External Noise Measurements in the Medium Wave Band

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Abstract—This paper presents an up to date study on external noise levels in the medium wave band based on field trials carried out in Spain and Mexico during years 2004 and 2005 respectively. External noise levels predicted by the ITU-R P.372 recommendation are based on measurements carried out more than 30 years ago and no updated results for the medium wave band have been published in this time. An increment on these noise levels have been measured, which leads to a significant impact on the minimum usable field strength requirements for the broadcasting systems used in this frequency band, such as the new Digital Radio Mondiale (DRM) and In-Band/On-Channel (IBOC) systems.

Index Terms—Noise, Noise measurement, Medium wave band, Field trials.

I. INTRODUCTION

This paper is the result of several studies on external noise levels measured within two extensive Digital Radio Mondiale (DRM) measurement campaigns carried out in Spain and Mexico [1]–[3] in the medium wave (MW) band. Digital audio broadcasting systems designed for the AM frequency bands like DRM [4]–[7] and In-Band/On-Channel (IBOC) [8] have revived the interest in the MW band and the need for updating the studies related to MW broadcasting.

External noise level is a very important parameter when establishing the minimum reception requirements for a broadcasting system. If the external noise level is greater than the internal noise floor of the reference receiver, the minimum field strength requirements will be significantly affected.

Current external noise level values for the MW band provided by the ITU-R P.372 recommendation [9] are based on measurements carried out more than 30 years ago [10]. As concluded in P.372 recommendation, the noise level in MW is mainly due to man-made noise (MMN). Human activities that produce electromagnetic noise, such as vehicle traffic, have increased in these 30 years, so it is sensible to think that the external noise levels in the MW band have also increased.

Since that time, no comprehensive man-made noise power measurements have been carried out [11]. It is during the last years when the need for updating those noise values has become evident, and new external noise measurements have been made especially in the VHF and UHF bands [11], [12] and also in the short wave (SW) band [13]. However no new external noise measurements have been carried out in the MW band.

The aim of the study presented in this paper is to make a first approach to up to date external noise levels and their behavior in the MW band. Supported by the external noise level measurements carried out in [1]–[3] a study based on the one presented in P.372 recommendation is done in order to:

- Obtain median values of external noise levels.
- Characterize the spatial variation of these median noise levels.
- Characterize the time variation of these median noise levels.

II. NOISE MEASUREMENT BASIS

A. Measurements in ITU-R P.372

ITU-R P.372 recommendation [9] is based on measurements carried out in six states of the United States of America over the period from 1966 to 1971 [10]. Those measurements were taken using a two meters length short vertical passive monopole antenna over a ground plane. Measurements were taken every ten seconds on eight different frequencies: 250 kHz, 500 kHz, 1 MHz, 2.5 MHz, 5 MHz, 10 MHz, 20 MHz, 50 MHz.

The parameter used to characterize the external noise level was the external noise factor defined as:

\[ f_a = \frac{p_n}{k \cdot t_0 \cdot b}, \]  \hspace{1cm} (1)

where \( p_n (W) \) is the available noise power at the output terminals of the antenna, \( k \) is the Boltzmann’s constant (1.38 \( \cdot \) \( 10^{-23} \) J/K), \( t_0 (K) \) is the reference temperature taken as 290 K, and \( b (Hz) \) is the noise power bandwidth of the receiving system. The noise power bandwidth used in those measurements was 4 kHz, although the use of a larger one was recommended [10].

It is more common to use the noise figure, which is the noise factor expressed in dB as:

\[ F_a = 10 \cdot \log(f_a). \]  \hspace{1cm} (2)

In those measurements if the recorded value of \( F_a \) was within 0.5 dB of the internal noise floor of the system, it was discarded. If the recorded value was more than 0.5 dB but less than 6 dB above system noise, the reading was corrected. Values more than 6 dB above the system noise were accepted directly.

UPV/EHU is an associated member of the DRM Consortium since December 2001 and takes part actively in different groups of the Technical Committee.
B. New Measurements in Spain and Mexico

External noise measurements carried out in Spain and Mexico have been taken using short vertical monopole active antennas over a ground plane. These antennas have been calibrated, so the noise power level at their output terminals can be converted to a field strength value using the antenna factor as:

\[ E_n(\text{dB} \mu\text{V/m}) = P_n(\text{dB} \mu\text{V}) + K(\text{dB} \text{m}^{-1}) \],

(3)

where \( E_n \) is the external noise field strength level and \( K \) is the antenna factor.

Once the external noise field strength level is known, the noise figure that would have been measured by a short vertical passive monopole antenna as the one used for ITU-R P.372 measurements can be obtained as [9]:

\[ F_a = E_n - 10 \cdot \log(f_{MHz}) - B + 95.5, \]

(4)

where \( f_{MHz} \) is the center frequency and \( B = 10 \cdot \log(b) \).

External noise measurements in Spain and Mexico were recorded every 400 ms and using a 400 ms integration period (which is the duration of a DRM frame). The noise power bandwidth used was of 9 kHz and 10 kHz in Spanish and Mexican measurements respectively. The working frequency was 1359 kHz for the case of Spanish measurements and 1720 kHz for the case of Mexican measurements. All external noise measurements were carried out on fixed locations.

Measured external noise values were at least 15 dB above the internal noise floor of the system, so no measurement correction was necessary.

III. Measurements in Spain

A. Measurement System

The measurement system used for Spanish measurements has already been presented in [1] and [2], so just some considerations related to noise measurement are presented here. A scheme of the system used for external noise measurements is depicted in figure 1. The acquisition and distribution section captures the external noise signal and distributes it to the measurement equipment. The measurement section consists on a field strength meter, which makes precise level measurements, a spectrum analyzer, which continuously captures traces of the spectrum in the desired channel, and a DRM receiver which provides the 400 ms measurement trigger as well as making redundant signal level measurements. All these equipment is controlled by a specifically designed software running on a laptop which also stores the coordinates of the measurement location obtained from a GPS.

A special configuration of the field strength meter was used to make precise external noise level measurements. This configuration consists on deactivating its 10 dB input attenuation and activating an input preamplifier of 20 dB. This was enough to reduce the internal noise floor of the system more than 15 dB below the minimum value measured for external noise level.

Antenna selection turned to be another key factor in order to achieve good measurement results for both signal and noise, especially in urban environments. Three antennas were considered:

- A short monopole active rod antenna. This antenna has been calibrated by the manufacturer and has a very stable antenna factor in the frequency range from 100 kHz to 100 MHz. Its noise figure has also been measured by the

![Measurement system used in Spanish external noise measurements](image-url)
manufacturer and, for the MW band, it is at least 10 dB lower than the lowest value expected for man made noise obtained from P.372 recommendation.

- A magnetic transfer passive helical antenna. Passive antennas do not suffer from amplification effects but provide lower signal levels. These levels will be closer to the measurement equipment internal noise floor.

- A modification to the short monopole active antenna. A 40 MHz low pass filter was used before its internal amplifier, thus filtering signals out of the AM band. This low pass filter modification has been measured with a network analyzer. The influence of this modification in the antenna frequency response is lower than 1 dB for the working frequencies. This is depicted in figure 2.

The wide frequency response of the original active antenna has a big counterpart since FM transmissions up to 100 MHz are also amplified. This contributes to saturation effects in the antenna amplifier, which result in antenna saturation noise. This situation arises in environments with high signal power out of the AM band, such as FM transmissions in urban environments.

Figure 3 shows an AM spectrum measured with the antennas presented above in a noisy environment. In this figure the antenna saturation effect is clear for the original active antenna. The antenna with the 40 MHz filter, on the contrary, does not suffer from this saturation noise and amplifies both signal and noise levels above the internal noise floor of the measurement equipment. The difference between the peak values measured by the active antennas is due to the saturation effect of the non-modified one, which distributes part of the signal power along the full bandwidth. The passive antenna logically also avoids saturation noise, but gives signal values closer to the measurement equipment internal noise floor.

Thus the antenna finally chosen for the measurement campaign has been the modified one.

**B. Measurement Locations**

An initial set of 43 measurement locations were selected both inside and outside Madrid city. In 27 of these locations the antenna amplified the signal level several dB in all the frequency band. This effect always happened in the same locations and was related in many occasions with the presence of power distribution lines. Taking this into account, only the locations with the lowest noise levels were taken as valid, leading to conservative results in the study. This situation is depicted in the histogram of figure 4.

The resulting set of measurement locations is not large enough to make separate studies based on different reception environments, but it suffices for a first conservative approach to general external noise levels in Spain.

Figure 5 shows the distribution of the measurement locations both inside and outside Madrid city, and figure 6 shows a typical measurement location in Madrid city.

Locations selected inside Madrid city were mostly residential locations with buildings of less than 10 floors. Locations selected outside Madrid city were located in service areas near the main motorways or at the sides of secondary roads.
IV. MEASUREMENTS IN MEXICO

A. Methodology

Mexican external noise measurements were carried out in a very similar way to the Spanish ones, but with the following differences:

- A noise power bandwidth of 10 kHz was used instead of the 9 kHz one used in Spain. This is because that is the canalization used in Mexico for MW services. This is not a meaningful difference for the noise figure study.

- A new version of the professional DRM receiver was used for field strength measurements instead of the field strength meter used in Spain. This DRM receiver makes an average during approximately 4 seconds in the field strength level, so the variation with time measured for the external noise level is smaller.

- A different active rod antenna was used. This new antenna did not show the behavior observed in the one used for Spanish measurements, so no antenna modifications were made. In order to validate this assumption, the signal field strength level measured by this new antenna was compared in different points with the approximated field strength level measured by the passive antenna, and similar values were obtained.

The resulting measurement system is thus a simplified version of the one already depicted in figure 1 for the case of Spanish measurements. The measurement section now consists on an updated version of the professional DRM receiver, and the power splitters used in the distribution section are no longer necessary.

V. MEASUREMENT LOCATIONS

For this study, a total amount of 30 locations were chosen along different radial routes inside Mexico D.F. From this set of measurement locations, only 2 have been removed from the study. One of these locations was placed in a trolley bus station and the other one between two high power distribution pylons. The distribution of these measurement locations is shown in figure 7.

It is necessary to remark the massive presence of cable lines (telephone, power distribution, etc.) connecting different buildings and crossing above the roads. A clear example of
this situation is shown in figure 8 and a more common case is shown in figure 9. This situation is very common in Mexico D.F. and thus all the measurement locations have been rated as the noisiest case considered in P.372 [9].

VI. RESULTS

A. External Noise Levels

Table I shows the mean values of the external noise figure and its associated noise field strength level resulting from the whole set of median noise levels of each measurement location. These values have been obtained for the 1359 kHz working frequency for the case of the Spanish measurements and for 1720 kHz for the Mexican measurements. For the case of P.372 prediction, a distinction between different reception environments is made, so a range of values corresponding to the extreme cases is provided.

From this table it is concluded that a big increment in the external noise level has been measured in both Spanish and Mexican campaigns in relation to the values predicted by P.372 and based on measurements carried out more than 30 years ago. This increment is, in the best case, of 10 dB for the case of Spanish measurements and of 40 dB for the Mexican ones.

An increment in the external noise level was expected since human activities (such as vehicle traffic) that generate external radio noise have increased in these 30 years. As shown in figures 8 and 9, Mexico is a very noisy city which is translated into the value resulting from external noise measurements.

The 30.5 dBµV/m and 59.5 dBµV/m values measured for external noise level are higher than the 24.5 dBµV/m internal noise floor value of the MW reference receiver specified in the ITU-R BS.703 recommendation [14]. Therefore external noise level displaces the internal noise floor in the minimum field strength requirement calculation. The result is an increment of at least 6 dB in the field strength requirements for the reception of services in the MW band and should be taken into account when designing broadcasting networks.

B. Variation with Location

Figures 10(a) and 10(b) represent on a Gaussian paper the variation with location of the median values of external noise levels for Spanish and Mexican measurements respectively. This variation is approximately Gaussian as expected from P.372 recommendation.

In order to characterize this variation with numeric parameters, P.372 recommendation uses the standard deviation ($\sigma$) of the median $F_a$ values and the deviation of their upper ($D_u$) and lower ($D_l$) deciles in relation to the median value. Table II summarizes the P.372 values for these parameters and the values obtained from these Spanish and Mexican field trials.

From this table it can be seen that the variation with location of the external noise level measured in these campaigns is smaller than the one predicted by P.372. This variation would probably result in higher values in an extensive external noise measurement campaign with a larger amount of measurement locations.

Both Spanish and Mexican measurements show that the observed behavior is not as Gaussian as the theoretical behavior considered for obtaining the $D_l$ and $D_u$ values in the predictions of the P.372 recommendation, as shown by the deviation of the lower decile which is bigger than the deviation for the upper one. This means that there is a bigger variation in the external noise levels between low noise environments than between noisy ones.

C. Variation with Time

In general, the variation with time measured for the external noise level within a given fixed location accords with the one
TABLE II

VALUES OF NOISE DEVIATION WITH LOCATION

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ITU-R P.372</th>
<th>Spain</th>
<th>Mexico</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma$ (dB)</td>
<td>2.3 – 7.1</td>
<td>1.0</td>
<td>2.5</td>
</tr>
<tr>
<td>$D_L$ (dB)</td>
<td>5.8 – 8.4</td>
<td>1.9</td>
<td>4.8</td>
</tr>
<tr>
<td>$D_u$ (dB)</td>
<td>5.8 – 8.4</td>
<td>1.1</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Fig. 10. Variation with location of the median noise levels

Fig. 11. Variation with time of the noise level

TABLE III

VALUES OF NOISE DEVIATION WITH TIME

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ITU-R P.372</th>
<th>Spain</th>
<th>Mexico</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma$ (dB)</td>
<td>–</td>
<td>0.9</td>
<td>0.4</td>
</tr>
<tr>
<td>$D_L$ (dB)</td>
<td>4.6 – 6.7</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>$D_u$ (dB)</td>
<td>9.2 – 11</td>
<td>1.2</td>
<td>0.4</td>
</tr>
</tbody>
</table>

The numeric parameters characterizing this variation with time for the whole set of Spanish and Mexican locations are summarized separately in table III.

Table III shows that the variation with time obtained from the measurements is much lower than the one predicted by P.372. This is due to time constraints of these measurement campaigns. The measurement interval used in each location is of three minutes, while the one used for P.372 measurements is of one hour. In the case of the Mexican measurements, there is also a 4 seconds average carried out by the DRM receiver. However, these values can be used as an indication of the short term variation of noise with time.
From this table it is also concluded that the deviation of the upper decile is bigger than the one of the lower decile. This is due to contributions to the noise level of external agents like vehicle traffic passing near the mobile unit. Later measurements carried out by the authors of this paper in Bilbao (Spain) using the same measurement system as the one used for Madrid measurements have confirmed this assumption as it can be seen on figure 12.

![Noise level vs Time](image)

**Fig. 12.** Effect of vehicle traffic on the noise level

This measurement corresponds to a measurement location with very dense vehicle traffic. In this figure the event of a motorbike passing near the measurement unit has been marked by a dotted line. It is clear the correlation between the presence of a motorbike and the occurrence of a noise peak. Similar tests were also made with cars and buses, but the correlation was not as clear as in the case of motorbikes.

**VII. CONCLUSIONS**

External noise measurements have been carried out within two DRM measurement campaigns in Spain and Mexico for the MW band during the years 2004 and 2005 respectively. These campaigns have showed that the measured external noise levels are high enough to lead to an increase of several dB in the minimum field strength requirements for the reception of services in the MW band.

A study on up to date external noise levels based on the set of measurements resulting from these campaigns have been carried out. This is the first comprehensive study on the external noise levels in the medium wave band carried out in more than 30 years. This study has confirmed the increase expected on external noise levels in relation to the values predicted by ITU-R P.372 recommendation. The increase measured is of at least 10 dB for the case of Madrid city and as high as 40 dB for the case of a extremely noisy city like Mexico D.F. The time and spatial variation of these noise levels has also been analyzed and agrees with the one expected from P.372.

From this study it becomes clear the importance of updating the external noise level predictions for the medium wave band and we recommend continuing making extensive external noise measurements. Today’s external noise levels are much higher than the internal noise floor of a MW reference receiver so they directly affect to the minimum field strength requirements for the reception of new services in the MW band, such as DRM and IBOC.

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