quality of the analogue service part. This is demonstrated saying that measures where carried out in 31 locations placed in different areas of México City and at different distances to the transmitter, and the reception was correct in 28 of them with DRM inside the simulcast signal.

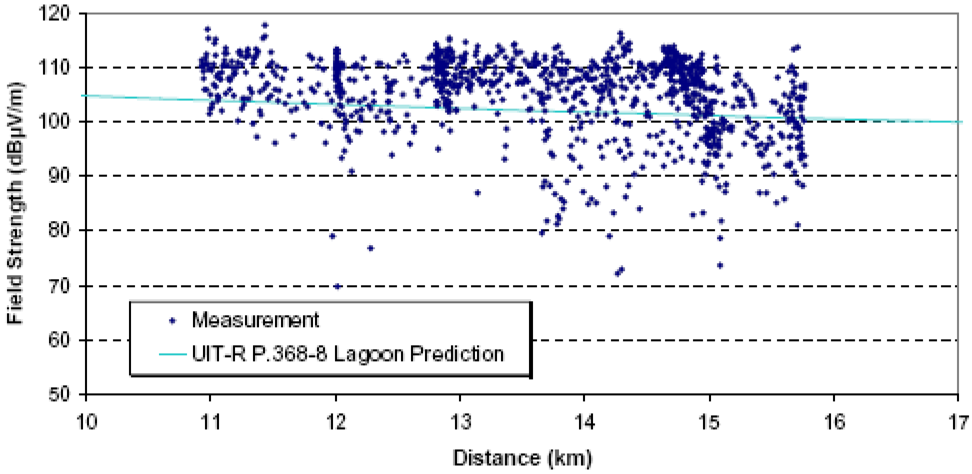
6.2.4 Mobile reception

Measured field strength values along a mobile route in México downtown are shown in *figure 14*. Each value in the graph represents a measurement interval covering a 30 meter distance to the transmitter, this means, tenth of a wavelength. The value depicted in each point is the median value of field strength in the mentioned space interval.

In the figure, ITU prediction values are depicted also, using parameter of 50 ms/m conductivity and 80 of relative permittivity corresponding to the “small lake terrain“ of México D.F.

FIGURE 14

Mobile reception in México D.F.. Predicted field strength in "small lake".



6.3 Evaluation of Radio Educación DRM service

6.3.1 Audio quality

Subjective audio quality of a DRM service depends on the bit rate provided by the transmitted DRM mode as it is mentioned in *section 3*. In this case the selected mode was 10K_A/64/16/05 with long interleaving for the whole field trials except for the specific tests carried out in some locations. This mode provides near FM audio quality and a useful bit rate of 22.1 kbps. Objective audio quality values can be assessed in DRM signal by means of measuring the number of correct received audio frames. If the percentage of correct audio frames is lower than the 98% of the total amount of received audio frames, the reception may be affected by drop outs while if it is higher than 98% the reception is considered quasi error free. This is a conservative criterion.

During the field trials, regular analogue emissions of Radio Educación were used for DRM audio, so a lot of types of contents were transmitted. Overall bit rate of the digital part of the simulcast signal depends on the used transmitting mode and on the transmission bandwidth. A transmission mode has to be chosen so robust that it can cope with propagation and environment conditions in order to provide quasi error free reception. The reception quality at a given distance from the transmitter also depends on the transmitted power too.

In México D.F. field trials, AAC coding has been used all the time with SBR and parametric stereo and two different bit rates. Moreover, a mono audio test has been carried out. In *table 17* the source coding features of the DRM modes of the tests are shown. The first row shows the coding features used in the majority of the field trials and the subsequent rows show the DRM modes used for carrying out some specific tests.

TABLE 17

Used audio codings

Coding	*Useful bitrate*	*Sampling frequency*	*SBR*	*Sonido*
AAC	22.1 kbps	24 kHz	Yes	Parametric Stereo
AAC	26.6 kbps	24 kHz	Yes	Parametric Stereo

As a general result we can say that parametric stereo provides a good subjective quality which is near FM quality for an average listener, so it can be used to transmit any kind of audio content with good quality. However, quality of transmission at 11 kbps bit rate is quite poor but higher than the quality of traditional analogue AM signal.

6.3.2 DRM reception reliability

This section shows the results of DRM reception reliability. Results are exposed in some subsections. First of all, AudioQ parameter is defined as it provides a threshold to separate correct and incorrect reception. In the next subsection, general results of fixed reception are discussed by means of DRM signal behaviour in 36 reception locations. In *Section 6.3.2.3* there is a study of reception in different environments. These different environments have been defined in *Section 4.1*. Finally, the last subsection consists of the evaluation of critical factors for DRM service reception in México D.F. and it includes an extrapolation of general reception in México country.

6.3.2.1 Correct reception definition

This section describes audio quality results obtained in previously defined environments for fixed reception. Tests have been carried out using audio signal transmitted by Radio Educación, so objective quality has been analyzed in terms of audio frame error rate. Objective audio quality has been measured using AudioQ parameter which is defined in percentage as:

$$AQ(\%) = \frac{Correct\,\mathrm{Re}ceivedFrames}{Total\,\mathrm{Re}ceivedFrames}$$

This parameter was measured during 3 minutes in each location and as the results showed very constant high values in almost all the measured intervals. This matches the expected stability of DRM in the medium wave band. The AudioQ parameter provides the ratio between number of audio frames correctly decoded after demodulation and correction made by the receptor and total number of received audio frames. The threshold of this parameter in order to get a quasi error free reception is a 98%. This threshold value is conservative according to the engineers who carried out the tests. This type of staff can be considered as “trained listeners” so the previous hypothesis ensures a good quality for an average listener. 98% threshold value is equivalent to 1.2 seconds of accumulated errors in 1 minute interval. This threshold is taken as a reference value for objective audio quality used in different tests inside DRM Consortium.

6.3.2.2 General results of fixed reception DRM quality

General results of fixed reception DRM quality in several locations of México City are shown in *table 18*. In this table, results of the 10K_A/64/16/L/0.5 transmission mode with a 22.1 kbps useful bit rate and audio contents of Radio Educación regular emission are shown.

TABLE 18

General results of fixed reception DRM quality

Measured Mode	10k_A/64/16/L/0.5
Total number of measured locations	36
Number of locations with audio quality higher than or equal to 98%	32
Correctly received locations (%)	88.88

As it can be seen in *table 18* there has been successful reception in most of locations of the field trials. **Out of 36 fixed locations measured in México City, 32 had quasi error free reception**. It is very important to emphasize that those locations where DRM digital system did not provide quasi error free reception featured difficult reception conditions even for AM signals in the medium wave band. The main reception difficulty in these locations was caused by very high levels of man made noise. In additions, in some of these noisy locations, field strength was not very high either.

TABLE 19

DRM reception problematic locations

Location	Environment	Tx(km)	AudioQ (%)
R3P4	Industrial	18.7	89.90
R1P3	Dense typical Mexican	12.5	92.62
R2P4	Dense typical mexican	15.5	95.07
R5P4	Non dense typical mexican	19.1	39.03

Decoding failures causes where DRM reception was not quasi error free will be analyzed in *section 6.3.3.2*. In this section, DRM compatibility with AM within the simulcast will be discussed in order to verify that the analogue signal is not one of the causes of DRM signal degradation.

6.3.2.3 Signal behaviour analysis in different environments of México City

Field trials planning exposed in section *4.1*, describe different types of environments selected to carry out the simulcast tests. The environments were chosen in order to have a sample wide and representative enough to assess reception quality of DRM services with typical México City reception features.

Tables 20 to 24 show results for each type of environment considered: Industrial, Open-Residential, Dense and Non Dense typical Mexican and Urban.

TABLE 20

Quality results in Industrial reception areas (Azcapotzalco)

ROUTE – POINT	AudioQ (%)	Tx (km)	E(dBµV/m)	SNR (dB)
R3P1	100.00	18.90	83.65	20.49
R3P2	100.00	17.90	79.54	21.96
R3P3	100.00	20.00	82.70	21.50
R3P4	89.90	18.70	79.76	17.19

Three out of four Industrial areas offered 100% quality values. The last one had an AudioQ value of 89%. Difficult reception situations have been analyzed and the conclusion is that there is more than one cause. The first one is that the R3P4 location has a very high radio electric noisy environment, due to being next to the external wall of a big industrial factory. Near this location there are a lot of noise sources like high power lines corresponding to the trolley buses. This noise influence was also noticeable in AM subjective audio quality that provided a level of 4 at this location.

TABLE 21

Quality results in Open Residential reception areas.

ROUTE – POINT	AudioQ (%)	Tx (km)	E(dBµV/m)	SNR (dB)
R7P3	100.00	14.39	90.45	21.66
R7P4	100.00	12.56	92.05	22.95
R4P1	100.00	17.3	91.27	23.82
R4P2	100.00	16.2	88.12	21.63
R6P4	100.00	11.6	94.11	26.31
R6P5	100.00	11.7	92.01	19.71

Reception in environments classified as Open-Residential areas is described in *table 21*. These locations corresponded to three different routes. In all the locations of Open-Residential areas audio quality values of 100% were obtained. SNR values were always higher than 19 dB and 26.31 dB was the maximum value.

TABLE 22

Quality results in Non Dense typical Mexican reception areas

ROUTE - POINT	AudioQ (%)	Tx (km)	E(dBµV/m)	SNR (dB)
R7P1	100.00	13.76	87.89	19.90
R7P2	100.00	14.13	84.28	17.55
R5P2	100.00	15.00	88.63	22.53
R5P3	100.00	16.20	83.07	19.25
R5P4	39.03	19.10	78.01	16.42
R5P5	100.00	17.10	88.19	23.89
R4P6	100.00	15.63	86.99	18.54

The type of environment so-called Non Dense Typical Mexican featured areas where there are buildings with a maximum of two storeys. In those areas, buildings are typically flat. The difference between Dense and Non Dense Typical Mexican areas relies on the street width and building height because it could be observed that in México City there was a clear difference between areas with 2-story buildings and areas with higher buildings, like the ones in Dense Typical Mexican, featuring between 3 and 7 stories.

These two types of environment occupy the major area of México City where a big part of the city population is distributed. That is the reason for capturing more measurements in these two types of areas.

TABLE 23

Quality results in Dense typical Mexican reception areas

ROUTE – POINT	AudioQ (%)	Tx (km)	E(dBµV/m)	SNR (dB)
C1	100	25.58	85.94	18.45
R4P3	100	15.1	81.88	18.79
R4P4	100	13.8	92.11	24.59
R1P1	100	11.8	84.64	19.31
R1P2	100	14.3	93.68	26.89
R1P3	92.61	12.5	82.99	21.14
R1P4	100	10.9	88.09	23.03
R1P5	100	11.3	84.90	20.31
C2	100	2.9	99.97	25.66
R5P1	100	9.95	88.75	23.03
R2P3	100	14.2	92.74	21.73
R2P4	95.06	15.5	83.54	16.86
R1P6	100	14.4	85.67	17.58
R1P7	99.86	11.77	84.69	16.82
R1P8	100	14.25	91.90	22.25
R1P12	100	14.4	88.87	29.63

Results show an excellent behaviour of DRM signal reception. With a total number of measurement locations of 16, in 14 of them the objective audio quality was of 100% in dense areas. There are two problematic locations in dense areas which have been detailed in the previous section of general results. In the case of Non Dense areas, similar results were obtained, with only one location where reception AudioQ was lower than 100%.

Urban areas were considered those with buildings composed of more than 8 storeys. Generally, these buildings are offices, hotels…. In México D.F. this type of urban buildings is associated with buildings encountered in the “Reforma” neighbourhood.

TABLE 24

Quality results in urban reception areas

ROUTE - POINT	AudioQ (%)	Tx (km)	E(dBµV/m)	SNR (dB)
R4P5	100.00	14.90	85.76	19.14
R2P1	100.00	15.00	88.20	19.73
R2P2	100.00	15.30	88.31	18.92

Most of measured locations in urban areas followed the tendency of the rest of environments. 100% of audio frames were correctly decoded in the three locations considered. As a conclusion, it can be said that the different environment types distinguished in México City did not have a noteworthy influence on the correct reception of transmitted DRM signals by Radio Educación in the field trials. *Table 25* shows a brief summary of results sorted by type of environment.

TABLE 25

DRM quality results in different type of environment

ENVIRONMENT	Total number of locations	Total number of locations with correct reception	Median SNR
Industrial	4	3	20.99
Typical Mexican (Dense)	16	13	21.44
Typical Mexican (non Dense)	7	6	19.25
Open Residential	6	6	22.30
Urban	3	3	19.14

6.3.2.4 Critical factors for Medium Wave DRM reception

The tests carried out have shown results, similarly to ones obtained from other DRM medium wave tests, which have been useful to identify different factors which affect DRM signal quality. After more than one month testing simulcast signal in México D.F. it can be said that the most important factors are:

– ***Man made noise*****:** This effect is not related to a specific area of the city but it is uniformly distributed in all areas. In some cases and depending on the distance to the receiver, aerial power lines and specially energy transformation stations proved to be a possible problem for DRM reception. It is important to emphasize that in locations where noise level affected DRM reception, subjective audio quality of the AM signal was also affected.

– ***Tunnels and bridges.*** Received field strength inside a tunnel or below a bridge presented some noteworthy drops with regard to the received field strength in the area around these structures. Fadings have a depth up to 20 dB in some cases. This effect is a well-known problem in medium wave propagation and it cannot be avoided in this band of frequencies where it affects to the same extent an analogue signal.

6.3.3 Coverage data

6.3.3.1 Fixed reception

DRM service coverage area is analyzed in *figure 15* where field strength median value over distance to the transmitter is depicted. Each value is depicted in green if the AudioQ reception in that location was higher or equal to 98%, that means a correct or quasi error free reception. On the other hand the value is red in the incorrect reception case.

Being not a representative location in usual reception conditions in the considered environments, location of Route 1 (first location) placed in “Benito Juarez” near big power line towers, is considered as a special case of reception. This condition was confirmed by the impossibility of correct reception of Radio Educación analogue service using commercial medium wave AM receivers in this location. Other broadcast stations were not properly received in this location. So this location has not been included in the values depicted in *figure 15*, it has been analyzed apart from the rest of the locations as a special case of reception conditions.

DRM digital service provided a correct reception in 88.88% of locations. Four locations did not provide an AudioQ value higher than 98% and they are analyzed in depth in subsection *5.3.2.* of this document. Sorted by increasing distance:

– *R1P3, Dense Typical Mexican area.* A trolley bus degrades DRM reception as it increases radio electric noise implying a SNR variation from 27.48 to 8.32 dB.

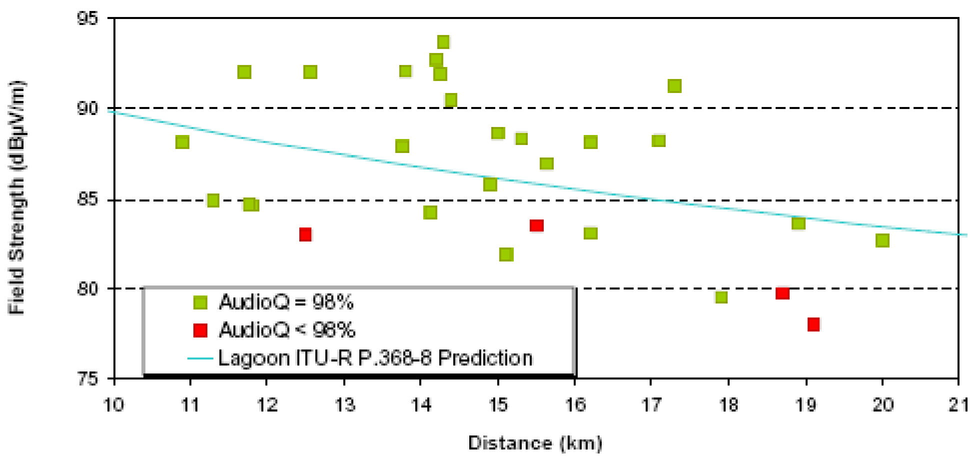
– *R2P4, Dense Typical Mexican area.* This location presents degradation of both DRM and AM signals. AudioQ value of DRM signal is higher than 95% so it is near the correct reception threshold of the DRM transmission mode under test. A minimum DRM SNR measured value was of 16.39 dB.

– *R3P3, Industrial area.* At this location received field strength level, 80 dBµV/m, was lower than major part of the trials. Measured AudioQ was near 98%, it was 89.9% so it can be considered that received field strength at this location was near the threshold value for a correct reception. Minimum measured SNR value was of 15.20 dB.

– *R5P4, Non Dense Typical Mexican areas.* This location has the lowest field strength level of the field trials and it seems to be located below the correct reception field strength threshold of the DRM part of the simulcast signal. Minimum SNR measured value was of 14 dB.

FIGURE 15

DRM service coverage with AM inside simulcast. Lagoon predicted field strength.



In this way, DRM service as apart of a simulcast signal was correctly received in all locations with a nominal field strength value higher than 80 dBµV/m, provided that the locations were not affected by unusual high radio electric noise levels. In those correct locations the SNR value was always higher than 15.5 dB. The field strength threshold value is considerably higher than estimated by ITU **[1]** for the same transmission configuration of DRM, i.e., 10K_A/64/16/L/0.5.

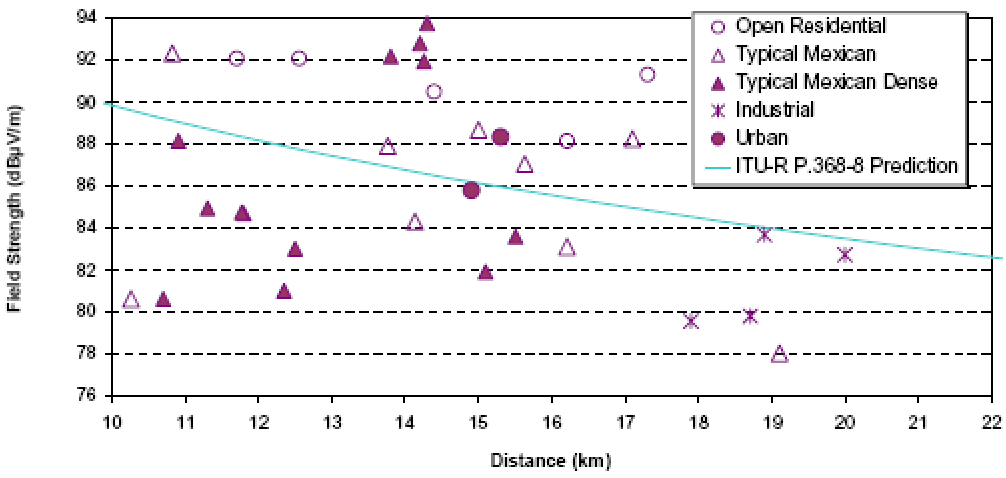
In the same way as an AM signal, received DRM signal field strength decreases with the distance to the transmitter but differences up to 10 dB can be seen between locations placed at similar distance to the transmitter. The influence of buildings and big vehicles attenuation, typical in those types of urban areas is the cause of such signal variation.

Comparison between measured field strength nominal values and lagoon terrain prediction following ITU method for ground wave, seem to fit quite well between them. However, predictions are mainly pessimistic as in AM analogue signal case happened.

Field strength highest values are found in locations with less attenuation due to the presence of buildings. All locations in Open Residential areas satisfy this condition, so, it can be seen in *figure 16* that in such areas predictions are specially pessimistic.

FIGURE 16

DRM field strength over distance to the transmitter in different environments.



6.3.3.2 Compatibility between DRM in simulcast mode and AM signals.

Locations mentioned in the previous subsection that featured non quasi error free DRM reception showed failure causes different from the ones usually causing degradation of the AM part of the simulcast signal. This way R1P3 location power ratio between AM and DRM signal in simulcast was lower than 16 dB, ITU proposed value. Nevertheless, the fall of this power ratio between DRM and AM signals did not affect the correct reception of DRM digital service in many other locations.

For the analysis of DRM compatibility 4 locations have been found where DRM signal reception was not correct. This incorrect reception is due to 2 different causes. First cause is that the received field strength level was near the threshold value for a correct reception, that is, the received signal to noise ratio was near the minimum SNR threshold for correct reception using 10K_64/16/L/05 mode. The second cause of incorrect reception was the presence of different urban elements which caused signal fading, such as trolley buses or big vehicles.

Analysing the R5P4 location it can be observed that reception was not unusually perturbed but field strength and SNR values are near the reception threshold values (see *figure 17*). Solution to this problem is transmitting more power level to increase received field strength value.

FIGURE 17

R5P4 location reception. (Non Dense Typical Mexican area)

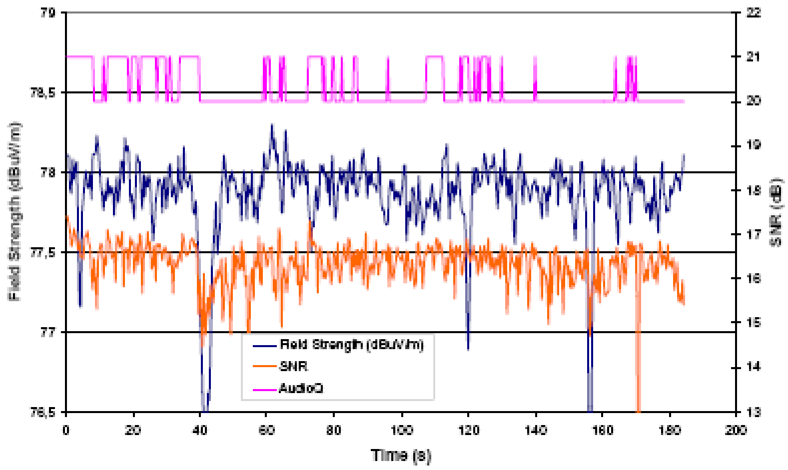
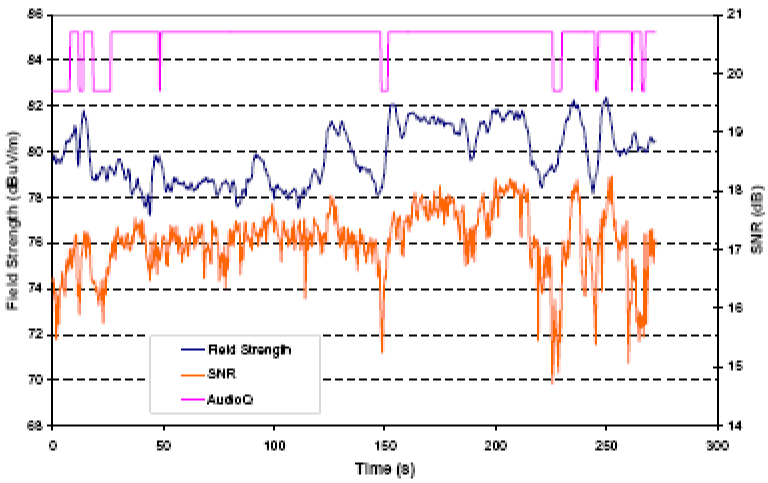


FIGURE 18

R3P4 location reception. (Industrial area)



In *figure 18* it can be seen that at this reception location not only received field strength was near the minimum threshold but also the presence of big vehicles like industrial lorries produced a SNR drop of 3 dB bellow the usual value, causing DRM audio to lost synchronization.

Finally, there are some special locations where trolley buses and power lines can be found close to the measurement vehicle, so signal fading was very high at times and although generally the reception is correct in these locations, when trolley buses are close to the measurement vehicle, the signal field strength decreases a lot causing an audio mute. In those locations, AM analogue signal had good subjective audio quality except when a trolley bus passed by. This event decreased subjective audio quality leading to incorrect reception.

Taking this analysis into account it can be concluded that AM analogue signal does not affect

DRM digital signal reception because of the lack of correlation between the presence of the AM analogue signal and the degradation of the DRM signal.

In the above mentioned difficult reception conditions, the DRM signal would be degraded even if the AM were not placed in adjacent channel. Power ratio between AM analogue signal and DRM digital signal in simulcast is not the cause of DRM signal degradation as it can be concluded from the fact that correct reception was granted by **32 out of 36** locations measured in different reception environments.

6.3.3.3 Mobile reception

In order to study mobile reception, a section of each route was chosen. The DRM mode used for these tests was also 10K_A/64/16/05, which allows a 22.1 kbps bit rate.

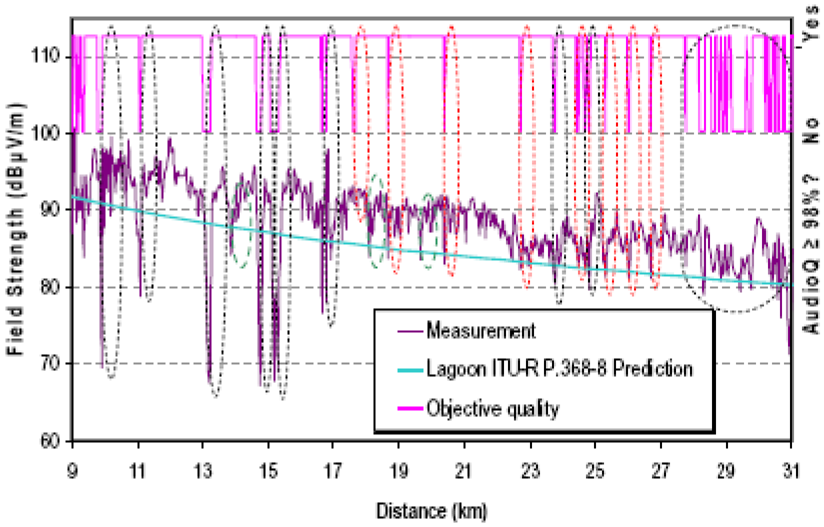
The parameter used to decide whether the reception was correct or not was the received signal quality, this is, AudioQ. However, for mobile reception, it was necessary to know the reception quality in smaller time slots than the ones used for static reception, so the time considered was the length of a transmission frame, which is 400 ms long. AudioQ, as stated in *6.3. section* is not valid to represent the signal quality of a transmission frame. This is due to the fact that there are only 10 audio frames in each transmission frame of the DRM mode considered, and a 98% quality value is no longer accurate. It has been stated that only one incorrect audio frame cannot be noticed by a listener, so it will be considered as a correct transmission frame for one with no more than one wrong audio frame, a wrong transmission frame will be considered in any other case. As for the AudioQ in mobile reception, it will be calculated as the correct DRM transmission frames percentage received over the total amount of frames within a certain distance interval of a route. Using a 98% criterion, an AudioQ of 90% implies poor correct reception; but it has been demonstrated the necessity of 3 incorrectly decoded audio frames within one DRM frame (400 ms) for the reception to be affected by a drop out noticeable by an average listener. 3 erroneous frames can be found in the same 400 ms frame or in two consecutive 400 ms frames. To avoid this situation, in this study correct reception has been considered when a frame had up to 1 erroneous audio frame, as stated above in this paragraph. In this way, inside two 400 ms consecutive frames only a maximum of 2 audio frames can be found but never a number of 3 erroneous consecutive audio frames. A 400 ms frame has been considered as erroneous when it included more than one erroneous audio frame. This is a restrictive criterion because in the case of a few errors, several 400ms consecutive frames can be considered as erroneous in this analysis whereas no audio error was noticed during reception by an average listener.

Simulcast signal DRM coverage has been analyzed carrying out a mobile radial route shown in *figure 19*. The field strength and AudioQ are depicted versus the distance to the transmitter. Each depicted value has been calculated taking into account a measurement interval including a spatial variation of 30 meters of distance from the transmitter. 1060 kHz wavelength is 10 times the measurement interval.

In the mentioned figure, depicted field strength value is the median of all field strength values contained in a 30 meters measurement interval. These obtained values have been compared with the ground wave ITU prediction method. On the top of the graph received objective audio quality of DRM service can be seen. If all the 400 ms reception has been considered as correct within a 30-meter measurement interval, the measurement interval has been considered as correct and the pink line is up. Otherwise the interval has been considered as wrong reception one and the pink line is down.

FIGURE 19

Field strength and received quality in mobile reception. Predicted field strength in "lagoon terrain"



The coverage route was divided into two different parts. Up to a 20 km distance from the transmitter, this route was inside México City and over 20 km measurements were taken in a motorway outside the City.

Field strength values between near locations reach values with a difference up to 25 dB because of the previously mentioned attenuation factors in urban environments. In absence of these attenuation factors, field strength values would always be between 5 and 10 dB over the predicted ones.

Most of incorrect reception cases can be associated with strong decreases of received field strength values caused by big obstacles typically found in urban environments. In the cases where the field strength values decreased strongly, the objective audio quality decreased too showing incorrect reception. In this way, inside the México City part there are 6 strong decreases of the measured field strength values depicted with a black dashed line. 4 of them produced field strength decreasing of 20 dB or greater and were caused by crossing tunnels or moderate length bridges. The rest of the drops were due to buildings or shorter bridges. In the part outside México City, where the distance is near 30 km from the transmitter, incorrect reception was the predominant behaviour of objective audio quality just when the graph tendency is below the field strength threshold value of 80 dBμV/m estimated in *6.3.3*.

Other incorrect reception cases were due to the increase of radio electric noise level, other typical effect in urban reception areas with a lot of noise sources. Red dashed line marks show incorrect reception cases when noise levels increased. In most cases where the noise level increased, received field strength decreased too but this decreasing was not sufficient to produce an incorrect reception and to degrade DRM objective audio quality because it can be found some other similar field strength decreases which did not lead to audio quality degradation.
Taking into account the afore mentioned factors, DRM service coverage can be considered to be around 24 km of distance from the transmitter for the 1.25 kW average power used, except in cases of unusual locations with big obstacles obstructing receiving antenna or with high levels of radio electric noise.

For the analysis of DRM service quality of the field trials in mobile reception one route of each of the selected different environments has been chosen. In *table 26* can be observed the data obtained in 5 route stretches.

TABLE 26

Mobile reception quality

	Route	Between locations	AudioQ
Open Residencial	7	P3P4	81,70%
Industrial	3	P2P3	97,92%
No Dense Mexican	5	P1P2	94,83%
Dense Mexican	1	P5RE	89,62%
Urban	2	P1RE	77,07%

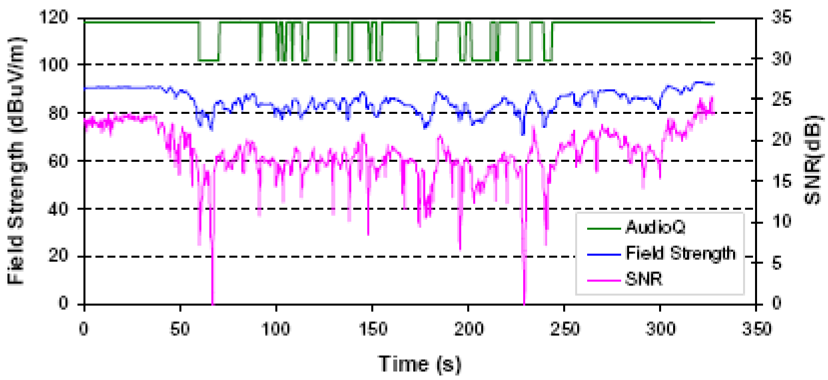
In Industrial areas the reception of DRM signal was better than in the rest of 4 different environments. It was not an expected result because in those areas many noise sources for medium wave band were expected. This result is due to the height of buildings found in industrial areas (most of them of 1 or 2 storeys) and the width of streets (there are wide streets) and because less traffic can be found than in the centre of México City. As it was expected, areas with most DRM reception difficulties are urban ones. In Open Residential areas the reception is worse than in other considered environments, in fact, urban areas are the only environments with worse reception than Open residential areas. Selected routes are analysed in the subsequent paragraphs:

In *figure 20* instantaneous AudioQ is depicted as previously explained for mobile reception, above received field strength level (dBµV/m) and the signal to noise ratio (dB) for a piece of a route in Open Residential areas.

It can be observed that the correct reception threshold can be pointed out at 17 dB of signal to noise ratio and around 80 dBµV/m of received field strength level. Field strength level is between 75 and 85 dBµV/m in the central part of the route, that is, slightly over the correct reception threshold.

FIGURE 20

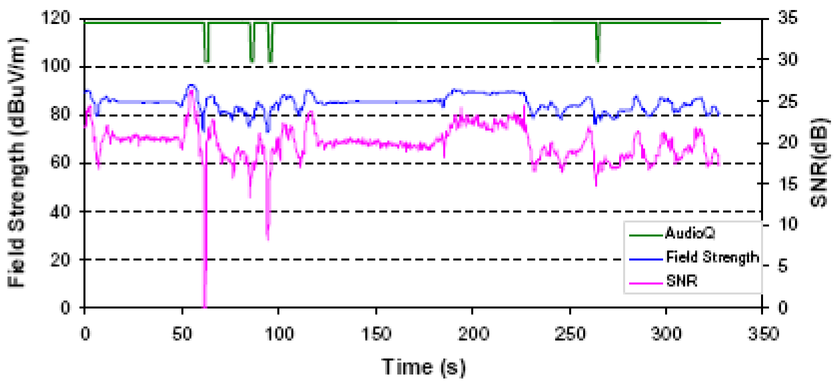
Mobile DRM reception in Open Residencial Areas



In industrial areas (*figure 21*) reception was excellent. As it has been previously mentioned, this is a good environment for propagation due to building height, street width and because there is not much traffic. The most important reception problem in this kind of environments is the presence of power lines and transformers where the received noise level increases a lot. Depicted field strength value does not vary a lot and it has not been affected by many fadings. In this case correct reception threshold is slightly lower than 80 dBµV/m so it can be said that noise levels are lower than in other areas as it can be concluded seeing the SNR threshold value of 15-16 dB.

FIGURE 21

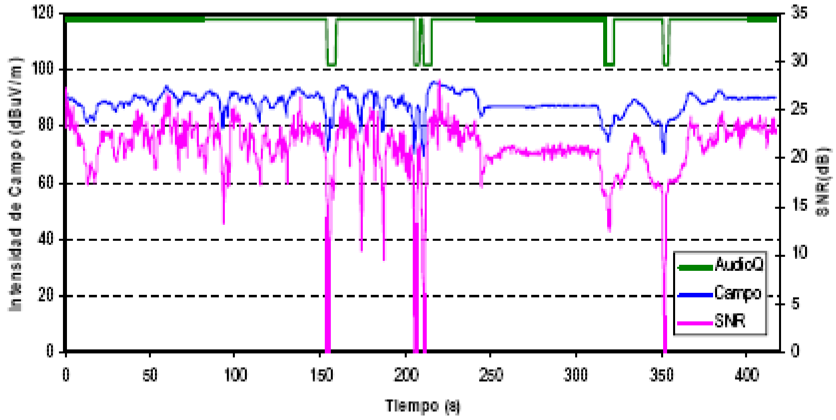
Mobile DRM reception in Industrial Areas



The next analyzed environment is No Dense Typical Mexican. In those areas there was a good reception, as *figure 22* shows. The results are very similar to those obtained for industrial areas. The only difference is the presence of some deep fadings that were not observed in industrial areas.

FIGURE 22

Mobile DRM reception in No Dense Mexican Areas



Reception in Dense Typical Mexican environments is much more difficult because of a higher variability of the received DRM signal. The attenuation effect of buildings produces received field strength decreasing. We have found a similar field strength threshold of about 80 dBµV/m.

FIGURE 23

Mobile DRM reception in Dense typical Mexican Areas

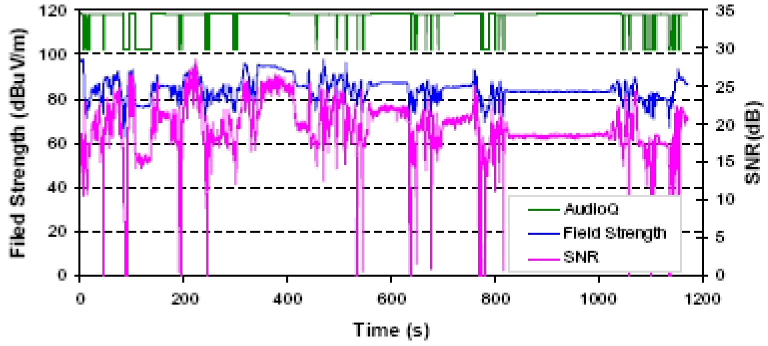
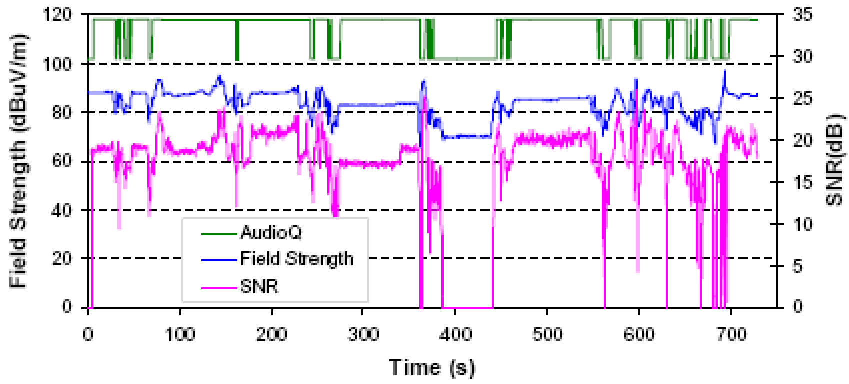


FIGURE 24

Mobile DRM reception in Urban Areas



The most difficult areas are urban ones. Buildings are higher than in the rest of México City, making a field strength decreasing to around 70 dBµV/m. For this field strength level, the decoded audio contained more erroneous frames than usual. In the analyzed route, in the centre of the graph, a 1 minute consecutive erroneous interval can be observed where continuous drop outs. This interval makes the total obtained statistic value worse. In the first part of the route some errors produced by Metrobus stations in México City can be seen. This kind of public transport has big metallic stations placed in the centre of streets. These stations made reception difficult as they caused the signal level to decrease and they induced erroneous reception.

6.3.3.4 Coverage area extension using transmitted power increment.

Observed data can be used to deduce a new hypothetical coverage area if the transmitted power was increased. For this analysis observed signal to noise ratio is used. Reception threshold value is around 17 dB of SNR. If the transmitted power increases in 3 dB, signal to noise ratio would increase in the same amount of dB. All values contained between 14 and 17 dB would be now correct reception values. 17 dB threshold value is very conservative because the estimated quality for each route with this method is lower than the received real quality (for example in

Open Residential area, with 81.7% measured objective quality, the estimation with a 17 dB SNR threshold would provide a quality of 74.27% and in Industrial area being the measured quality of 97.92 % the estimated audio quality would be of a value of 95.12%). In *figures 25 and 26* an example, the effect of transmitted power increase can be observed in the No Dense Typical Mexican route. Two different power increases of 3 dB (2.5 kW of transmitted power) and 6 dB (5 kW of transmitted power) have been considered for the estimation.

FIGURE 25

Estimated reception in No Dense Typical Mexican route for 2.5 kW transmitted power.

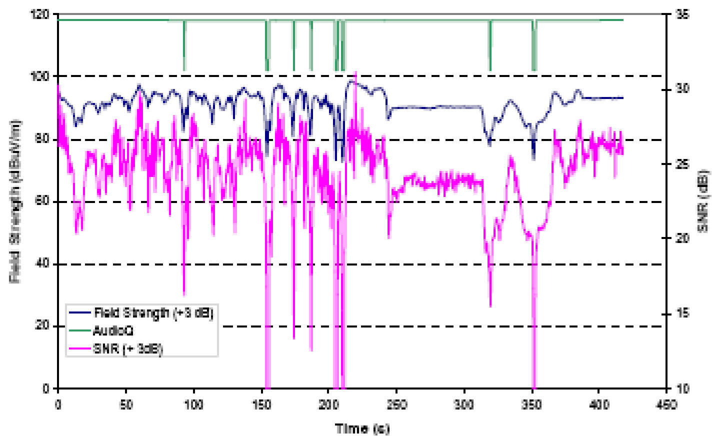
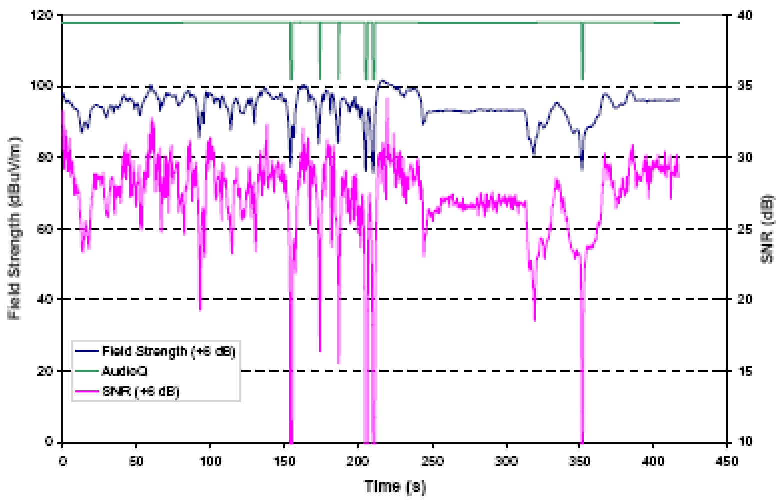


FIGURE 26

Estimated reception in No Dense Typical Mexican route for 5 KW transmitted power.



This analysis has been carried out for the 5 routes previously mentioned and general results are given in *table 27*.

TABLE 27

Mobile reception quality for 2.5 and 5 KW transmitted power.

Environment	Route	Part	AudioQ Real 1.25kW	AudioQ estimated 1.25 kW	AudioQ estimated 2.5 kW	AudioQ estimated 5 kW
Open Residencial	7	P3P4	81.70%	74.27%	93.29%	97.19%
Industrial	3	P2P3	97.92%	95.12%	99.27%	99.51%
No Dense Mexican	5	P1P2	94.83%	94.55%	97.61%	98.37%
Dense Mexican	1	P5RE	89.62%	86.78%	96.84%	98.00%
Urban	2	P1RE	77.07%	74.00%	86.28%	89.52%

It is very important to emphasize that with an increase of only 3 dB of transmitted power, that is, transmitting DRM with 2.5 kW, a coverage of 95% can be achieved in most kind of reception environments, except in Urban areas with a value of 86% and Open Residential areas with a value of 93%. This would be the usual transmitted power of Radio Educación transmitter because for this field trials it was in half of its operation capacity (50 kW AM in the simulcast with DRM versus 100 kW AM in regular emissions). Using a 6 dB increasing, 5 kW RMS DRM transmitted power, coverage would be of 97% in all different areas except in Urban ones where the coverage would be near the 90%. In order to achieve this 6 dB increase a transmitter with more power would be necessary or the power ration between analogue and digital part could be reduced to 13 dB in simulcast signal. A priori, this could slightly degrade the AM analogue signal subjective audio quality.

6.4 Specific tests

6.4.1 Power ratio modification between analogue and digital signals.

Most recent studies show that the best value for power ratio between analogue and digital signal in simulcast for a correct reception is of 16 dB, being the DRM signal always below the analogue signal. So the simulcast signal has been transmitted using the mentioned power ratio.

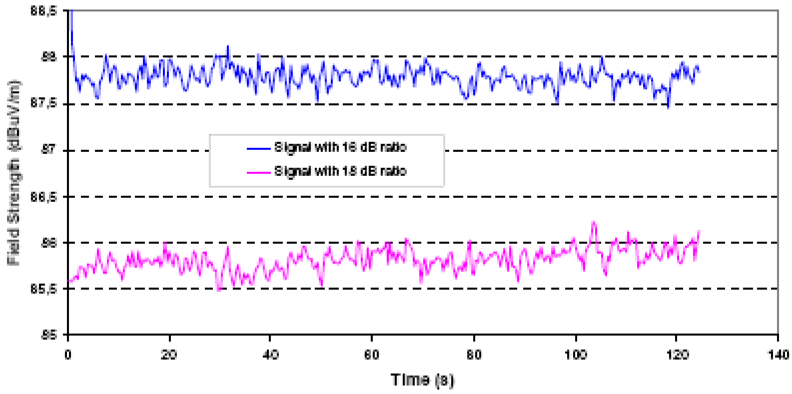
As it has been explained in previous section, reception of AM analogue signal was correct so it was planned a specific test increasing DRM signal transmitted power in order to analyze a possible degradation of the subjective audio quality of the AM signal.

Mentioned tests were carried out in 2 different parts: the first part consisted of increasing power ratio up to 18 dB to analyze if AM subjective audio quality was better than using 16 dB power ratio. In *figure 27* 16 dB ratio measurement is depicted in blue and 18 dB ratio measurement below it.

The result of this test was an excellent AM subjective audio quality like using 16 dB power ratio. There is not a noticeable difference in AM subjective audio degradation when changing from 16 to 18 dB power ratio. This increase is a disadvantage for DRM because DRM coverage is decreased by 2 dB while there is no improvement in AM subjective audio quality. DRM signal audio quality, in this case, was of a value of 100% all the time using both ratios, 16 and 18 dB in the chosen measurement location (R1P6).

FIGURE 27

Specific test using 18 dB power ratio between Am and DRM signals



Second part of this specific test was carried out March 28th of 2006 in R1P6 location and consisted of varying power ratio between analogue and digital signal from 18 to 13 dB in 1 dB steps. *Figure 28* shows measured field strength during this specific test.

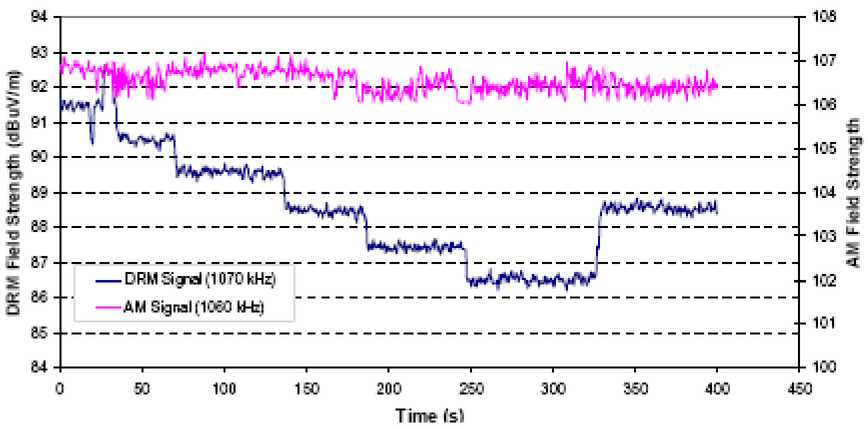
It can be seen how power ratio increases from 13 dB to 18 dB to return to its original value of 16 dB.

In this case the subjective audio quality of AM signal was not affected using the mentioned commercial receivers. In fact, some of Radio Educación workers considered as "trained listeners" were asked to listen to this specific test using their commercial receivers and no one noticed any AM subjective audio quality degradation. AM subjective audio quality evaluation was rated 5 all the time. Moreover, audio quality of DRM digital signal was of 100% all the time too.

Alter carrying out this specific test and taking into account that it is a unique test carried out one day and in one specific location we could say that when digital signal is situated 13 dB lower than analogue signal, there is no audible degradation in AM signal for listeners of commercial receivers. This conclusion implies the possibility of increasing DRM transmitted power in 3 dB so that DRM part coverage is also increased.

FIGURE 28

Specific reception test using 13-18 dB power ratio



6.4.2 DRM signal bandwidth variation within simulcast signal

Being the mode 10K_A/64/16/05 transmitted for all the field trials, a specific test was carried out to assess the difference between a reception of 9 kHz bandwidth DRM signal using 9K_A/64/16/05 mode and the 10 kHz bandwidth signal. *Figure 29* and next table show obtained results for these specific measurements.

TABLE 28

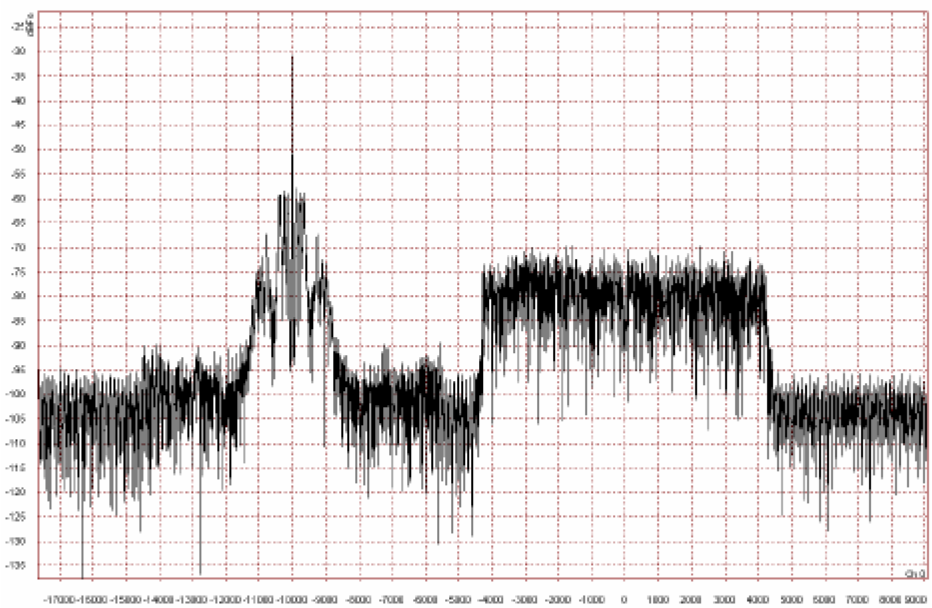
Comparison between 10 kHz and 9 kHz bandwidth modes

	10 kHz		**9 kHz**	
	AM (1060 kHz)	DRM (1070 kHz)	AM (1060 kHz)	DRM (1070 kHz)
Received field strength	106.18	87.76	106.13	87.98
Audio Quality	5	100%	5	100%

In *Figure 29* spectrum it can be observed that frequency distance between DRM part and AM part in simulcast signal is of 10 kHz using a 9 kHz reduced bandwidth for DRM. In the other option considered for the rest of the field trials, DRM signal bandwidth is of 10 kHz theoretically thus obtaining a bigger possibility of interference over the analogue signal of the simulcast. **AM subjective audio quality had a degree of 5** all the time and DRM service availability was of 100%. Considering that there was no quality degradation in the AM part in both 10 kHz and 9 kHz bandwidth modes, and taking into account that 10 kHz mode provides a higher data bit rate (see *table 3 of section 3*) it can be concluded that this is the proper transmission mode for México D.F. simulcast field trials.

FIGURE 29

9k_A/64/16/L/05 mode spectrum.



6.4.3 Transmitted mode variation

Once 10 kHz bandwidth mode over 9 kHz has been chosen for optimal spectrum use, some specific tests were carried out changing the bit rate of the transmitted mode of the DRM part of simulcast. Additional tested modes were extreme cases taking into account transmitted bit rate and robustness. It is necessary to reach a compromise between robustness and transmitted bit rate, so the most robust mode was tested in the first place, secondly a mode allowing the highest bit rate and finally an intermediate mode. In this test it was verified, as expected, a correct reception of 10k_A/64/16/06 and 10k_A/16/4/05 DRM modes and a good subjective audio quality of AM part of simulcast. The most robust mode had more coverage area and it was easier to receive but subjective audio quality of digital part was not so good as in the usual mode used in the field trials. On the other hand, with the least robust mode the opposite situation was observed, subjective audio quality of DRM signal was very good and it had a high bit rate but the necessary signal to noise ratio for a DRM correct reception was very high (near 19 dB) producing a decrease of simulcast digital part coverage.

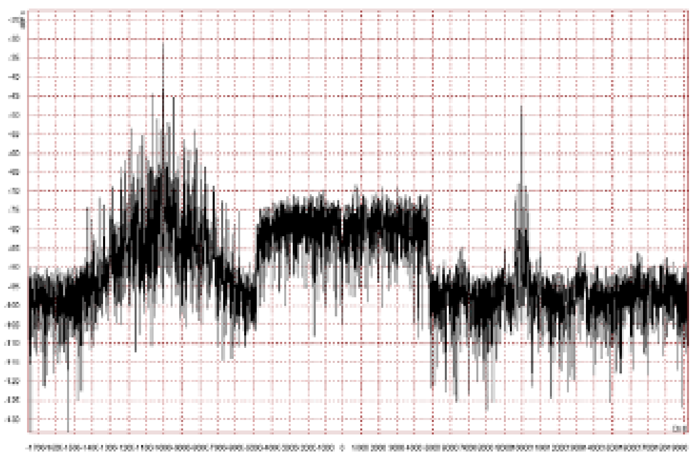
Finally, it can be concluded that the optimum transmitting mode in medium wave simulcast in a propagation environment like México City is the intermediate case 10k_A/64/16/L/05 that was used for most of the field trials.

6.4.4 Adjacent channel interference test

During simulcast field trials in México City it was observed that in the north of the city there was a Radio station called “Radio Mexiquense” which could be tuned at 1080 kHz frequency with 10 kHz bandwidth. In this case, some areas where 3 signals appear in channels separated 10 kHz could exist, the analogue and DRM part of Radio Educación simulcast followed in the frequency spectrum by “Radio Mexiquense”. So, a specific test in C2 location was carried out where a possible interference of simulcast DRM signal over 1080 kHz analogue signal was intended to be observed. In *figure 30* below the spectrum of the 3 mentioned signals in adjacent channels is depicted.

FIGURE 30

Channel N+30 kHz interference measurement



Received field strength level and evaluated audio quality of both, simulcast and adjacent signal are summed up in the table below.

TABLE 29

Signal characteristics in N+2 kHz channel

Station	Radio Educación	DRM	Radio Mexiquense
Frequency (kHz)	1060	1070	1080
Field Strength (dBµV/m)	102.8	85.9	86.17
Field difference with 1060 kHz (dB)	0	16.9	16.63
Quality	5	100%	5

The difference of field strength between the analogue signal of Radio Educación and the DRM part kept the expected value and it can be observed that received field strength level is similar in the case of the DRM part and the Radio Mexiquense signal. Even though, audio quality of three mentioned signals is good so it can be concluded that there is no interference between them. Moreover, different locations of the field trials in the north of México City were measured in the presence of Radio Mexiquense signal.

As Radio Mexiquense signal was not degraded in 1080 kHz, although it was received with low field strength level in the studied location, it can be concluded that the possible interference caused by the DRM signal over Radio Mexiquense signal was not noticeable in commercial receivers.

6.4.5 Specific test near high voltage power towers

In order to carry out a specific measurement near a high radio electric noise source, a fully characterized magnetic transference antenna was used. *Figure 31* bellow shows the environment where these measurements were made on March 15th of 2006.

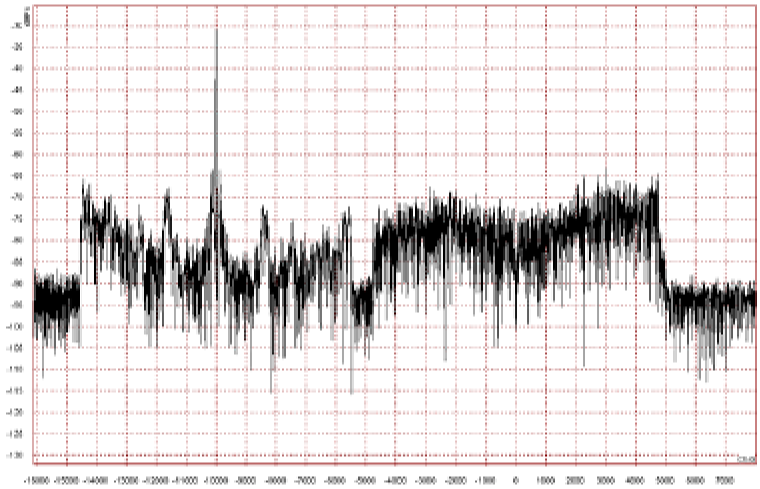
FIGURE 31

Location environment of high voltage tower test

In the case of commercial receivers, noise affects in the same way to all of them because the evaluated AM subjective audio quality was rated 1, the worst in the whole field trials. In this location, none of AM analogue emissions in México City could be properly received. However, the results of this measurement are shown in *figure 32*.

FIGURE 32

Simulcast spectrum near high voltage towers.



To corroborate the effect of high radio electric noise sources on the DRM signal a measurement using a medium wave calibrated passive antenna was carried out. A correct DRM reception was measured in this location. Even so, there were some effects in DRM spectrum as it can be observed by the fact that the DRM spectrum is not as flat as expected. There were some drops in different areas of DRM spectrum. Taking into account DRM reception in this location and the mentioned drops, it is possible to affirm that those drops did not affect the digital signal because there was a correct reception (see *table 30*).

TABLE 30

Measured parameters near high voltage towers.

Antenna	Passive Magnetic
Signal	DRM
Received Field Strength (dBµV/m)	84.8
SNR	17.45
AudioQ	100%
AM subjective Audio Quality	1

6.4.6 Specific test below wires in Typical Mexican areas

During field trials it was observed that when the measurement vehicle passed below some kinds of wires crossing streets from side to side and forming kind of meshes in Typical Mexican areas, an important received field strength drop was observed. In *figure 33* below, one mobile measurement field strength reception is depicted where measurement vehicle was passing through this kind of street with crossing wires. First, measurement vehicle is approaching the wires, and when it reaches to the minimum, measurement vehicle begins to moving away from the wires. In *figures 33* and *34* different effects observed while passing below some typical wires in México City can be seen.

In the first figure a fading effect in received field strength level is shown that can produce an audio mute and in the second figure the opposite effect can be seen, where field strength level increases when passing below the wires due to radio electric noise.

This mentioned effect is stressed by the location of the measurement system antenna in measurement vehicle. The height of measurement vehicle added to antenna height is around 3.5 meters so, R&S antenna was placed very close to most of wires that can be found in typical Mexican areas. This is not a regular situation because in a real usual reception with a commercial receiver, the antenna height will be at a maximum of 2 meters. For this reason it can be concluded that this effect will be lower in real conditions of reception.

FIGURE 33

Mobile reception below some wires in Typical Mexican area

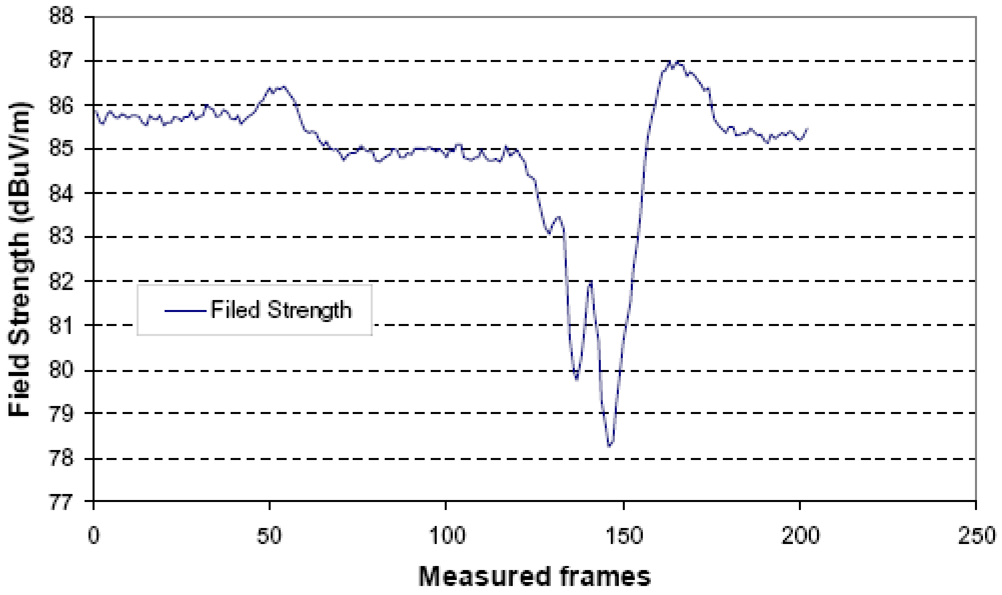
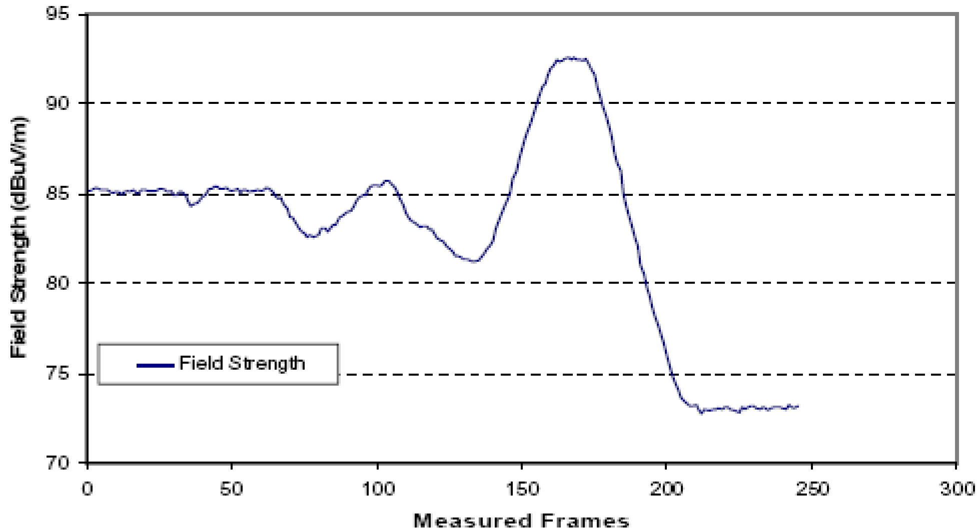


FIGURE 34

Mobile reception 2 below some wires in Typical Mexican area



6.4.7 Specific test near trolley buses.

Other specific test was carried out by means of measuring near the presence of trolley buses because it was observed that there was an influence of those vehicles in received signal in certain locations. For this specific test, one measurement was carried out in a location near a trolley bus station whose environment can be seen in *figure 35*.

FIGURE 35

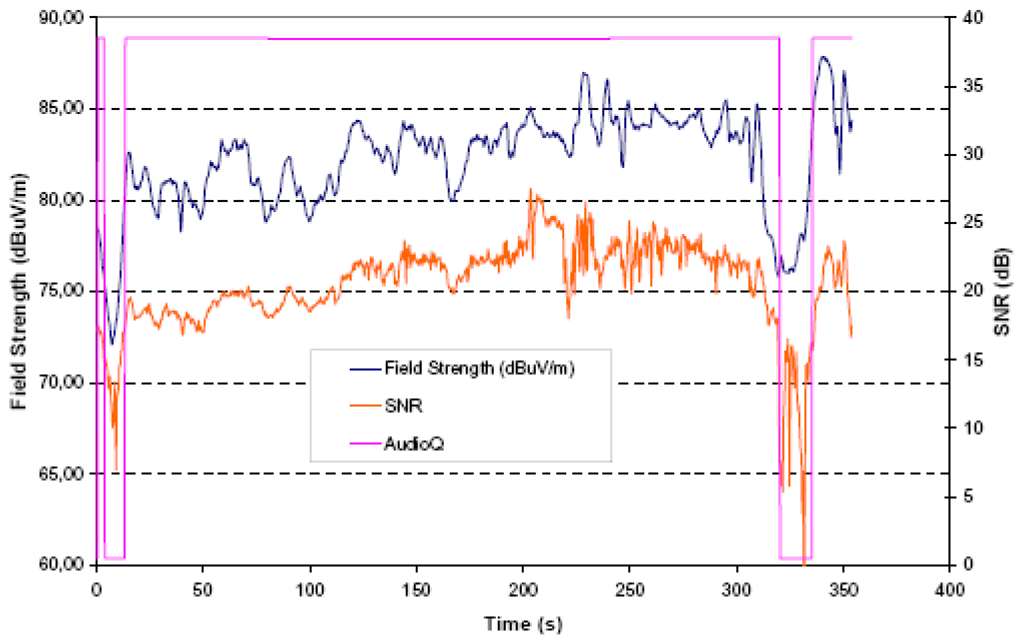
Measurement environment near trolley buses.

In this case, as well as the presence of a trolley bus in certain moments, there was a lot of traffic in that location. *Figure 36* shows measured signal field strength level:

At the beginning and at the end of the measured signal there were 2 trolley buses near the measurement vehicle and it can be seen that the received field strength decreases strongly even 7 dB producing a DRM audio mute. In this case, the assessment of received analogue AM signal with commercial receivers showed the subjective audio quality of degree 4 all the time except when a trolley bus was passing near the antenna. In this situation, subjective audio quality decreased to a degree of 3 with noticeable degradation in commercial receivers AM reception.

FIGURE 36

Measured signal near trolley buses

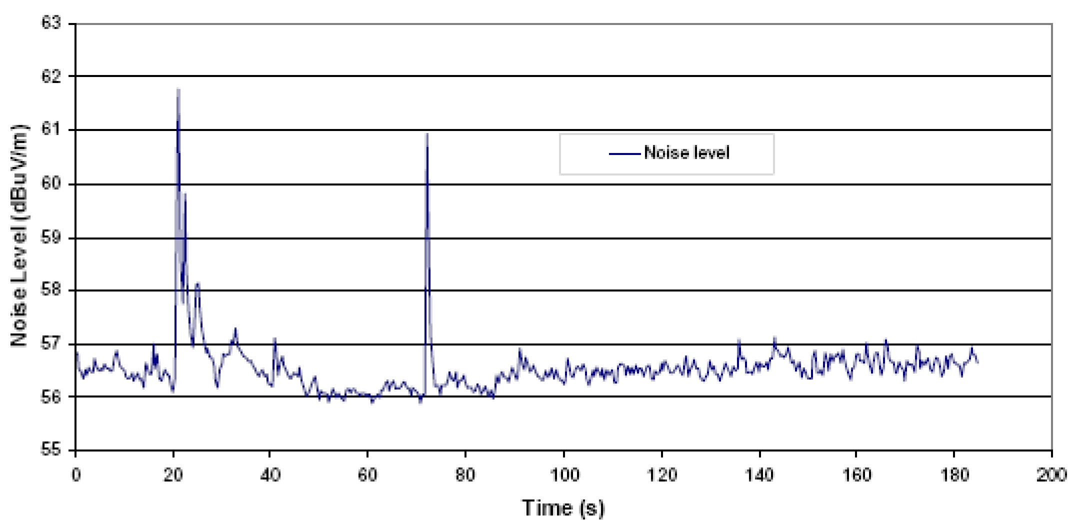


Taking into account measured radio electric noise in locations near trolley buses, noise value is more or less constant all the time but there were some locations where noise level increased when a trolley bus was near the measurement vehicle obtaining measurements as shown in *figure 37*.

In this location trolley buses passed through at a 50 meters distance from the receiving antenna and in a perpendicular direction from the street where the location was placed. It can be seen a considerable instantaneous increase of noise level in presence of a trolley bus.

FIGURE 37

Noise measurement near trolley buses



So, two different types of effects produced by trolley buses in México City can be considered. One of them is the usual shadow effect produced by a big vehicle in medium wave bands and the other one is the increase of noise level produced by some kind of motors and power lines used by this kind of vehicles.

6.4.8 Indoor Measurements

Indoor tests were carried out during the trials described by this document. These indoor tests were done to evaluate the subjective quality of the received AM signal in the presence of the nearby simulcast DRM signal. The subjective evaluation was done using the set of analogue AM receivers described in previous sections of this document.

The indoor reception of the DRM signal was not evaluated in these trials. The calibrated reception system is based on an antenna placed on a ground metalic plane that it is attached to the roof of the measurement vehicle and thus was not able to be used indoors.

The subjective evaluation of the received AM quality assessed in 6 different indoor location. Along the whole measurement campaign, this subjective evaluation was done several times on different dates inside the premises of Radio Educación in Colonia del Valle (México D.F.).

Radio Educación is located in a 3 story building. The evaluation tests were done in indoor locations at each of the 3 stories. The audio quality received with a Sony CFDS40 was rated **5 (excellent, no degradation)** using ITU BS-1284-1 recommendation criteria. Reception using other receivers, shown in *table 1,* was rated 4. The subjective audio quality was evaluated by Radio Educación Production Department staff, obviously considered as trained listeners.

Another indoor test was done at the "Secretaría de Comunicaciones" in Mexico D.F. using a CFDS receiver. The quality was again rated as 5. Finally, subjective quality was evaluated inside the Hotel Imperial, placed in "Paseo de la Reforma", where the reception was similar to the one achieved at the Radio Educación building.

Figure 38 shows locations where the AM subjective audio quality has been evaluated in indoor environments.

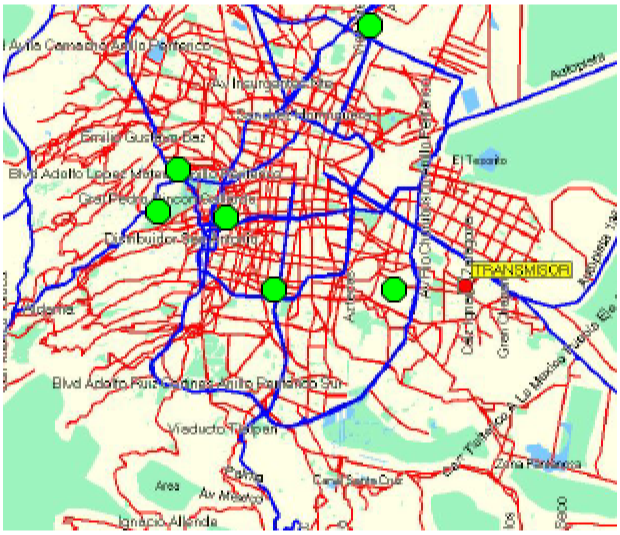
TABLE 31

AM subjective audio quality in indoor environments evaluated with different commercial receivers.

Location	External environment	AM subjective audio quality				
		Sony ICF SW 10	Sony CFDS400	Grundig MiniWorld PE	Panasonic RQ-CR07V	Other receivers
Radio Educación	Dense Mexican	4	5	4	4	5
Paseo de Reforma	Urban	4	5	4	4	5
Secretaría de Comunicaciones	Dense Mexican	---	5	---	---	---
Culiacán	No Dense Mexicano	---	---	---	---	4
Transmitter (Iztapalapa)	No Dense Mexicano	5	5	5	5	5
Ecatepec	No Dense Mexicano	---	---	---	---	4

FIGURE 38

Evaluated locations in indoor environment



Finally, indoor tests were done when performing the AM-DRM power ratio evaluation test. At the beginning of this test the AM-DRM power ratio was 18 dB and then this ratio was decreased in steps of 1 dB down to 13 dB. The analogue AM subjective quality was monitored while decreasing the ratio and again Radio Educación staff rated the quality as **5 all the time** during the test.

To sum up, the evaluated subjective audio quality in 6 different indoor locations in placed in different areas within México City was correct in all the cases. The tests were done using several commercial AM receivers which represent the existing receiver market in México DF.

7 Conclusions

As digital audio signals in general, the DRM signal was either audible if the signal-to-noise ratio was high enough, or muted if it was so low that the error correction mechanism failed, giving

noticeable “audio dropouts”. For the 10 kHz channel the DRM audio quality was similar to a FM broadcast without the full stereo effect, but with a system called “parametric stereo” which simulates it. Also, listeners were kindly surprised by the lack of noise in the audio.

This result can be applied to the use of the DRM system in all bands because the audio quality that it can provide depends on the available binary rate and therefore the DRM mode, but not the frequency band.

It was found that audio dropouts detectable by non-professional listeners do not occur if the signal-to-noise ratio is greater than 17 dB. This value is approximately 19 dB less than the signal-to noise-ratio necessary for the reception of an intelligible AM signal. After the results shown in *6.3.2* it has been found that the system presents a very high reliability with values near to 100% in the different types of environment in Mexico D.F. There have only been problems of reception in 4 out of 36 locations; these are extremely difficult locations as they are located in places where there is a high electric noise.

A “perfect reception area” can be defined as the contour where there are little or no perceptible audio dropouts. A little farther away, annoying dropouts were expected and, even a bit farther away, audio mute was probable. However, due to other factors that have relevant influence in the coverage, like the orography, the buildings type or the type of human activity, the relationship between the transmission power and the coverage area is not so easy to calculate.The measurements carried out in these tests demonstrate that with a power of 1.25 KWatt for DRM signal a correct reception has been achieved in 32 out of 36 locations in distances from about 4 to 20 kilometres from the transmitter.

Because signal-to-noise ratio depends exactly on the local position of the receiver, there are small areas even within the coverage contour where the power level dropped (e.g. a bridge) or the noise level was high enough to force the receiver to mute the corrupted signal. In equal or even far better conditions, the AM signal would also be degraded because it requires a higher signal-to-noise ratio than the DRM signal.

It can be emphasized that the overall noise encountered in the Medium Wave band has been very important. Extensive measures of electric noise have been taken at 1720 kHz and measured noise levels have been quite a lot higher (40 dB) than the references in the reports and International Telecommunication Union recommendations.

As mentioned previously, the *table 27 in 6.3.3.4* estimates the coverage radius as a function of average DRM power, taking into account increases of 3 and 6 dB above 1.25 kWatt used in this test. To estimate the coverage in environments similar to Mexico City, the calculus is not based in a simple power-distance relation, but in fixed points and mobile measurements.

8 Acknowledgements

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