Experiments Concerning the Spectrum Structure Inside an Automotive EMC Laboratory

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***Abstract*—The electromagnetic environment has changed rapidly in the last decades: the density of pollution sources has increased exponentially. In this paper, a series of measurements inside an Electromagnetic Compatibility (EMC) laboratory are reported. Comparisons are made between measurements made in the usual frequency range used in EMC Automotive Testing: 200 – 3000 MHz. The differences that appear in different chambers are validated by using the noise power density. Noise measurement for the experimental setup is analyzed in detail, considering the contribution of the antenna, cable and pre-amplifier. An alternative method to find the spectrum part containing only noise is proposed.**

Keywords—spectrum analyzer; EMC laboratory; noise measurements; noise power density

I. INTRODUCTION

Users that wish to communicate by radio means encounter a huge increase in interference levels mainly due to man-made noise (MMN). MMN leads to a rise in noise floor and to the appearance of a large number of interfering signals. MMN can be characterized by several parameters like the power spectral density, the amplitude probability distribution, pulse spacing distributions, and pulse duration distributions [1], [2].

The revolution in communications and computing from the last decades, leading, among others, to the fifth-generation communications technology and Internet of Things, had an important impact on the spectrum structure and occupancy especially in industrialized, high density urban areas. The density of interfering sources has increased dramatically and the character of MMN has changed [1].

Current research on interference and MMN is mainly directed toward radio noise inside industrial premises, whose importance is set mostly by the ever-increasing number of devices [2], [3]. Many studies have been carried over in the last years for assessing the level of electromagnetic MMN in various frequency bands and geographical regions and comparisons have been made between urban, rural and remote areas. In MF, HF and lower part of the VHF band of the Amateur Radio Service, measurements showed that in city and residential environments the current ITU-R noise floor data have to be updated to cover the increased levels of the noise [1]. Also, the importance of reducing the measurement uncertainties is discussed. For example, the authors in [1] suggest that the use of a magnetic loop antenna instead of an E-field antenna would be more useful, because of large measurement uncertainties that could appear with the last one mentioned.

From [4] one can conclude that there are more spectrum opportunities above 1 GHz than below 1 GHz and there are more indoor than outdoor. The actual spectrum occupancy varies with frequency, time, location, detection threshold and system setting [4]. These initial results provide important guidance for further studies. The duty cycle statistic is effective in giving a general idea of the availability of different frequency bands. Also, complete statistical models for the spectrum occupancy are surveyed [5], [6]. These models are more useful for dynamic access and control of opportunistic spectrum [4]. The knowledge of radio noise level is the key element for estimate the spectrum occupancy, and both noise level and spectrum occupancy are fundamental in setup a radio communication using opportunistic techniques offered by Cognitive Radio in vehicular networks.

The variation in the signal spectrum over periods of several days to several weeks have been investigated in [7]. The measurements have been made between 20 MHz and 6 GHz, with a bandwidth resolution of 200 kHz. For the purpose of dividing the signal spectrum into 4 frequency areas, three different antennas were used. All 3 antennas were characterized by vertical polarization and omnidirectional character [7], [8]. The number of measured points was determined by means of the Agilent E4440A spectrum analyzer whose performance allowed for the measurement of a maximum number of 8192 points. Sweep time with a value of 1 s represented a compromise between computer resources and amount of data recorded over a week [7].

In this paper, setup and results of spectrum and MMN measurements inside a facility containing an Automotive EMC laboratory are reported. The paper is structured as follows. Section II presents the configuration setup used for

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measurements, such as type of antennas and measuring receiver, along with the settings of the equipment. Next, measurement results are reported, comparing the field inside and outside the EMC Laboratory. In Section III, noise estimation procedure and measured power spectral density examples are presented. Conclusions are drawn in the last Section.

II. Spectrum Occupancy Measurements

A. Configuration setup used for measurements

In this section, the configuration setup of the measurements is presented. The spectrum measurements were performed inside the Electromagnetic Compatibility (EMC) Laboratory from Continental Automotive Timisoara. The main objective of this study was to investigate the spectrum structure from the laboratory in order to evaluate the spectrum allocation. The general setup of the measurements is illustrated in Fig. 1.

The measurement setup consisted of a directional antenna, a spectrum analyzer and connecting RF cables. The antenna was a VUSLP 9111 B – Log Periodic type from Schwarzbeck. The antenna is broadband, designed for receive or transmit application in the frequency range of 200 ÷ 3000MHz. A Rohde & Schwarz ESR 7 Spectrum Analyzer was used for collecting the data recorded. The frequency capabilities of ESR7 Spectrum Analyzer are from 9 kHz to 7 GHz and it can detect signals in the range of -130 dBm to 30 dBm. In order to increase the sensitivity of the measurement of the signals, the internal pre-amplifier of the spectrum analyzer was used [7].

The choice to investigate the frequency range from 200 MHz to 3000 MHz is motivated by the fact that real-life signals most commonly operate therein [7]. This range was separated into two frequency sub-bands: the first one between 200 MHz - 1700 MHz and the second one between 1700 MHz – 3000 MHz. The resolution bandwidth (RBW) of Spectrum Analyzer was set to 100 kHz and the video bandwidth (VBW) of equipment was set to 1 MHz (due to operation of wireless systems, such as FM or GSM radio [7]).

The total number of measurement points investigated in this paper for the frequency range of interest was 8192, with a sweep time of 1s. The antenna was placed both in vertical and in horizontal polarizations.

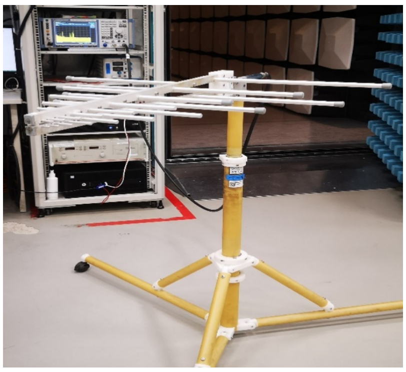

Fig. 1 Spectrum occupancy measurement system

B. Spectrum occupancy measurement results

The measurement results obtained from the spectrum analyzer have been processed off-line. The antenna factor for the VUSLP model given by the manufacturer and the correction for the cable losses have been considered.

Measurements have been performed inside the facility that contains the EMC laboratory and in a room near the laboratory. The following graphs report a comparison between results obtained inside (upper part of the figure) and outside (lower part of the figure). The measure of interest is the electric field expressed in dBuV/m. Firstly, Fig. 2 presents the results obtained when the Log Per antenna was vertically polarized, and measured in the first sub-band of interest: 200 – 1700 MHz. A more intense activity in the spectrum, especially at 400 MHz and 800 MHz (in the GSM area of interest) can be noticed in the lower part of the figure.

In the next plot, Fig. 3 the polarization of the antenna is maintained in vertical position, with measurement in the next sub-band 1700-3000MHz. Again, in the bottom of the figure a more intense electric field results in the frequency ranges: 1900 MHz (UMTS), 2100-2200 MHz (Wireless) and 2600-2700 MHz (LTE) can be noticed.

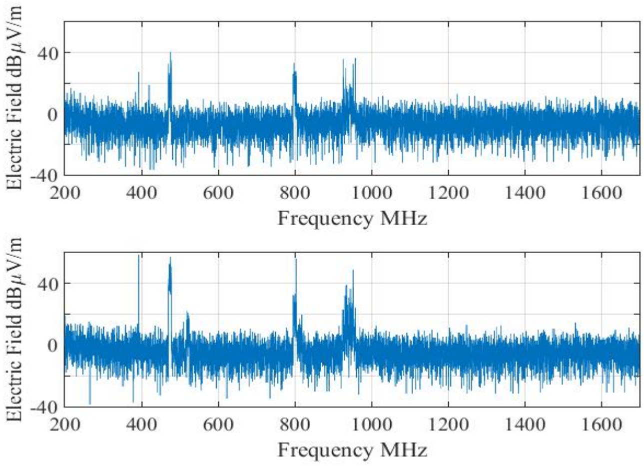

Fig. 2 Vertical polarization between 200-1700 MHz

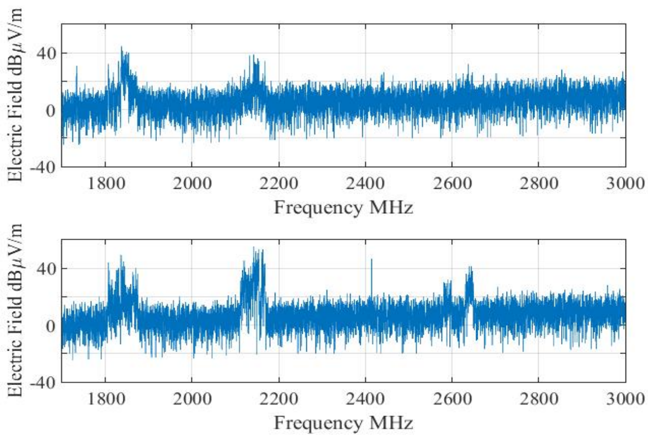

Fig. 3 Vertical polarization between 1700-3000 MHz

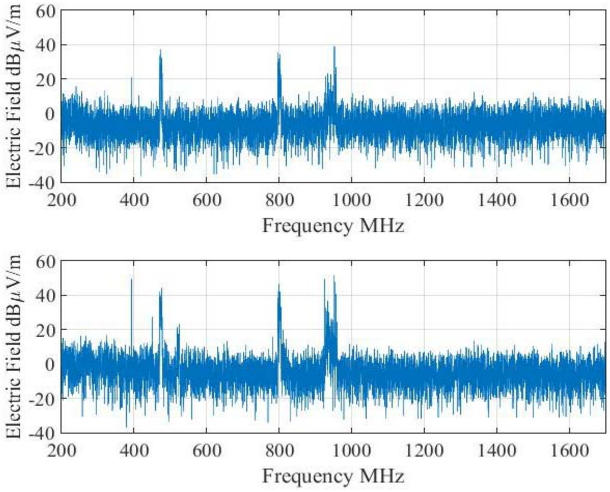

Fig. 4 Horizontal polarization between 200 – 1700 MHz

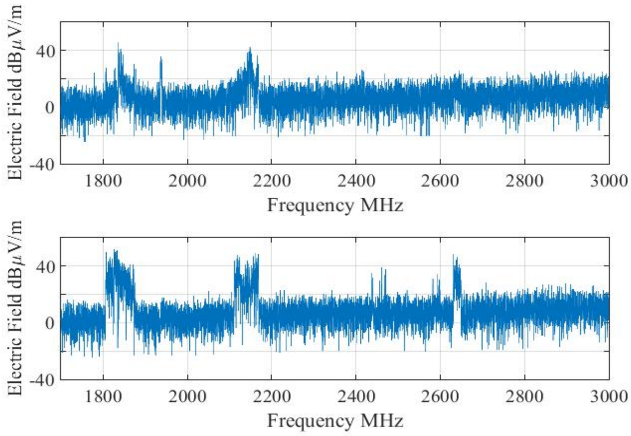

Fig. 5 Horizontal polarization between 1700 – 3000 MHz

Afterwards, Fig. 4 displays the result in which the polarization of the antenna is switched from vertical to horizontal, with measurement in the first sub-band as previously mentioned (200-1700MHz). A similar behavior to the one in Fig. 2 can be noticed, with an increased activity also in 800-900 MHz band.

Finally, in Fig. 5, the second sub-band (1700-3000MHz) and again horizontal polarization with similarities to Fig. 3 is presented. Again, in the band of UMTS, Wireless and LTE, a more intense presence in the lower part of the plot can be noticed.

III. Noise Measurements

An increase in background noise floor affects modern radio communications. This noise, due to man-made noise and a large variety of electromagnetic interferences, overcomes other noise sources, such as cosmic noise or atmospheric electrical phenomena.

Measuring radio noise in practical applications can be significant for radio environment characterization and different type of radio link planning.

A. Noise measurement analysis

The noise measurement experimental setup is presented in Fig. 6. It consists of an antenna with frequency dependent gain G_A, power antenna factor A and noise temperature T_A (all quantities are expressed in linear units in this sub-section). The cable has a power loss L and, as known, a noise factor $F=L$. The preamplifier entering the structure of the spectrum analyzer (SA) has a power gain G_A and a noise factor F_1. The gain is supposed sufficiently large to make the SA noise factor F contribution in the chain negligible. We consider further that the gain G_A includes the SA gain G.

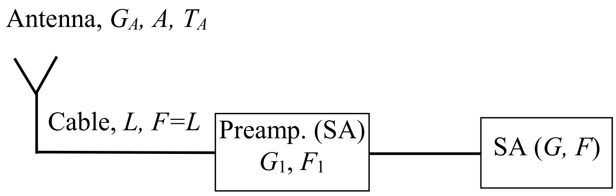

Fig. 6 Noise measurement setup

We denote by N (W/m^{2}Hz) the surface power spectral density received by the antenna, the target of the measurement. By denoting by B the noise bandwidth, the total power at the antenna outputs reads (k being the Boltzmann constant):

$$N_A = \frac{NB}{A} + kT_A BG_A \quad (\mathrm{W}) \tag{1}$$

Between the noise factor F and the noise temperature T there exists the relation:

$$T = (F-1)T_0, \quad T_0 = 290 \text{ K} \tag{2}$$

We apply now the Friis formula to obtain the equivalent noise temperature of the cascade cable-preamp as follows:

$$T_{eca} = T_{ec} + \frac{T_{ea}}{\frac{1}{L}} = (F_1 L - 1)T_0 \tag{3}$$

The noise power at the output of the measurement chain (at room temperature T_0) can now be readily obtained as:

$$N_P = \frac{NBG_1}{LA} + \frac{kT_A BG_A G_1}{L} + k\frac{F_1 L - 1}{L} T_0 BG_1 \quad (\mathrm{W}) \tag{4}$$

The SA reading includes the gains, so that the actual measured value is $N_{Pm} = N_P / G_1 \quad (\mathrm{W})$.

We can now solve for the surface power spectral density:

$$N = N_{Pm}\frac{LA}{B} - kA\left(G_A T_A + \frac{F_1 L - 1}{L}T_0\right) \quad \left(\frac{\mathrm{W}}{\mathrm{m^2 Hz}}\right) \qquad (5)$$

If $G_A T_A << \left(F_1 - \frac{1}{L}\right)T_0$, (5) can be further simplified, making unnecessary the knowledge of the antenna parameters G_A and T_A.

For the noise bandwidth B, the SA resolution R can be used as an approximation. However, in general, the noise bandwidth is slightly larger than the 3-dB bandwidth.

B. Noise measurement results

Noise measurement require an adequate measuring method, the assumption that noise is Gaussian and that some part of time-frequency window do not contain any intended distinguishable transmitters [9]. Selecting a proper frequency for noise measurement can be a difficult task specifically on highly occupied parts of the spectrum.

The proposed method in [9] consider a sorted signal samples and that the noise samples are lower as the samples containing some transmitted signals.

To find the part of the spectrum containing only noise, we used an analysis in frequency domain: the signal bandwidth is split into N sub-bands of bandwidth B and for each sub-band the mean power is computed. It can be assumed that the smallest power sub-band contain only noise.

To highlight the influence of the measurement bandwidth on the measured noise level, Fig. 7 plots the measured noise power density converted in electric field using antenna factor against the number of points N for two signals.

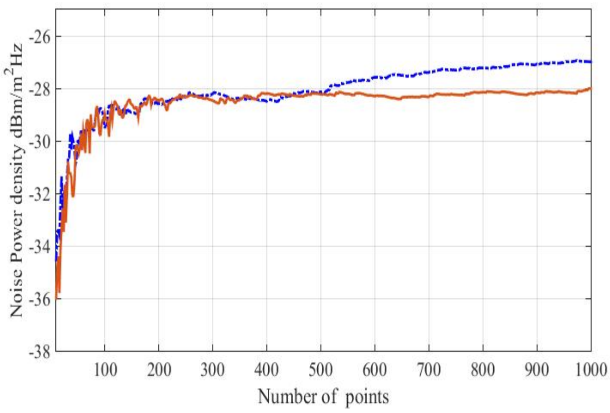

Fig. 7 Noise level function of number of measure points

A small variation less than 1 dB is observable for a signal having small occupancy degree (red in Fig. 7), while a signal with a higher occupancy degree has a larger variation for high bandwidth (blue in Fig. 7).

IV. CONCLUSIONS

In this paper, measurement equipment setups and spectrum occupancy results inside an EMC laboratory have been presented in order to study the influence of man-made noise. The study was motivated by the fact that an increased background noise affects radio communications.

Measurement results inside and outside the EMC laboratory have been reported and the differences have been validated by using noise power density technique. An analysis of the noise estimation power spectral density setup by taking into account the contribution of the antenna, cable and the pre-amplifier has been proposed. A procedure for estimating the noise power density from acquired data containing signals and noise has been described.

The proposed equipment and techniques will be used in the future in longer term measurement campaigns.

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