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Empirical Analysis of Medium Wave Field Strength Prediction in Urban Environments

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***Abstract*—This paper presents results obtained from four extensive field trials of medium wave DRM (Digital Radio Mondiale) which were carried out in Madrid (Spain), Delhi (India) and Mexico D.F. (Mexico) using different transmission frequencies. The objective is to provide medium wave field strength spatial variability values for urban environments using empirical analysis methodology. The influence of the transmission frequency on medium wave propagation in urban environments is included. Both, long and short term components of the signal spatial variability are studied characterizing wide, medium and narrow streets, and the attenuation caused by different urban fast variation occurrences is statistically featured. All the results presented in this paper are essential for future network planning of new emerging digital broadcasting services and have been validated using the Generalized Lee Method.**

***Index Terms*— Broadcasting, Digital Radio, Propagation**

I. Introduction

NEW digital radio broadcasting systems [1] in the medium wave band are emerging in the last years and the service set up is starting now, so they require an accurate field strength prediction in order to improve the future network planning. Reception requirements for digital services are more demanding than analogue ones, so this paper analyzes the propagation on this frequency band.

The ITU-R recommends [2] different prediction curves in order to model and predict medium wave band propagation but they are not defined for reception in urban environments. Up to now, short and long term signal variability has been studied for rural areas [3], that is, time and spatial variability. In the case of urban environments, only characteristics of field strength time variability have been determined [4]-Hence, the spatial variability for urban environments needs to be analyzed.

The studies recently developed have defined two different methodologies in order to achieve reliable data for medium wave prediction and spatial variability in urban environments. On the one hand, theoretical Generalized Lee Method application [5] and on the other hand, data provided by empirical analysis [6] can be used. It has been proved that obtained parameters using both methods fit well but the statistical theoretical characterization of the medium wave propagation can not be achieved by means of the Generalized Lee Method [7]. For these reasons it is necessary to characterize urban propagation spatial features at medium wave by means of providing statistical empirical values in order to improve the planning in built-up areas which is an essential scope for this kind of broadcasting services.

The Generalized Lee method provides important parameters such as the cell size in order to calculate the long-term variation or the minimum distance between field strength measurements to be uncorrelated. As mentioned before, the Generalized Lee Method does not provide the statistical theoretical distribution of field strength spatial variability so it is necessary to apply the empirical method defined in [6]. The mentioned paper [6] introduced the empirical methodology and identified the main urban elements that affect medium wave field strength propagation in urban environments. Some preliminary results based upon a small fraction of the measurements were also given.

This paper presents the full empirical results for medium wave propagation in urban areas by means of data gathered from different field trials carried out in Delhi (India) Mexico D.F. (Mexico) and Madrid (Spain) using DRM (Digital Radio Mondiale) and AM analogue signals at different frequencies within the band, namely 666, 810 1060 and 1260 kHz . Measurement, processing and analysis are based on several factors previously identified such as street width and building density. Nevertheless, more than 500 km have been analyzed in order to complete the analysis that was started with roughly 50 km in [6]. In addition, both the influence of frequency on spatial variability behavior, and the rate of occurrence of the urban factor that cause this variability, are thoroughly studied in the statistical analysis. Finally, at this final stage of the work, the validity of the analysis that has been carried out, has been supported by the results provided by the Generalized Lee Method theoretical analysis [7].

The paper exposes the empirical data processing and results of the spatial variability analysis attending to three different transmission-reception features. Firstly, different transmission frequencies and differences between propagation values are analyzed. Secondly, the long-term variation is studied in order to obtain reliable data discerning between wide, medium and narrow streets. This section provides different statistical results in order to plan digital services in the medium wave band. Finally, the short-term spatial variability is presented showing results for different urban fast variation occurrences such as bridges crossroads, wires and metallic structures.

II. OBJECTIVES

The main objective of this paper is to characterize different influential factors on daytime MW DRM signal reception in urban environments. The final aim of the study presented on this paper is to provide essential empirical statistical values of field strength spatial variability for planning purposes in urban environments. The results will be focused exclusively on mobile reception and include the following specific issues.

- Analyze the influence of transmission frequency on medium wave band propagation in urban environments,
- Provide long-term spatial variability values in statistical terms discerning between wide, medium and narrow streets.
- Study the short-term field strength variability for influential factors that cause fast variation occurrences in medium wave field strength values in the mentioned environments.

III. MEASUREMENT CAMPAIGNS

The analysis carried out in this paper is based on data gathered during four different measurement campaigns that evaluated the DRM (Digital Radio Mondiale) medium wave broadcasting service in mobile reception. Those measurement campaigns covered the whole range of the mentioned frequency band, namely 666, 810, 1060 and 1260 kHz, and they were carried out in Mexico D.F. (Mexico), New Delhi (India) and Madrid (Spain). These cities are representative of noteworthy different kinds of urban environments as well.

Figure 1 shows a general reception system whose different configurations have been used for measuring DRM service parameters in the medium wave band. This measurement system captured one field strength value and a set of DRM signal parameters and auxiliary data every 400 ms, that is, the DRM frame duration. All data were conveniently stored in plain text format files

. As previously mentioned, it is necessary to take into account as much data diversity as possible in order to perform a representative overall analysis of the urban effects on the random routes that have been measured in the mentioned cities

These cities show quite different urban features. Next table shows some of the most important characteristics of those three urban environments.

Consequently, a total of 96 random routes covering more than 500 km overall have been measured and analyzed.

From this point of the paper on, 1-2 pairs-of-lanes streets have been considered as narrow, 3-4 as medium and 5 or more as wide.

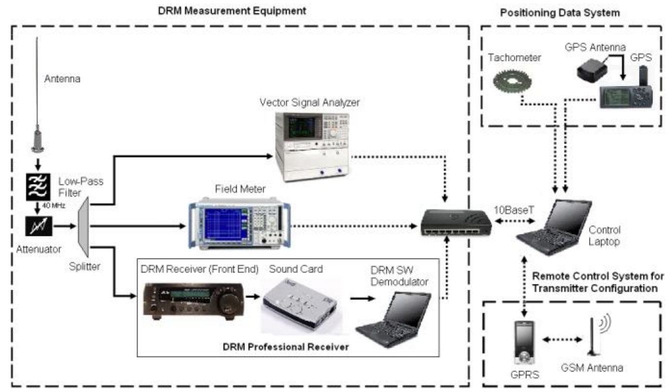


Fig. 1 Generic Measurement System for DRM service in the medium wave band.

TABLE I
URBAN ENVIRONMENTS: GENERAL FEATURES

City	Delhi	Madrid	Mexico
Density (p/km^2)	9300	5200	5900
Traffic	Very high	High	Very High
Height of Buildings (storeys)	1-2	6 or more	3-4
Width of Streets (lanes)	2-3	1-2	4-6
Terrain height (m)	250	650	2200

IV. METHODOLOGY

The paper carries out an empirical data processing in order to assess the spatial variability of the received field strength levels due to the propagation path from the transmitter. Data processing is based on strength values gathered on the field in the urban environments previously mentioned. The basic procedures and methodology in order to analyze the measured data are explained in [6] which sums up the work previously carried out. This mentioned methodology has been validated with another analysis method called Generalized Lee Method and which results are exposed in [7]. Both methods provide similar results with an acceptable error lower than 3 dB in most cases

The first step of the empirical analysis should be carried out avoiding clutter effects, that is, considering the attenuation of urban factors which are not located in the vicinity of the transmitter. This is achieved by means of measurements at points which are located in wide streets and open areas. The next processing step will consist of adding the effects due to urban factors close to the receiver, to those predicted field strength values- These effects are the long and short-term variability of the signal which are fully characterized in this paper by means of an empirical statistical analysis.

Using the reference values calculated in wide streets and separating them as a function of transmission frequency and distance to the transmitter, all the field strength values are normalized and compared in order to study the propagation differences between different transmission frequencies within the medium wave band. For that purpose, and taking into account that in Madrid two different measurement campaigns were carried out, field strength values transmitted in 810 and 1260 kHz are compared only for wide streets.

As mentioned in the previous paragraphs, secondly, the values for open areas and wide streets are considered as the starting reference point in order to calculate the effects caused by other kind of streets and urban factors near the receiver. Hence, streets have been divided into three different categories according to their width: wide, medium and narrow streets. Medium wave received field strength is lower as the reception location street is narrower. As a result of this analysis, prediction for any kind of streets could be given as a function of transmission frequency. Apart from the received field strength difference between wide, medium and narrow streets, the variability of the signal is pointed out by means of the standard deviation measured in all kinds of streets and frequencies.

Finally, different urban occurrences affecting the medium wave propagation are statistically analyzed. Some of the urban influential factors on signal attenuation were already identified [6] so only the statistical characterization of these fast variation occurrences is presented in the "Results" section. Both, the field strength attenuation depth and length, and the rate of occurrence, as well as several statistical features are shown and analyzed for each identified urban element at the studied reception environments.

V.RESULTS

This section explains the obtained results following the previously mentioned methodology. First, the propagation differences are presented depending on the used transmission frequency by means of taking the obtained mean field strength values for wide streets as a reference. Second subsection exposes the field strength long-term variation using the empirical method and comparing reference values (wide streets) with medium and narrow streets and, finally, the last subsection studies the field strength short-term variation by means of the statistical analysis of fast variation occurrences caused by different urban factors.

A. *Transmission frequency Influence*

Some authors have mentioned the importance of transmission frequency in order to improve the coverage of broadcasting services in the medium wave band [8] but the lack of reliable measurements did not allow to properly characterize it. Figure 2 (a) shows the field strength mean values that have been calculated using the empirical method. The exposed data was recorded in the same reception and transmission conditions exception made of the transmission frequencies. In the graph, dark squares depict field strength values calculated for 810 kHz transmission frequency and pale circles for 1260 kHz.

It can be clearly seen that the calculated mean values for lower frequency are considerably higher in urban environments than those measured at frequencies located in the upper part of the band. This is due to the fact that the size of urban obstacles and high buildings is more significant against lower wave length MW signals thus causing higher attenuation. In order to provide a clear idea of the difference between the two frequencies, the median field strength values have been gathered, for each frequency, every 500 m in an attempt to avoid the influence of the distance to the transmitter [2, 6].

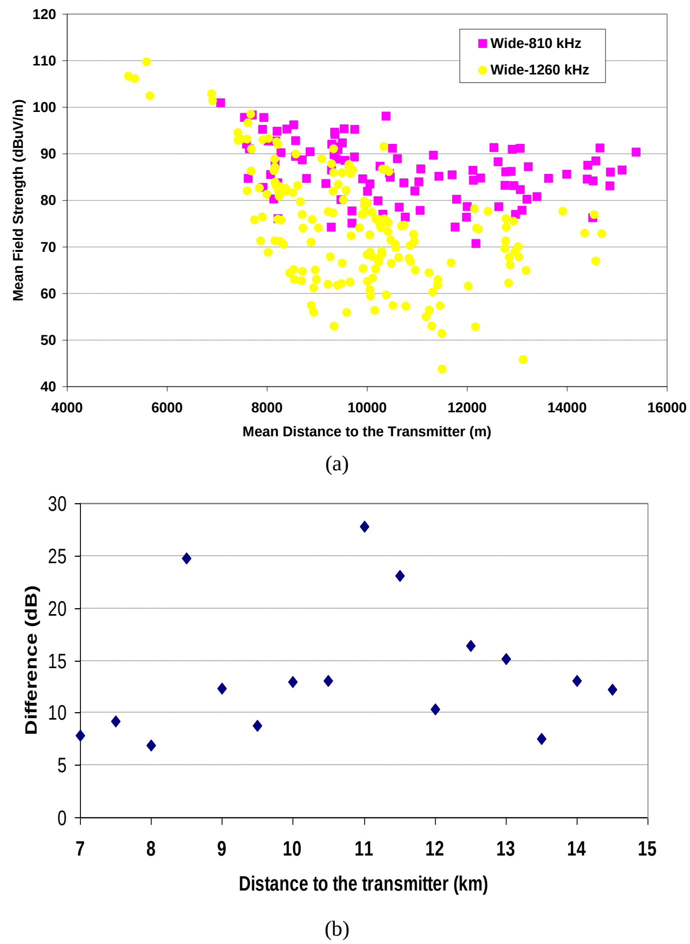


Fig. 2 Calculated values for 810 and 1260 kHz in urban environments (a) and differences between them (b)

The difference between those gathered values of the two frequencies under test is shown in Figure 2 (b). It can be observed that all the calculated differences are placed between 6 and 16 dB depending on the specific urban features of the measured areas excepting 3 points which show noteworthy higher values than the rest, that is, differences higher than 20 dB and located at 8.5 and between 11 and 12 km from the transmitter. Those areas with higher difference values correspond to locations where the most important and high buildings of Madrid are located.

B. *Long-term variation*

Once the influence of transmission frequency has been studied, it is necessary to establish the difference between wide streets and other kind of streets such as medium and narrow ones. As said in the methodology section, wide streets and open areas have been chosen as reference values in order to characterize field strength in urban environments.

Table II shows the mean differences between reference values and medium and narrow streets and, additionally, standard deviations are shown as well.

TABLE II
URBAN MEAN DIFFERENCES WITH RESPECT TO WIDE STREETS

City Frequency	Delhi 666 kHz	Madrid 810 kHz	Mexico 1060 kHz	Madrid 1260 kHz
Medium Mean	4.2 dB	6.4 dB	3.2B	11.1 dB
Medium Deviation	1.1 dB	4.3 dB	3.5 dB	6.8 dB
Narrow Mean	N/A	12.1 dB	9.3	19.9 dB
Narrow Deviation	N/A	6.1	5.1	8.2 dB

Both, mean values of difference between wide, medium and narrow streets, and the standard deviations, are related to the homogeneity of the urban environment [6], and its effect over the propagation depends on the transmission frequency. Thus, regarding the homogeneity of the environment, it can be observed that the calculated values are higher in the city of Madrid, the most inhomogeneous of the four, because of its built-up features. On the other hand, regarding the transmission frequency especially at the frequency of 1260 kHz, the higher one, noteworthy elevated differences are found.. The maximum attenuation value is around 20 dB and corresponds to measurements in narrow streets and 1260 kHz in Madrid.

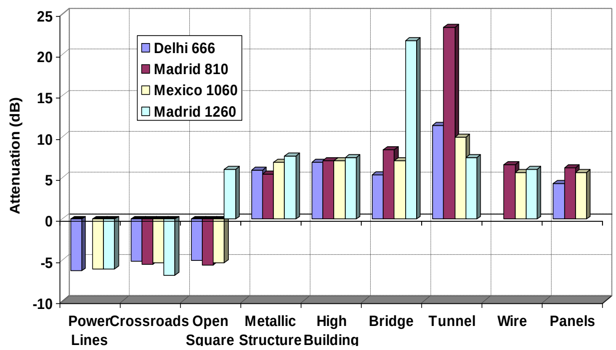
C. *Short-term variation*

Once the field strength mean differences corresponding to general urban features are analyzed, it is necessary to study specific field strength fast variation occurrences, that is, the short-term variation of the received field strength signal. As explained in [6], only occurrences 4 dB higher or lower than the calculated reference value have been considered within each area following the figure recommended by the ITU-R [9]. Figure 3 (a) shows the obtained attenuation mean values for most frequent occurrences.

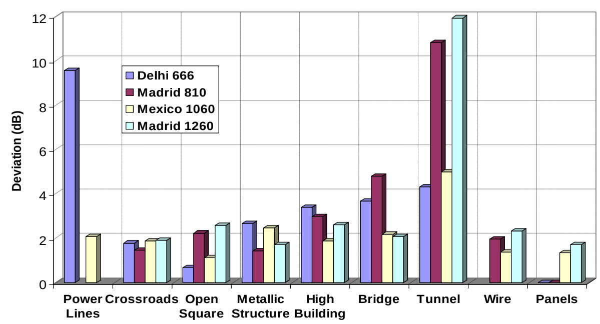
The first conclusion extracted from the graph is that the mean values of the fast variation occurrences are practically the same for different urban environments (cities) and transmission frequencies, that is, these, are factors that affect the long-term variation mainly. There are three elements which cause an increase of the field strength such as power lines, crossroads and open areas or squares. On the other hand, the rest of the studied urban elements cause mean attenuations between 5 and 10 dB with the exception of tunnels and bridges which cause usually higher attenuations.

Figure 3 (b) shows the calculated standard deviations around the attenuation mean values caused by fast variation occurrences. The figure points out that all the calculated attenuations are located 2 dB around the depicted mean excepting the bridges or tunnels cases, since the variability depends on the obstacle size. Different examples of the same type of obstacle usually have similar size in all cases with the exception of bridges and tunnels.

Moreover, the maximum achievable attenuation values have been calculated for the exposed urban elements in order to give an idea of the magnitude of the attenuation in critical cases. For example, metallic structures, bridges and aerial wires could reach up to 20 dB of attenuation, traffic panels up to 10 dB and bridges, tunnels or high buildings up to 40 dB or higher.



(a)



(b)

Fig. 3 Mean attenuation (a) and standard deviation caused by fast variation occurrences (short-term variation)

Apart from those depicted urban elements, different additional occurrences have been analysed and they could be compared with the ones already studied in this section. Parks, roundabouts and overpasses or flyovers can be considered as “open areas”, trees as “structures” or walls as “buildings”. An extra category gathering all unknown fading occurrences has been added in order to take them into account in the subsequent calculi and results.

Another important calculus to be presented is the duration of the fading occurrences in terms of space, that is, the distance of the mobile reception which was affected by each fast variation occurrence. Figure 4 depicts the mean duration of the previously mentioned occurrences.

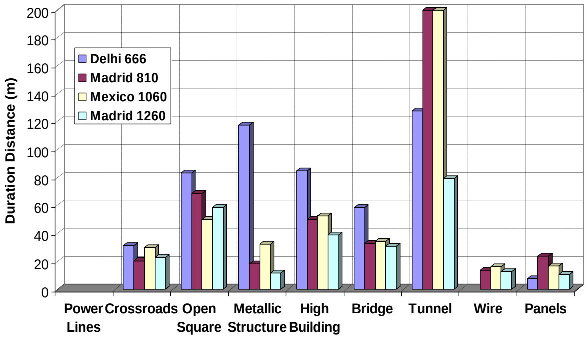


Fig. 4 Mean duration of urban fast variation occurrences

The distance duration of the occurrences is very variable, obviously depending on the size of the obstacle or urban element that causes it. But again, it can be seen that all the calculated durations are located between 20 and 30 meters except for high buildings or tunnels. It is necessary to point out that although bridges are usually large structures, they are usually crossed underneath perpendicularly, so, its size in terms of shadowing or propagation is not too large.

Finally, the last result and essential to take into account for planning purposes, is the calculus of the spatial percentage representing fast variation occurrences over the whole coverage area in medium wave band propagation. For that purpose, occurrences causing negative attenuations have been discarded because they have no effect in the coverage impairments. Table III shows the percentages obtained for the measurement campaigns carried out in the three mentioned cities.

TABLE III
PERCENTAGE OF DISTANCE AFFECTED BY FAST VARIATION ATTENUATING OCCURRENCES

City	Delhi 666 kHz	Madrid 810 kHz	Mexico 1060 kHz	Madrid 1260 kHz
Percentage (%)	17.9	10.9	12.9	12.7

Regarding planning purposes, fast variation occurrences prevent the achievement of necessary coverage for a correct reception in digital broadcasting services, so, those values are essential for broadcasters in order to take into account the transmission power increase necessary to overcome different reception impairments.

VI. CONCLUSIONS

This paper exposes the main calculated spatial variability values by means of empirical methodology in the medium wave band in urban environments. This analysis will be essential for broadcasters to improve network planning for new digital broadcasting services in urban areas which concentrate the major part of the listeners.

The first important feature to take into account is the transmission frequency, that is, frequencies at lower part of the band present clear advantages for medium wave urban propagation because different elements in the vicinity of the receiver, such as high buildings or narrow streets, cause lower impact over the ground wave propagation. The difference between 810 and 1260 kHz transmission frequencies could reach more than 15 dB in critical cases.

The long and short-term components of the received field strength have been separated. As far as the long-term is concerned, the extra attenuation caused by medium or narrow streets compared to wide ones depends on the urban environment features and could reach up to 10 dB if the transmission frequency is placed at the upper part of the medium wave band.

In the case of short-term variation it has been demonstrated that those occurrences represent at least the 10 % of the coverage area so, they should be taken into account in order to predict urban coverage areas at medium wave band. For that purpose an empirical field strength statistical characterization has been carried out. The major part of the fast variation occurrences lead to mean attenuations between 5 and 10 dB and show a variability of 2 dB, except for bridges and tunnels which lead to higher attenuation values.

Apart from that, the duration of the occurrences, in terms of distance has been pointed out for this kind of urban elements or fast variation occurrences which presented values between 20 and 30 meters in most cases.

It is necessary to say that all results presented in this paper have been validated with results obtained using the Generalized Lee Method. This method was specifically developed to achieve spatial variability parameters for different frequencies and reception environments.

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