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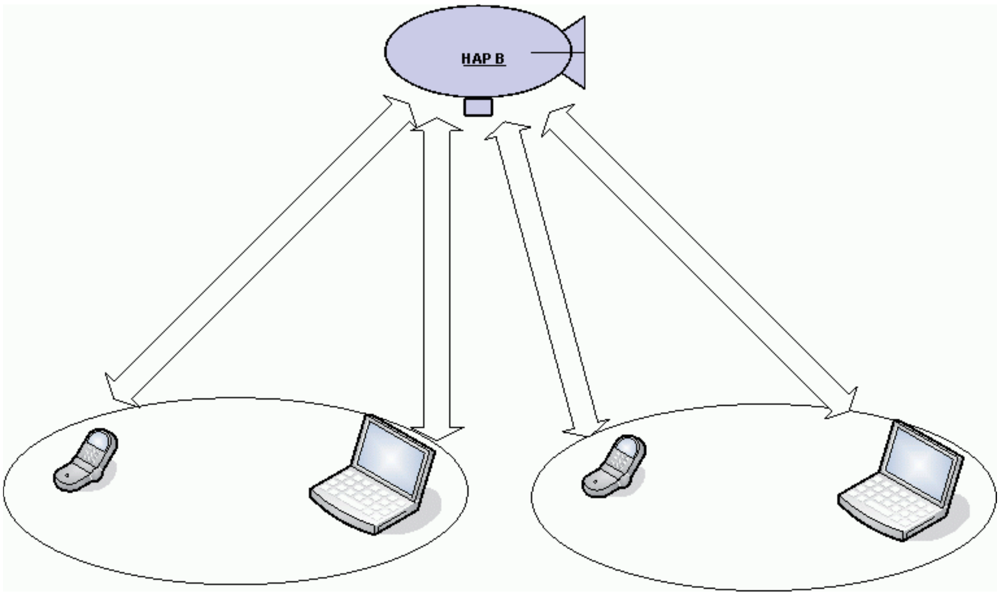

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Man-Made Noise in Our Living Environments

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Abstract

The ITU's (International Telecommunication Union's) man-made noise levels are based on measurements performed in the 1970s. Some measurements have been carried out since then, showing that noise caused by automotive ignition systems has been reduced, but man-made noise in business areas and city centers increased, especially due to the widespread use of electronic systems. The interference scenario also changed, from analog communication systems in relatively free-space conditions, to digital systems in living areas, often semi-enclosed such as offices, industrial production plants, and even inside cars and trains. Several measurements have therefore been carried out to estimate the level of man-made noise in these semi-enclosed environments.

1. Introduction

The knowledge of the electromagnetic ambient or radio noise is of particular interest in planning and setting up wireless systems, and for estimating the risk and impact of electromagnetic interference (EMI). Radio noise external to the radio receiving system is derived from either natural sources – such as atmospheric, galactic noise, and lightning – or unintended radiation from electrical and electronic equipment, power lines (including railway systems), and internal-combustion engines. This unintended radiation is called man-made noise (MMN). It is assumed to comprise two dominant and distinct components: white Gaussian noise (WGN) and impulsive noise (IN) [1-4]. The impulsive noise is further classified into Class A and Class B, these two classes respectively being narrowband (with respect to the receiver's bandwidth) and broadband. Class B is typically made up of wideband pulses, often caused by ignition circuits, lightning, and switching elements causing spark gaps. However, it is important to recognize that the distinction between white Gaussian noise and impulsive noise is based on statistical models. The widespread use of all kinds of electronic systems creates noise levels that are often a combination of both white Gaussian noise and impulsive noise.

The levels for radio (including man-made) noise are usually taken from ITU-R 372-8 [5]. The atmospheric-noise figures are taken from CCIR 322 [6]. The levels in these documents are based on measurements made in the 1960s and 1970s in the United States [7, 8], although the update rate of the ITU document suggests including new information ("-8" version). Technology changed considerably in the last decades, as well as the use of wireless systems. An example of the change in utilization of the ether is the widespread use of wireless systems for monitoring data and control in wireless-local-area networks and in industrial environments. Some measurement campaigns have been carried out to update the man-made noise levels as reported in [7], and a short overview of the results is presented in the next section.

It is remarkable that nearly no data is available on the EM ambient levels in semi-enclosed environments. Semi-enclosed environments are industrial sites, such as production plants, offices, houses, and even include cars, trains, or planes. Wireless communication systems are being used in these semi-enclosed environments, while the interference model is based on the conventional assumption that free-space radio-communication systems have to be protected. The interference case will be discussed in Section 3. Measurements have been carried out to characterize the EM ambient levels in industrial environments. The results are presented in Section 4.

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2. Man-Made Noise

The basic document for describing radio noise is ITU-R-P.372 [5]. It gives the external noise figure,

$$F_a = 10\log f_a \quad [\text{dB}], \qquad (1)$$

where f_a is the noise factor, defined as

$$f_a = \frac{p_n}{kt_0 b}. \qquad (2)$$

p_n is the available noise power from an equivalent lossless antenna; k is Boltzmann's constant (1.38×10^{-23} J/K); t_0 is the reference temperature (K), taken as 290 K; and b is the noise-power bandwidth of the receiving system (Hz).

In the case of man-made noise, we have to convert measured field strength in a measuring bandwidth to the noise figure, F_a. The power in a matched receiver due to a measured electric field strength, E, is

$$P_r = SA = \frac{1}{2}\frac{\left|\hat{E}\right|^2}{\eta_0}A_e, \qquad (3)$$

with

$$A_e = \frac{\lambda^2}{4\pi} \qquad (4)$$

for an isotropic antenna with unit gain and no losses. The noise power in an equivalent lossless antenna can thus be replaced by the man-made noise as measured. Converted to logarithmic units, the noise figure related to the field strength, E_n, of the noise, measured with a bandwidth b, becomes

$$F_{aM} = E_n + 95 - 20\log f_{\text{MHz}} - 10\log b \quad [\text{dB}]. \qquad (5)$$

Probabilistic descriptions of the received noise waveform are required to determine system performance and the amplitude probability distribution (APD) (exceedance probability) of the received envelope that is used. The most important minimum expected median values of F_a are shown in Figure 1. The average of the upper-decile deviation of the man-made noise in business, residential, and rural environments is approximately 10 dB (depending on time and location), measured in the 1970s. Data is available only for the business area between 200 MHz and 900 MHz, which is also shown in Figure 1. In the HF range, the background noise is the ambient noise in the external environment, i.e., the atmospheric noise. In the VHF and UHF ranges, it was assumed to be the receiver noise, but it later appeared to be the galactic noise. This level was exceeded by man-made noise. In 1970s, a significant component of man-made noise in VHF was due to ignition impulses from motor vehicles.

Since the publication of the radio noise levels in CCIR 322 and ITU-R-P.372, several experiments have been carried out [7-32] (listed on publication date). It is not the intention to be complete, but to determine the trends. Measurements performed in business areas of Montreal and Ottawa, and in residential areas of Ottawa, were described in [10, 13]. These showed that there has been no significant increase of the manmade noise, but even a decrease in the noise level, caused in part by the practice of using buried

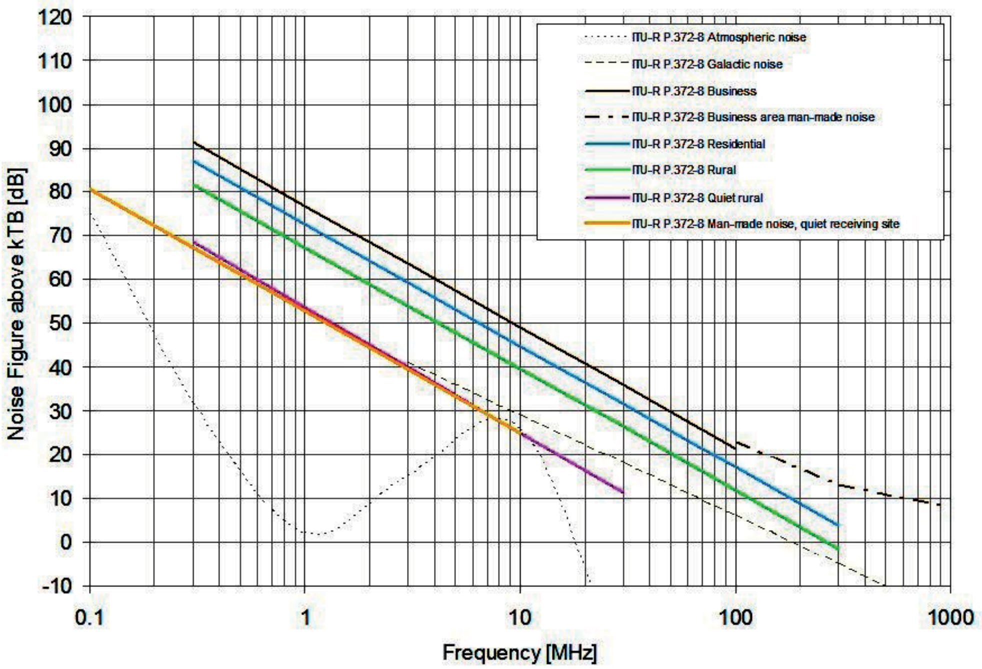

Figure 1. The minimum expected median values of F_a.

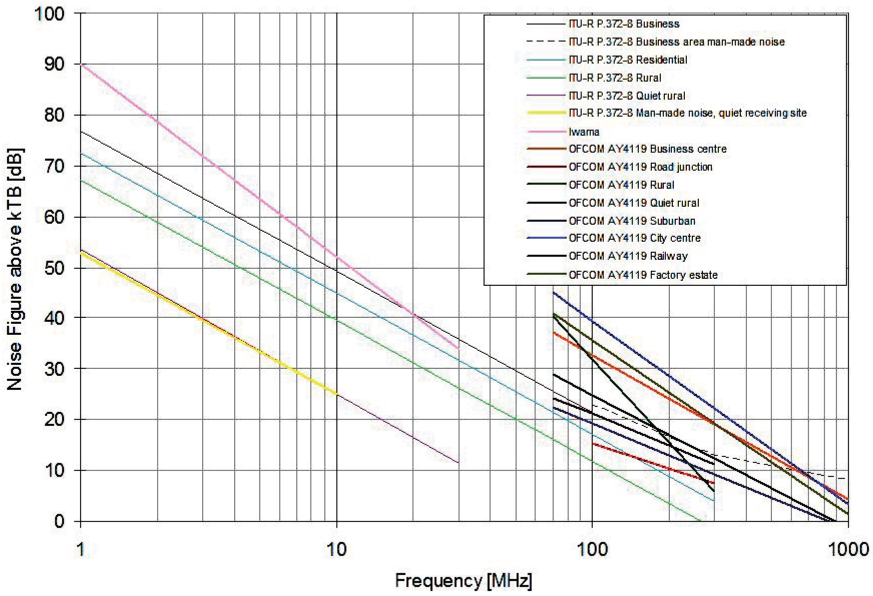

Figure 2. Recent results for the minimum expected median values of F_a.

power lines rather than overhead power lines. In [14], it was stated that the CCIR methods may have been made inaccurate by technological advances. For example, newer automotive ignition systems radiate less noise, but personal computers capable of producing considerable noise have become ubiquitous in business and residential environments. This was confirmed in [15], where measurements showed that automotive noise was no longer a significant VHF noise source, but that computers were found to be capable of generating a significant amount of noise. A follow-up report on man-made noise-power measurements at VHF and UHF frequencies [18] concluded that 402.5 MHz UHF noise levels in business areas were high enough to adversely affect communication-system performance some of the time. This report also remarked that more measurements were needed to determine the extent of these high noise levels.

OFCOM awarded a contract in 2001 for setting up a measurement facility for measuring the man-made noise in various areas [17]. Measurement results were published in 2003 and 2005 [20, 21]. One argument supporting the performance of these measurements was that the ITU measurements were performed in 1974, when digital RF systems were not widely deployed. Figure 2 gives the values for F_a for man-made noise. The decile deviations are approximately the same as stated in [5]. Man-made-noise data was collected in eight locations: a (large) city center, a factory estate, a business center, a town center, a shopping center/mall, a major highway, and suburban and rural locations, at mid-morning, evening, and rush hour (in relevant environments). The study concluded that the decreasing levels as a function of frequency were comparable with the ITU report, but that the overall level was substantially higher. The highest man-made noise levels were found at the city center, the factory estate, and the business center. The road junction showed lower results, which again showed the effectiveness of measures taken via European legislation to reduce the automotive-ignition noise.

Measurements in Sweden [25] showed lower noise levels than the ITU levels. This was true except for urban areas and the city of Stockholm, where the man-made noise was up to 15 dB higher. Iwama [32] showed a much higher man-made noise at lower frequencies in the HF region, decreasing faster in the UHF region. The resulting curve is also shown in Figure 2.

A NATO (North-Atlantic Treaty Organization) study group investigated the impact of widespread use of power-line communication (PLC) and digital data communication (xDSL: various forms of digital subscriber line) on HF communication links. HF communication is the backbone system for safety-critical services, including the armed forces [31]. This group concluded that the ambient noise was not changed in the last decades. To prove this, measurements were performed in rural areas in parts of the spectrum without any man-made noise interference, resulting in the atmospheric-noise levels. Real man-made noise will never be measured in this manner. However, their problem was the various suggestions made that man-made noise has increased. This argument was being used by power-line communication providers in a way that even more man-made noise could be allowed. Power-line communication, as xDSL, will cause unintentional RF emissions, which directly may increase the established noise floor nearby, or by cumulative propagation far away from multiple distributed sources. This type of emission is quite different from that produced by electronic devices and equipment: it is broadband noise, most of the time with a high level, and extending over the HF band. The incidental noise generated even by devices and equipment compliant with EMC standards can greatly exceed the existing noise floor, but due to the statistical nature of the incidental noise, reception of long-haul HF signals is still possible. These HF communication systems are opportunistic. If incidental noise prevents communication at any particular time, the transmission is repeated at a later time, when the interference has ceased. However, this protocol does not

Figure 3. The locations of the house and train track for the measurements in Figure 4.

work with a broadband noise floor increased by power-line communication and/or xDSL.

3. Interference Case

In the 1970s, the man-made noise was mainly due to ignition impulses from motor vehicles. This has changed to man-made noise due to the use of electrical equipment [15]. Especially in the VHF range, computers were found to be capable of generating a significant amount of noise in this band [18].

Most existing radio receivers are designed for the case of additive white Gaussian noise (WGN), and their performance may deteriorate in other scenarios, for example, when subjected to impulsive noise [25]. In rural environments, the man-made noise can be approximated as white Gaussian noise, but in urban and suburban environments, the man-made noise is often impulsive noise (IN). For digital communication systems, white Gaussian noise does not represent a major problem, as long as the mean power of the desired received signal is high enough. The impulsive noise is harmful for digital communications because each pulse may cause bursts of bit errors and possible loss of synchronization. In [19], the use of a root-mean-square was suggested for weighting the effects of disturbances on digital communication systems, instead of the conventional quasi-peak detector, as described in [33].

An extreme example of underestimating the man-made noise was the German toll project [34, 35]. Several billions of Euros were lost due to interference in GPS receivers in industrial areas and city centers, and the system had to be redesigned, causing a long delay without income (from toll).

The conventional detectors in electromagnetic-emission measurements are based on quasi-peak measurements, which is actually a filtering process, reducing the impulsive noise. The quasi-peak detector depicts the reduced noise impression of impulsive noise in analog radio systems. However, impulsive noise due to modern electrical and electronic systems can more easily disturb modern digital systems, as shown in [26, 27]. To confirm this assumption, a test was performed in the digital terrestrial broadcast band (DVB-T), around 850 MHz, in a house in a suburban area in Spain near to a train track, as shown in Figure 3. The received signal is shown in

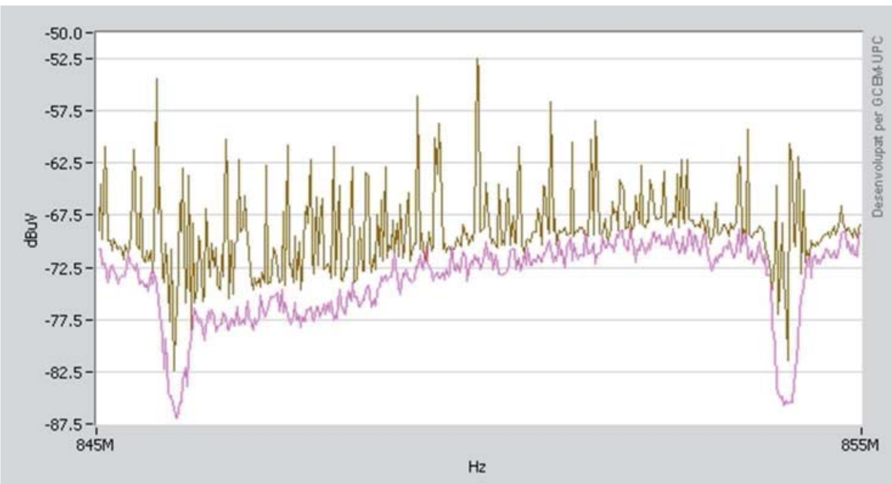

Figure 4. The DVB-T signal received in the house: (lower curve) the correct signal, (higher curve) with interference from the train.

Figure 5. The interference due to man-made impulse noise.

Figure 4. The passing train disturbed the DVB-T reception. The interference was repeated in the lab, and the effect is shown in Figure 5.

Another key issue is the classic interference case. This assumes a source of noise on the road, or from a neighbor, which interacts with the wanted signal received with an antenna placed on the rooftop of a building, as shown in Figures 6 and 7, respectively.

In our modern living environment, many electronic systems are used, including modern wireless communication systems. A huge increase of wireless control systems can be observed, especially in the transport sector, from the wireless bridge-control systems on large cruise liners, to the next-generation passenger planes, where fly-by-wire could be replaced by wireless. However, many wireless systems are already in use in industrial production plants, and many interference problems have had to be solved.

Figure 6. A classic interference case, from a neighbor to your aerial (cartoon by Rupert Besley).

Figure 7. A classic interference case, from the environment (cartoon by Rupert Besley).

Wireless data transmissions – for instance, in the 433 MHz band – are already disturbed, and the coverage of digital video broadcast services (DVB-T) and Tetra (400 MHz) is much lower than predicted in these environments.

A key problem is the limited knowledge of man-made noise in these semi-enclosed problems. In [15], it was stated that further study was needed to determine how narrowband noise power from computers and other electronic devices within a building would impact a receiving antenna mounted on or near an office building. In [18], the conclusion was that more measurements were needed, especially to make future measurements inside of buildings and vehicles.

An additional issue is the multiple reflections inside semi-enclosed environments at VHF and UHF, where the wavelength of the noise is smaller than the dimension of the semi-enclosed environment. These multiple reflections erratically scatter man-made noise and radio waves, and interfere with or block wireless transmissions.

4. Ambient EM Survey in Semi-Enclosed Environments

IEC 61000-2-5 [36] provided some guidance for the characterization of the ambient electromagnetic levels under different circumstances. However, the electromagnetic environments inside transportation equipment, vehicles, trains, ships, and aircraft, are not described. The procedure to establish the ambient EM levels was described in [37]. However, there is almost no data available on the ambient EM levels in industrial environments. This is the

Figure 8. Some of the semi-enclosed, industrial environments where EM ambient surveys were performed.

case for both conducted and radiated ambient levels. The knowledge of the ambient noise is of particular interest in planning and setting up wireless data communication in industrial applications, and to estimate the risk and impact of electromagnetic interference.

Based on press reports, NIST (National Institute of Science and Technology, Boulder, USA) performed tests in manufacturing plants crowded with stationary and mobile metal structures, such as fabrication and testing machinery, platforms, fences, beams, conveyors, mobile

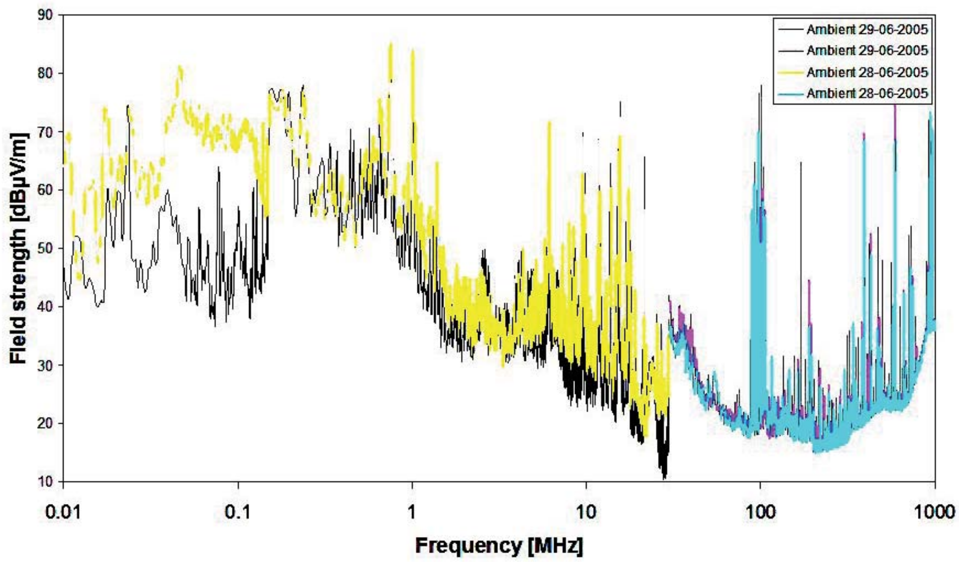

Figure 9. Some scans in semi-enclosed industrial environments.

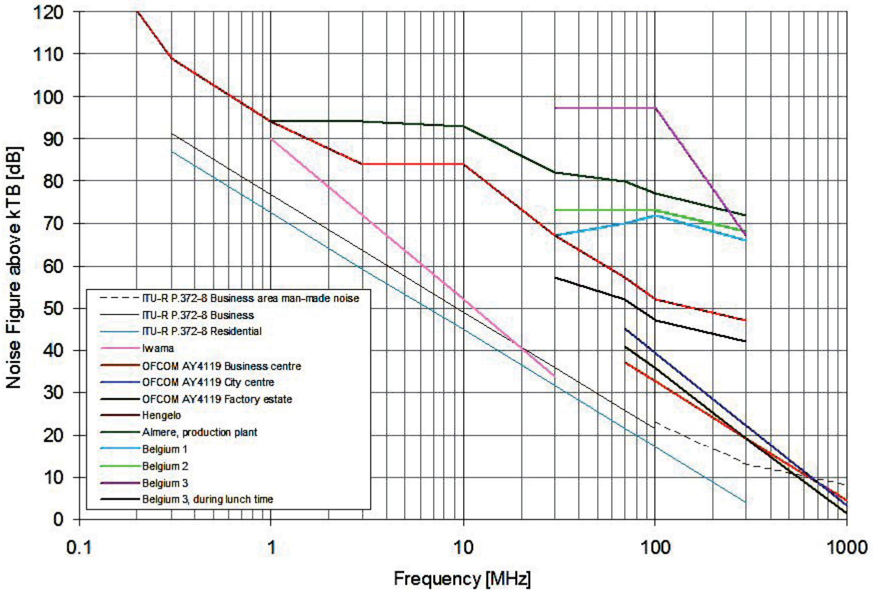

Figure 10. The noise levels in semi-enclosed industrial environments. The lines within the ellipsoid are the noise levels outside the buildings.

forklifts, maintenance vehicles, and automobiles in various stages of production. The survey showed that interference from heavy equipment could impair signals for wireless-data-transmission applications, such as those used in some controllers on the production floor.

Within the framework of COST 286, several institutes performed site surveys following [36, 37] in industrial environments, including KHBO Brugge-Oostende, Belgium; University of Liege, Belgium; University of Catalunya, Spain; University of Hannover, Germany; University of Twente, The Netherlands [23, 24, 26, 27, 28, 30, 38, 39]. These site surveys were not complete measurement sessions, and so had limited long-term monitoring and statistical evaluation of data. Measurements were performed in the HF, VHF, and UHF bands, using equipment and bandwidths as described in [33]. At microwave frequencies, electromagnetic interference due to man-made noise is often less than the interference caused by improper frequency management or the scattering of radio waves. These scatterings and/or multiple reflections cause multipath interference, where radio signals travel in multiple complicated paths from the transmitter to the receiver, arriving at slightly different times [40]. Pictures of some of the environments are shown in Figure 8. Hundreds of measurements were performed. Some scans are shown in Figure 9. Some noise-figure curves have been added based on the surveys, as shown in Figure 10. Some measurements have even been carried out inside machines [30]. Maximum field-strength levels have been measured but no noise figures, as shown in Table 1.

The difference in man-made noise levels looks enormous, and it is. The large increase is due to the high emission levels of machinery controlled by computers, frequency converters, and valves. These machines have to fulfill rather relaxed and high radiated-emission levels at distances of 10 m to 30 m. In the survey, we investigated the emission levels around these machines with measuring distances sometimes less than 2 m. One measurement was performed during lunchtime. Comparing the results, on average the man-made noise has decreased by 40 dB.

5. Conclusion

Man-made noise has changed in the last decades. Noise from automotive ignition has been reduced, but the man-made noise caused by electrical and electronic equipment increased in the conventional outside areas.

Type of Machinery	*Frequency Band [MHz]*	*Maximum Emission Level [dBμV/m]*
Frequency converter	*1-200*	*170*
Punch press	*1-1600*	*169*
CNC center	*1-400*	*169*
Laser cutting machine	*1-1700*	*162*
Weaving machine	*1-2000*	*156*
Welding machine	*1-50*	*140*
Computer	*1-150*	*138*

Table 1. Measurements made inside machines.

Most modern man-made noise is impulse noise, which causes more interference in digital systems than in the old analog systems.

Based on the survey and limited measurement data, we observed that inside semi-enclosed living environments, the man-made noise is much higher – 20 dB to sometimes more than 40 dB – than the baseline noise levels described in ITU-R P.372.

If new services are introduced in these environments, assuming the old man-made noise levels, then serious link problems will occur: many examples of EMI after the introduction of new services have been reported. The main cause of the high man-made-noise level is the conventional-interference case founded on the current electromagnetic-compatibility standards, which do not consider wireless communication systems operated in semi-enclosed environments.

The conclusions are based on the limited measurement data available. More research and measurements are needed to build up a statistically significant set of measurement data. The impacts of different bandwidths than the CISPR bandwidths, and other detectors (such as rms instead of quasi-peak), on interference in digital communication systems should also be investigated.

6. Acknowledgement

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