

DRM (Digital Radio Mondiale) Local Coverage Tests Using the 26 MHz Broadcasting Band

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Abstract—The digital sound broadcasting DRM (Digital Radio Mondiale) standard has established worldwide, and the number of transmissions on air has increased significantly since the approval of the standard. This paper presents the results of the one of the first DRM field trials using the 26 MHz band for local broadcasting that were carried out in Mexico. The main objective of these trials was to test the usage of the 26 MHz frequency broadcasting band to cover a local area in a similar way to FM broadcasting. This band has been usually used to broadcast long distance transmissions mainly under high sun-spot activity.

When the 26 MHz band is used for local broadcasting, the tropospheric propagation is the main mechanism instead of the ionospheric refraction used in HF. At these frequencies the first Fresnel ellipsoid is usually obstructed, and multipath at urban environments is strong. In this article, practical minimum signal-to-noise ratio and field strength levels are calculated for this novel usage of the 26 MHz frequency band.

Index Terms—Digital audio broadcasting, digital radio, DRM, HF radio propagation, reception reliability, urban areas.

I. INTRODUCTION

THE DIGITAL sound broadcasting DRM (Digital Radio Mondiale) system is a non-proprietary standard that operates in the frequency bands under 30 MHz [1]–[3].

The transmissions at those frequencies can propagate by means of groundwave, ionospheric propagation or a combination of both mechanisms [4]. Therefore, the coverage area of a DRM transmission goes from local areas in MF (medium frequency), regional areas in MF and LF (low frequency) up to large and far away areas in HF (high frequency).

The HF bands are usually utilized to broadcast programs to targets far away from the transmitter using ionospheric propagation. To achieve a successful transmission the ionosphere must refract the electromagnetic signal to the earth. The ability of the ionosphere to refract signals depends, among other factors, on its ionization state. For a given ionization state, the refraction is achieved for frequencies under the MUF (Maximum Usable Frequency). Frequencies over this threshold will not be refracted

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TABLE I
TECHNICAL CHARACTERISTICS OF THE TRANSMISSION

Transmitter Center:	Santa Fe
Broadcaster:	Radio Educación
Coordinates:	99° 15.920' W; 19° 22.071' N
Frequency:	25.620 MHz
Altitude:	2560 m (300 m above the average height of the city)
Mean power:	200 W
Antenna gain:	7 dBi
Height of mast:	62 m
Height of the antenna:	40 m

back to earth. MUF increases as the ionization state of the ionosphere increases.

The 26 MHz band is usually over the MUF, but when the solar activity is high (which occurs each eleven years), the MUF increases and the transmission is possible. The ionospheric propagation can also be done due to the apparition of the sporadic E layer. This ionospheric layer is not directly related to the sun cycle, and its effect appears more frequently in summer time, being difficult to predict its appearance [5]. For these reasons the 26 MHz band has been scarcely used for long distance transmissions, and could be used for local coverage services. However, the ionospheric propagation, due the F and E layers [6] and the sporadic E layer [5] must be taken into account when planning the local use of the 26 MHz band due to the possible interferences that they could produce [7].

The DRM Consortium proposed time ago the possible alternative use of the 26 MHz broadcasting band [8], and hence, a few trials have been done [7], [9]–[11]. The 26 MHz band has a 430 kHz bandwidth, which could be used for 43 DRM transmissions with 10 kHz bandwidth modes, or 21 DRM transmissions using 20 kHz modes. The frequency planning of this band is coordinated by international coordination groups, ASBU, ABU-HFC and HFCC, as it is regulated by Article 12 of Radio Regulations [12]. Each country authorities would be in charge of frequency assignments while the coordinating committees should be informed.

The tropospheric component is the main propagation mechanism when using the 26 MHz band for local coverage. The diffraction and the multipath are of great importance. Ionospheric propagation should only be taken into account for interference calculations.

TABLE II
DRM TESTED MODES

REF. ID.	BW (kHz)	Mode	MSC	SDC	Code rate	Bit rate (kb/s)
18K_A/64/16/0.6	18	A	64-QAM	16-QAM	0.6	48.64
18K_B/64/16/0.6	18	B	64-QAM	16-QAM	0.6	38.18
18K_B/16/4/0.5	18	B	16-QAM	4-QAM	0.5	21.20
10K_B/16/4/0.5	10	B	16-QAM	4-QAM	0.5	11.64

In this article, an extensive and carefully planned field trial performed during July of 2005 in México D.F. is described. The transmissions were performed in the 26 MHz frequency band with a DRM transmitter and a mean power of 200 Watts. These trials were organized by the DRM Consortium, the University of the Basque Country and Radio Educación.

II. OBJECTIVES

The ITU provides minimum field strength and signal-to-noise ratio levels for different DRM modes and different estimated propagation channels [13]. The ITU data suitable for HF frequencies were obtained considering ionospheric propagation channel models. In consequence, there are not so far any system threshold values suitable for tropospheric propagation channels.

The main target of these trials was to test the viability of using the 26 MHz frequency band for local coverage and obtain a first set of planning parameters. This objective includes the determination of the most suitable DRM modulation parameters for this propagation channel. Other objectives include:

- Obtain the minimum field strength for a correct reception for a set of DRM modes.
- Obtain the minimum signal-to-noise ratios for a correct reception of a set of DRM modes.
- Obtain the necessary power that would be needed to cover a city like Mexico City.
- Evaluate the influence of different kind of urban environments in the reception of the DRM signal.
- Test the DRM modes with 18 and 20 kHz bandwidths.

III. EXPERIMENTAL NETWORK

The transmission center was located at Santa Fe, in the southwest outskirts of México D.F. Santa Fe is a very hilly area 16 km away from the city center. Santa Fe is 300 meter over the mean height of the city.

The mean power of the DRM transmitter was 200 Watts. The transmitter could be configured remotely from any internet enabled PC. As the transmitter was located in the outskirts of the city, a directive three element vertical polarization Yagi-Uda antenna was chosen.

This antenna was installed in a tower pointing towards Mexico City center, which was located about 45 degrees north-west from the transmission center. The antenna horizontal 3 dB beamwidth was 120 degrees and its gain was 7 dBi (data given by the manufacturer). The main lobe of the antenna was wide

enough to ensure that the gain variation on the measurement area was negligible.

In Table I the main technical characteristics of the transmission are summarized.

The DRM system has four OFDM modes: A, B, C and D. Theoretical calculi show that the robustness of modes A and B is strong enough to cope with delay spread and Doppler spread due to multipath in the coverage area under test. Therefore, several combinations of parameters were used with those OFDM modes.

One of the targets of the trials was to evaluate the 18 and 20 kHz bandwidth DRM transmission modes. Although 20 kHz was the preferred signal bandwidth, 18 kHz bandwidth was used instead, because the acquisition system was optimized for 18 kHz. The results obtained with a bandwidth of 18 kHz can be easily extended to 20 kHz.

In Table II the modulation parameters of each mode, along with the allowed maximum bit rate are summarized. In the table, the IDs that will be used to refer to these modes during this document are also presented. Two groups of basic parameters were chosen, one highly protected, mode 18K_B/16/4/0.5, and another less protected one, mode 18K_B/64/16/0.6, which allowed higher bit rates.

In order to analyse the behavior of other parameters of the DRM modulation, modes 10K_B/16/4/0.6 and 18K_A/64/16/0.6 were also chosen. All the tests were performed using long interleaving because is more appropriate for this type of propagation channel [1].

The 18K_B/16/4/0.5 mode allowed a useful payload bit rate of 21.20 kb/s. This bit rate is high enough to allow the transmission of audio with parametric stereo. This coding scheme is part of the MPEG-4 AAC family and offers an excellent quality for low bit rates [14]. With the high bit rate modes, i.e. the 18K_B/64/16/0.6 and 18K_A/64/16/0.6, the MPEG-4 AAC full stereo mode was used. The 10K_B/16/4/0.6 mode allowed a bit rate of 11.64 kb/s, suitable for CELP coded speech content [1].

As the DRM standard allows up to four audio channels in the DRM signal, the four DRM modes were used with different audio channel configurations. These different combinations do not affect the minimum SNR and minimum field strength calculated for each DRM mode.

The mobile reception was done using a fully equipped modified van, as depicted in Fig. 1. The signal was received using a R&S HE010 modified active antenna. This antenna was added a low pass filter to avoid FM signal interferences and active circuit saturation. The antenna was calibrated after the addition of

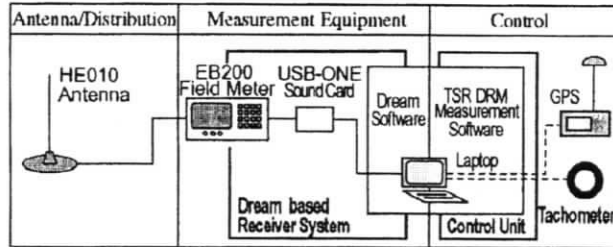


Fig. 1. Diagram of the measurement system.

the low pass filter and once installed on the roof of the van. The antenna fed the RF signal to the EB200 field meter. This piece of equipment performed two different tasks. On one hand, it was able to measure the received signal strength, and as the system was calibrated, the field strength. On the other hand, it was used as a front-end of the DRM receiver. It was capable of downconverting the RF signal to zero IF IQ analog signal. This IQ signal was then sampled using a professional audio sound card, and demodulated using a modified version of the DReaM software receiver [15]. The DReaM software was modified to provide the measurement system with DRM specific parameters following the RSCI protocol [16]. The measurement system also consisted of a GPS to record the position of the measurements, and a tachometer to measure distances with higher precision. An ad hoc software tool was developed to control the measurement system and it recorded and organized the data captured by the equipment.

IV. MEASUREMENT METHODOLOGY

Two kinds of measurements were made, on fixed locations and along routes. The distinction made between static and mobile reception is based on the two kinds of radio listeners: the “on foot” ones and the “on board” ones. The fixed point measurements were performed during 15 minutes in predefined locations. Most difficult reception conditions were featured by mobile reception, mainly due to fast signal variations.

Four types of urban environments were taken into account to classify the predefined fixed points. The characteristics of those environments are:

- “*Typical Mexican*” is an urban environment with wide streets and two storey buildings.
- “*Dense Urban*” is an area with high buildings.
- “*Open Residential*” includes not very built up or open areas such as parks. In this case, two different areas were selected: the Chapultepec wood and the Sport City.
- “*Low Dense Industrial*” is an industrial area without heavy industry.

Four measurement routes were planned, one per environment type. As the route 1 showed low received power due to terrain obstructions, another route with similar characteristics was planned, this one named route 5. A route was composed of both static and mobile measurements. In each route, 5 or 6 locations for static measurements were chosen. Between successive static measurement locations, mobile measurements were performed. The routes were performed on different days using different

TABLE III
MEASUREMENT ROUTES

Route name	Environment	Area	Mean distance to transmitter
Route 1	Typical Mexican	Benito Juarez	11.5 km
Route 2	Dense Urban	Reforma Polanco	10 km
Route 3	Low Dense Industrial	Azcapotzalco	15 km
Route 4	Open Residential	Chapultepec – Sport City	9.5 - 17 km
Route 5	Typical Mexican	Aragón-La Villa	20 km

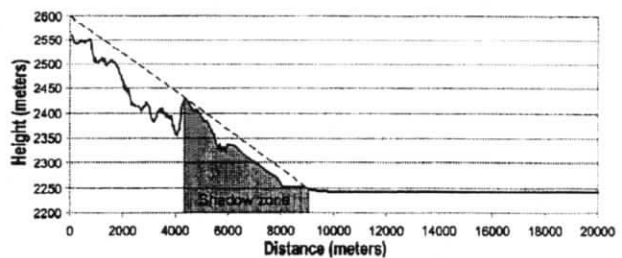


Fig. 2. Terrain profile from transmitter in 45° North-East direction. The dotted line indicates the direct path from the transmitter.

DRM modes. In total static measurements were taken in 60 locations and more than 600 km of mobile measurements were recorded. In Table III the different zones where the measurements were performed are described.

The control software received and stored all the data generated by the different measurement equipments. The most important measured parameters were the field strength, the signal to noise ratio, and the objective audio quality. The field strength was measured by the EB200 field meter. The signal-to-noise ratio was calculated by the DReaM receiver software [15]. The audio quality was measured as the percentage of correctly decoded audio frames.

The reception was considered correct when the percentage of correct decoded audio frames was equal or greater than 98% [17]. It should be noted that minutes with correctly decoded audio frame percentage below this threshold could lead to errors not detectable by the listener. Therefore, this threshold was conservative.

The SNR and field strength values considered in the analysis were the median of the measured values.

The field meter was not capable to measure two frequencies at the same time. Consequently, the noise measurements were carried out previous to the DRM signal measurements at each location. To know the noise level at each measurement point, the noise level at four channels was measured, and the estimated noise was calculated as the median value of them. The measured value was checked using the measured field strength and the signal-to-noise ratio. The noise level was measured with a 30 kHz bandwidth. The measurement system base noise was measured prior to the measurements once the mobile system was installed. The measurements were done considering all the possible factors (vehicle engine on/off, laptop on/off, etc). The

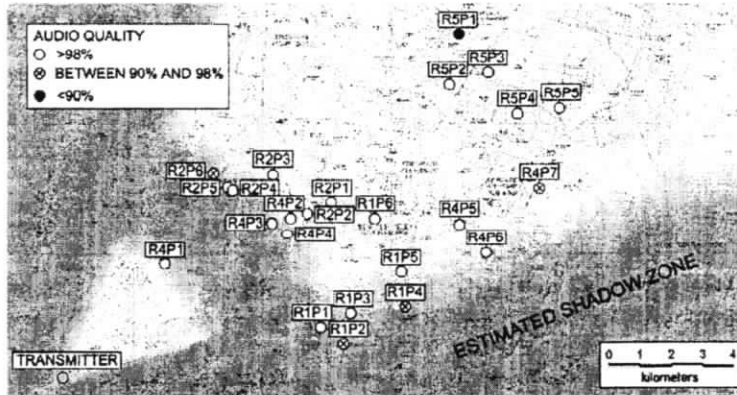


Fig. 3. Audio quality received with the 18K_B/16/4/0.5 mode.

system noise threshold was $-10 \text{ dB}\mu\text{V}$ (using the same 30 kHz bandwidth). The noise values given in this paper take into account the internal noise of the whole measurement system and being both internal and external noise uncorrelated the system noise have been removed from the measurements.

Other interesting parameter to analyse was the variability of the signal. The signal at 26 MHz is diffracted and reflected by terrain irregularities and buildings. This produces a strong multipath at the receiver. The multipath is mainly produced by the buildings, that is, the difference in the path length can be from some meters to several hundred of meters. The coherence bandwidth in these conditions can be several hundred of kilohertz [18]. As the DRM signal has a maximum of 20 kHz of bandwidth, it must be considered as narrow band signal. Therefore, the multipath produces flat fading, and hence, a big variability is expected. This variability is an important factor in the reception quality. The variability was measured in decibels using the standard deviation.

V. STATIC RECEPTION RESULTS

The transmission center was at a height of 2560 m, 300 m over the mean height of the city. The antenna was surrounded by higher hills except in the North-East direction, that is, the direction towards the city center. So those hills had no great influence on these trials. Approximately between 5 km and 10 km of distance from the transmitter there is a shadow zone, where the terrain elevations obstruct the line that goes from the transmitting antenna to the receiver. Fig. 2 shows the terrain profile corresponding to a 45° North-East azimuth. Along a part of the profile the line of sight was shadowed by terrain irregularities. For this reason it was decided not to capture any measurement at locations situated at distances between 5 km and 9 km from the transmitter.

The transmitter power was low, and as the fixed points were far away from the transmitter, a majority of the measurements were made using the most protected mode, the 18K_B/16/4/0.5 mode.

A. 18K_B/16/4/0.5 Mode

The 18K_B/16/4/0.5 was the most protected mode of the modes tested in this trial.

TABLE IV
AUDIO QUALITY OF 18K_B/16/4/0.5 MODE

Mean Audio Quality	98.71%
Number of total measured points	24
Number of points where Audio Quality > 98%	19
Number of points where Audio Quality > 97%	22
Number of points where Audio Quality > 90%	23

24 static reception measurements were recorded along the measurement routes using this mode. The mean audio quality of these points was 98.71%, which is over the 98% threshold. In 19 of those 24 points, the audio quality was higher than 98%. In three of the 5 remaining points, the quality was between 97% and 98%. In Table IV those results are summarized.

In Fig. 3, the 24 points are depicted on the map. The names of the points indicate the number of the route and the position of the point along the route. For example, the R1P4 is the fourth point of the first route. The estimated shadow zone is the area in which the terrain obstructs the line of sight path between transmitter and receiver. This figure does not account for building obstructions. As shown in Fig. 3, all the points with poor reception, except R5P1, are at the fringe of the theoretical coverage area of the transmitter. Points R1P2 and R1P4 are in the shadow zone. The received signal strength in the R5P1 point is low. The location was just beside a building and the distance to the transmitter is the largest one of the measurement campaign. As it can be seen in Table V, man made noise was also high. This measurement point was located in a street with heavy traffic.

Obtained data allowed to calculate the minimum SNR level needed for a correct reception of the DRM signal using the mode 18K_B/16/4/0.5. In Fig. 4 the measured median SNR of the 24 fixed points is depicted versus received audio quality. Following the tendency given by different points, a signal-to-noise ratio level of 18 dB should be enough to receive the transmission correctly. This is true for all the points, except for the seventh point of the fourth route, as it can be seen in Fig. 4. This place is located next to the airport, in a street with heavy traffic. At this

TABLE V
POINTS WITH AUDIO QUALITY LOWER THAN 98% WITH
MODE 18K_B/16/4/0.5

Point	Field strength (dBμV/m)	Std. Dev. (dB)	Noise (dBμV)	Problem
R1P2	34	1.90	-6	Low and variable signal
R1P4	36	1.84	-1	High noise
R2P6	39	1.59	-0.5	High noise
R4P7	42	1.32	5.4	High noise
R5P1	29	1.93	-2.75	Low signal and high noise (low SNR)

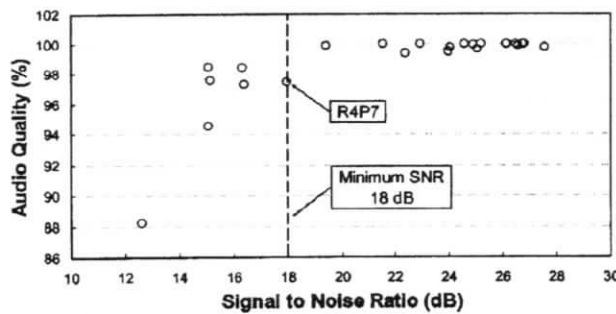


Fig. 4. Audio quality vs. signal to noise of the fixed points. 18K_B/16/4/0.5 mode.

point the highest noise levels were measured, as it can be seen in Table V.

The ITU does not specify minimum SNR values for 18 kHz channels. Nevertheless, a comparison could be made with the values given for 10 kHz bandwidth channels [13]. The values given by the ITU for HF channels vary from 14.6 to 18 dB. In spite of the similarity between the values obtained in this study and the ones given by the ITU, it should be taken into account that the ITU thresholds are suitable for ionospheric propagation channels while, for local coverage, the main propagation component is tropospheric.

Comparing those levels with the current analog transmissions, the minimum C/N to receive an AM signal is 36.5 dB [19] that is 18.5 dB higher than the SNR needed for DRM.

In Fig. 5 audio quality versus median field strength is shown.

In this case the reception threshold is 37 dBμV/m. However, there are two points above this threshold that do not reach the 98% audio quality. One of them is the seventh point of the fourth route, as stated before. The other point is the sixth point of the second route. At this point high noise levels were also measured.

The 37 dBμV/m value is only 3 dB below the theoretical field strength needed to receive an AM signal, that is, 40dBμV/m [19]. The reason for such a high threshold is the man made noise. The 40 dBμV/m field strength threshold is defined in absence of external noise, taking into account only the internal noise of the receiver. The man-made noise of México D.F. is very high. Therefore, a higher field strength

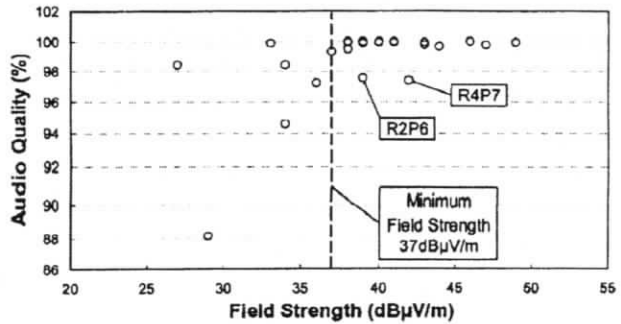


Fig. 5. Audio quality vs. received field strength of fixed reception. Mode 18K_B/16/4/0.5.

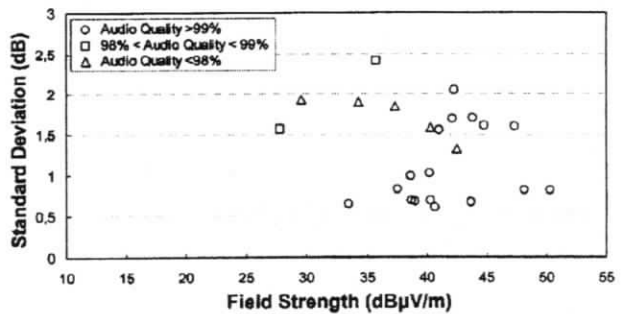


Fig. 6. Effect of the received signal strength variability in the audio quality for the 18K_B/16/4/0.5 mode.

level is needed to achieve a correct reception. This is also applicable to the AM signal, for which the real threshold must be far higher than the given by the ITU.

The analysis of the five points in which reception was not good, shows that the main cause of failure was the noise level. In four of those points the noise level was higher than usual, especially with received DRM signal levels as low as 37 dBμV/m. This shows that noise is a main factor to be taken into account when defining minimum field strength values. In Table V, the problems detected in the points with bad reception have been summarized.

During the measurement campaign it was observed in different reception environments that the presence of traffic in the vicinity of the measurement point increased the variability of the signal. The vehicles passing near the receiver reflected the DRM signal and caused multipath, variable delay spread and Doppler. With respect to the variability, it is also remarkable that the received signal strength changed up to 10 dB when moving 3 or 4 meters away. This is an evidence of multipath caused flat fading at this frequency. The flat fading can lead reception impairments in this new use of the 26 MHz band. A method to overcome this problem will rely on the single frequency network configurations where the location of the flat fading spots from each transmitter will be uncorrelated.

Fig. 6 shows that a combination of low power signal values and high variability can produce errors in the receiver. In fact, at field strength levels below 40 dBμV/m, high quality reception can only be achieved when signal variability is small.

TABLE VI
RESULTS OF 18K_B/16/4/0.5 MODE

Mean Audio Quality	98.71%
Number of total measured points	24
Number of points where Audio Quality > 98%	19
Minimum signal to noise ratio	18 dB
Minimum field strength	37 dB μ V/m

TABLE VII
RESULTS OF 10K_B/16/4/0.5 MODE

Mean Audio Quality	95.75%
Number of total measured points	7
Number of points where Audio Quality > 98%	5
Minimum signal to noise ratio	16-17 dB
Minimum field strength	38 dB μ V/m

TABLE VIII
RESULTS OF 18K_B/64/16/0.6 MODE

Mean Audio Quality	88.24%
Number of total measured points	8
Number of points where Audio Quality > 98%	3
Minimum signal to noise ratio	22 dB
Minimum field strength	>43 dB μ V/m

TABLE IX
RESULTS OF 18K_A/64/16/0.6 MODE

Mean Audio Quality	93.08%
Number of total measured points	6
Number of points where Audio Quality > 98%	2
Minimum signal to noise ratio	-
Minimum field strength	-

B. Results of Other DRM Transmission Modes

In Tables VI–IX, data obtained for all the DRM transmission modes used, including the 18K_B/16/4/0.5 stated before, have been summarized.

For modes 18K_A/64/16/0.6 and 18K_B/64/16/0.6, received field strength level was insufficient. It can also be seen that the minimum SNR needed for 18K_B/64/16/0.6 mode is 4 dB higher than the needed for 18K_B/16/4/0.5 mode. This value is lower than the values given by the ITU [13], which are between 5.3 and 5.5 dB, depending on the propagation channel.

TABLE X
FIELD STRENGTH AND NOISE STATISTICS DIVIDED BY ENVIRONMENT TYPES

Environment type	Mean distance to the transmitter	Field (dB μ V/m)	Field variability (dB)	Noise (dB μ V)
Typical Mexican	11.5 km	37	1.55	-4.6
Dense Urban	10 km	39.5	1.44	-4.9
Low Dense Industrial	15 km	35	1.27	-8.2
Opened Residential	9.5 - 17 km	40.5	1.15	-10
Typical Mexican	20 km	37	1.04	-6.6

It should be stated that modes 18K_B/64/16/0.6 and 18K_A/64/16/0.6 can be correctly received, but higher power than the one used in this trials will be needed.

C. Effect of the Environment in the Reception

Reception environment is a key factor in the reception of any radio service. In order to study its effect in the DRM system, different routes were planned in different environments. The chosen routes and their characteristics can be seen in the Table III. As stated before, the noise and the field variability were observed as the main factors when determining the behavior of the DRM signal. In Table X field strength and noise statistic data measured along the five routes are shown. The term "field variability" is the mean value of the standard deviation of the measured field in each fixed point. This shows the variability of the signal.

It can be observed that the received field strength values are not apparently correlated with the distance to the transmitter. This result is not surprising, as the path loss is heavily influenced by factors not directly related to the distance. The obstruction made by the buildings showed to be an important factor that produced significant losses in some cases. These losses were not correlated with the distance to the transmitter. The influence of the environment type and terrain obstacles are clearly appreciated when comparing routes one and five. Those areas were classified as belonging to the same environment category (typical Mexican). Route five is located 20 km away from the transmitter, while first route is only 11.5 km away. Nevertheless, the received field strength is similar in both cases. The reason is that the first route is in the vicinity of a shadow zone. As expected, the variability observed in open environments is also small.

Table X shows measured man made noise levels in the 26 MHz band. As expected, the noise level at the *open environment* was the lowest. It should also be noted that the noise at *low dense industrial* zone was smaller than the one of the *dense urban* area. The reason is that in the *low dense industrial* zone analysed in Mexico there were less traffic and electromagnetic noise sources.

In Table XI audio quality and median SNR results for each area are shown, for mode 18K_B/16/4/0.5, exception made for the industrial zone, where this mode testing was not scheduled.

Reception in the *open residential* environment was almost perfect (99.5%), and it showed the highest signal-to-noise ratio,

TABLE XI
AUDIO QUALITY AND SNR STATISTICS DIVIDED BY ENVIRONMENT TYPES
MODE 18K_B/16/4/0.5

Environment type	Mean distance to the transmitter	SNR (dB)	Mean Audio Quality (%)
Typical Mexican	11.5	20.24	98.25
Dense Urban	10	25.07	99.30
Opened Residential	9.5 - 17	26.15	99.95
Typical Mexican	20	22.38	97.32

The results were very good in other more noisy zones, as the ones of the first and second routes. In those routes, in addition to noise, there was high signal variability due to multipath propagation. Apart from that, overall, the audio quality was higher than the 98% threshold.

It can also be observed, that in *dense urban* environment, reception was better than in the *typical Mexican* one, which was unexpected. Traffic is not the factor that causes this difference because both environments have similar traffic levels. Noise, another important factor, is also the same in both areas. The reason may be the difference of 3 dB that is in the received field strength. In the two routes of the *typical Mexican* environment, the median field strength level is 37 dB μ V/m, which is just the threshold for a correct reception, as stated before. Meanwhile the signal level in the *dense urban* environment is a little higher and it allows better reception.

D. Effect of the Traffic

Traffic close to the measurement location was observed as a very important factor. The engines of the cars are an important source of radioelectric noise [20], [21]. In order to study the effect of the traffic on the reception of DRM signals, the data obtained from mode 18K_B/16/4/0.5 was separated into two groups, first group containing the points in which traffic was moderate or heavy, and a second group containing the points with low traffic. Other sources of noise were the trolley buses, being sparks produced by the trolley, origin of radioelectric impulsive noise. Interferences produced by the radio emitters, very typical in México, should also be taken into account.

Audio quality, minimum SNR and field strength level results obtained for mode 18K_B/16/4/0.5 can be observed in Table XII.

Table XII shows the influence of the traffic density in the reception quality. Points without traffic show high performance and those locations that show reduced quality were affected by traffic despite other factors. Being excellent the reception in all the points without traffic, it is impossible to calculate with precision the minimum SNR and field strength thresholds. Therefore, the minimum values with excellent quality have been taken as the threshold.

Fig. 7 shows the relationship between field strength and audio quality classifying the points by traffic level with 18K_B/16/4/0.5 mode reception. Points without traffic need lower field strength levels than points with traffic. The reception threshold is near a value of 31 dB μ V/m for locations where

TABLE XII
RECEPTION WITH AND WITHOUT TRAFFIC FOR 18K_B/16/4/0.5 MODE

	Total	Locations without traffic	Locations with traffic
Mean Audio Quality	98.71%	99.60%	98.18%
Number of points where Audio Quality > 98%	19	9	10
Number of total measured points	24	9	15
Minimum SNR	18 dB	< 15 dB	18 dB
Minimum field strength	37 dB μ V/m	-	37 dB μ V/m
Field variability	1.30 dB	1.00 dB	1.48 dB
Median noise	-5.6 dB μ V	-10 dB μ V	-4.6 dB μ V

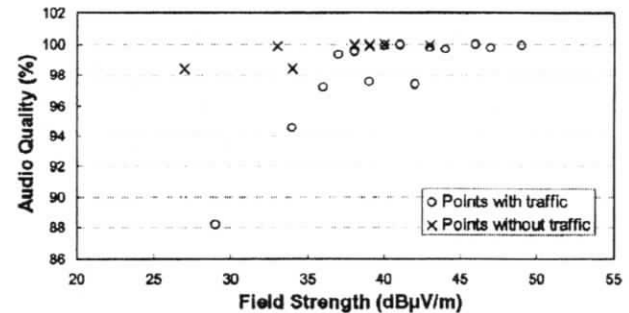


Fig. 7. Traffic influence on audio quality vs. field strength of static reception. Mode 18K_B/16/4/0.5.

the traffic influence was negligible. The threshold value can rise up to 6 dB more if a certain location is heavily influenced by noise and signal variation produced by moving vehicles close to the receiver.

Performing a similar analysis with the remaining tested DRM modes, the same tendency is shown. The points without traffic for modes 10K_B/16/4/0.5 and 18K_B64/16/0.5, five overall, had a perfect reception.

VI. MOBILE RECEPTION RESULTS

A. Radial Route

As stated before, mobile measurements were done in the same zones as static measurements. In addition to the five routes explained, a route without static measurements was also included. This route was a radial route in northeast direction, beginning 10 km away from the transmitter, at the start of the Viaducto road. This mobile measurement went all along the Viaducto road, passing by the international airport, and taking the Texcoco highway (see Fig. 8). In this route, two different sections can be told apart. The Viaducto is a wide road, 3 lanes each way, built on the bed of an ancient river with sharp walls at the sides. Its shape is similar to a tunnel where the roof has been opened. The Viaducto mean height is always under the city mean level. Furthermore, the Viaducto has many tunnels, and holds very heavy traffic. Even if it is a high velocity road,

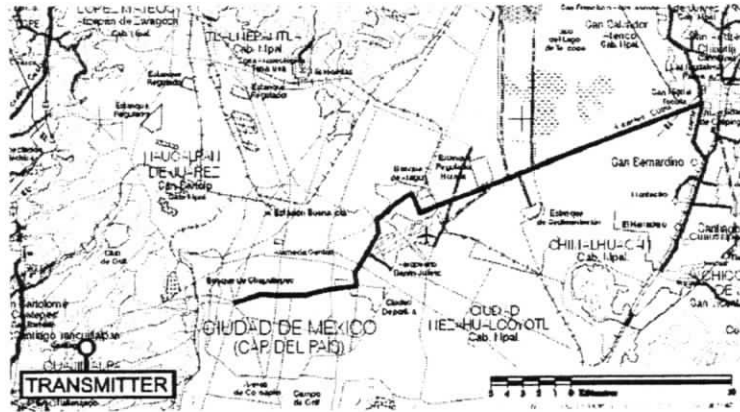


Fig. 8. Radial route.

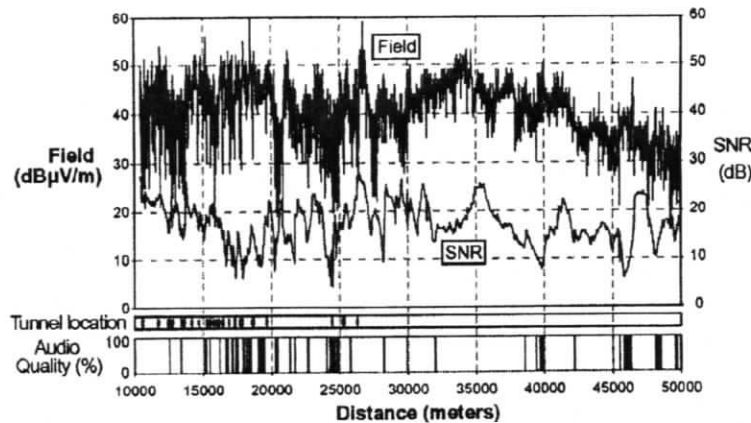


Fig. 9. Signal strength, SNR and audio quality of the radial route.

the mean speed is about 50 km/h, with a maximum of about 80 km/h. Due to the traffic level, the speed at this road is very variable with many accelerations and decelerations. The Texcoco highway is a 15 kilometers straight road, built in open environment. The traffic level is moderate and the cars move very fast, over 100 km/h. The route between the end of the Viaducto and the beginning of the highway is a road with heavy traffic.

The mobile measurements done along this route were performed using mode 10K_B/16/4/0.5. Fig. 9 shows the field strength level, the signal-to-noise ratio level and the audio quality of the received signal.

The most important conclusion that came out from the measurements performed along this radial route was that all the errors in reception up to a distance of 16 km from the transmitter were caused by the tunnels. Furthermore, it should be stated that in several tunnels there was an error free reception. From 16 km to 20 km away from the transmitter, errors were caused by low signal levels. 25 km away from the transmitter, reception was really bad due to interferences coming from the airport. It should be noted that from 30 to 45 kilometers from the transmitter, there were very scarce errors in the reception. The reason is that the Texcoco highway is in Open Environment. In this zone field strength level is much more stable than in the

Viaducto. The multipath is lower than in the city, thus, the variability is also smaller. It can be seen that in the first half of the route, the field strength does not follow a clear tendency. Nevertheless, for distances further than 34 kilometers away from the transmitter, the negative slope tendency is clear. This reinforces the fact that in the city, the received levels were more influenced by the topology of the city, than by the distance from the transmitter.

All the transmission frames with signal-to-noise ratio levels higher than 20 dB were received perfectly. Frames with signal-to-noise ratio between 18 and 20 dB, were received with an audio quality of 98.6%. Consequently, for mobile reception and mode 10K_B/16/4/0.5 the SNR reception threshold is 18 dB.

B. Effect of the Environment in Mobile Reception

Data from different environments have been analysed, but little differences have been found among them, except for the *open residential* environment. The study was performed using the most protected mode, that is, 18K_B/16/4/0.5 mode. The coverage in each route varied from 20% to 25%, except for route 4, where the coverage was greater than 50%.

TABLE XIII
AUDIO QUALITY AND SNR STATISTICS DIVIDED BY ENVIRONMENT TYPES
MODE 18K_B/16/4/0.5—MOBILE RECEPTION

Route	Environ.	Coverage (200 W)	Coverage (2 kW)	Coverage (6.3 kW)
Viaduct- Texcoco	Four lane road	Up to 15 km (90%)	Up to 42 km (93 %)	More than 42 km (~100%)
Route 1	Typical Mexican	29 %	91 %	~ 100%
Route 2	Dense Urban	23 %	87 %	~100%
Route 4	Open Residential	51 %	94 %	~100%
Route 5	Typical Mexican	21 %	87 %	~100%

C. Estimation of Required Transmission Power

As stated before, with a signal-to-noise ratio of 20 dB a perfect reception of the DRM signal in movement can be achieved. Increasing the signal-to-noise ratio in each route, the coverage increase of each route can be calculated. In Table XIII the theoretical results obtained for 2 kW and 6.3 kW transmitter powers are shown, along with the real results of the 200W transmitter.

As it can be seen, with 2 kW RMS power, that is, increasing the power of the transmitter by 10 dB, an estimated coverage of the 90% of the city is obtained. If the power would be increased by 15 dB (up to 6.3 kW), almost all the city would be covered. Some tunnels and very noisy spots would require very high power levels to be covered. These special points are not covered by analog transmissions. Nevertheless, an operational broadcast could be performed with a transmission power between 2 kW and 6.3 kW.

VII. CONCLUSIONS

The results of the trials show that the 26 MHz band can be used for local broadcasting using DRM. The main concerns come from the interferences that could be caused by other transmitters due to ionospheric propagation.

The 18 kHz bandwidth DRM transmission mode provided a reliable service and offered a good choice with high audio quality in zones where these bandwidths suit the spectrum constraints. An example of application is the 26 MHz broadcasting band which is nowadays very scarcely used.

The main propagation mechanism in the 26 MHz band is the tropospheric propagation. Therefore the received signal levels showed a high variation in urban environments due to diffraction and multipath. The propagation channel is affected by flat fading which means great variability and black spots, points in where the reception can be difficult. It is envisaged that single frequency networks will produce smoother field strength level distributions within the coverage in large cities and thus will reduce considerably the effect of flat fading.

The minimum field strength level needed for a DRM transmission at those frequencies is far lower than the field strength needed for an AM transmission in the MW band.

The man-made noise has been found relevant in this measurement campaign and it should be taken into account when planning DRM services in this band. The noise levels measured,

though, are much less than the ones that can be found in the Medium Wave band.

Slight reception behavior differences have been found with respect to different environment types, except for the *open residential* environment where the reception is much better than in *typical Mexican, low dense industrial* and *dense urban*. It has been demonstrated that the presence of traffic increases the minimum field strength requirements up to an amount of 6 dB for static reception.

The results show that a 200W RMS transmitter is not enough to cover Mexico D.F. Based on estimations made using the results of the measurements, the 90% of a city like Mexico D.F. would be covered using a 2 kW RMS power transmitter and a power of 6.3 kW would be needed if the coverage should reach the 100%.

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DRM (Digital Radio Mondiale).

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