International Telecommunication Union

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Radiocommunication Sector of ITU

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(09/2009)

Man-made noise measurements in the HF range

SM Series

Spectrum management

International Telecommunication Union

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REPORT ITU-R SM.2155

Man-made noise measurements in the HF range

(2009)

1 Introduction, background

Radio noise from different sources introduce a certain unwanted background RF level at the input stage of any receiver that the wanted signals have to overcome for successful reception. Recommendation ITU-R P.372 defines the term radio noise as well as its different sources and states average values for each source separately. Below 1 GHz, noise from one or more of the following sources may be dominant, depending on the frequency:

- Galactic noise
- Atmospheric noise due to lightning
- Man-made noise (MMN).

In the HF frequency range we usually have a mixture of atmospheric and man-made noise, whereas in the VHF/UHF range man-made noise is dominant.

Atmospheric noise mainly originates from lightning. Its average values are well established and not likely to change considerably over a long time period. MMN, however, is the aggregated sum of all unintended emissions from multiple electrical and electronic equipment, including emissions from wired telecommunication systems such as powerline, local area networks, etc. The level of the MMN is heavily dependant on the density and nature of these noise emitting sources. It may also considerably change over several years. This Report shows practical ways to measure the MMN below 30 MHz.

Due to propagation, dense frequency occupation and the practical lack of lossless antennas, measurements of radio noise below 30 MHz are far more difficult than at higher frequencies.

An important part of radio noise is the MMN resulting from unwanted emissions of electrical and electronic devices. Emissions from each of these devices can be categorized as follows:

- *White Gaussian noise (WGN)*: Emissions that have a noise-like amplitude distribution with a bandwidth that is generally higher than the measurement bandwidth.
- *Impulse noise (IN)*: Emissions that are present only for a certain percentage of the time, usually consisting of pulse trains (bursts) of a limited, short duration and sometimes repeating at a certain rate (pulse repetition frequency or PRF).
- *Single carrier noise (SCN)*: Emissions with a more or less constant amplitude and a bandwidth that is smaller than the measurement bandwidth.

Recommendation ITU-R P.372 defines the MMN to be the sum of multiple emissions from an unknown number of sources. SCN is generally received from one single source only and as such excluded from the definition of MMN. When measuring radio noise, it has to be assured by means of selection of the measurement location and frequency, that this part of the MMN does not dominate the results. Whereas the aggregated sum of many sources emitting SCN and WGN quickly adds up to a WGN-like signal in the receiver, this is not true for many IN sources: In a long time recording of the MMN containing impulses from many hundred different sources, pulse characteristics will still be noticeable.

Recommendation ITU-R SM.1753 provides guidelines on measurement and evaluation of radio noise in all frequency ranges. This report describes in more detail noise measurements especially in the HF frequency range, including the evaluation of impulse noise and the separation of MMN and atmospheric noise. This approach corresponds to the "Type C" measurement in Recommendation ITU-R SM.1753. As an example, the report also describes the HF MMN measurement system used in Germany and results obtained with it.

2 Characteristic parameters of MMN

2.1 WGN

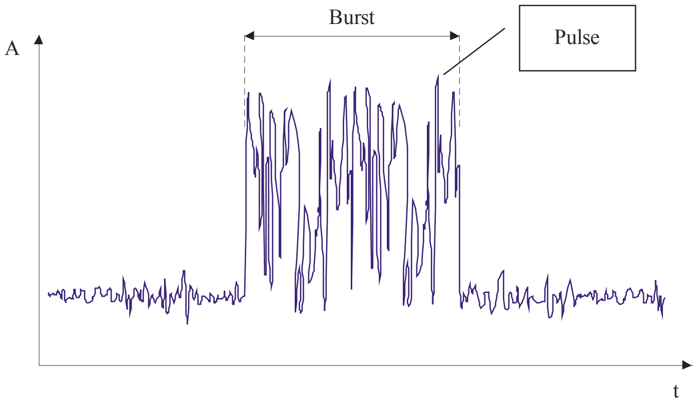
For WGN it is sufficient to measure the RMS level of the MMN, integrated over a sufficiently long time (e.g. 1 s). This is usually done by applying the RMS detector of the measurement receiver and recording the indicated results that can later be averaged over the desired time interval (e.g. 1 h).

2.2 IN

The typical amplitude vs. time function of real impulse noise sources is usually not rectangular. Instead, these sources emit a series of very short impulses that can be seen as bursts (see Fig. 1).

FIGURE 1

Level vs. time of a typical impulse noise source



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To characterize IN and its possible interference potential to radiocommunication receivers, the following parameters are of special interest:

- Impulse or burst level
- Impulse or burst length
- Impulse or burst repetition time
- Total impulse or burst time in percent.

Most of the above mentioned parameters can not be measured directly. Instead, the measurement equipment has to collect samples at a very high speed that are not weighted by a detector "raw data sampling". The IN parameters and their statistical distribution is later derived in the evaluation process.

3 Problems and solutions

Especially in the HF frequency range, we face the following major problems and suggest the following solutions:

a) No frequency can be found for the noise measurement that is free of wanted or intended emissions for the whole measurement time (usually 24 h) due to dense occupancy of the HF spectrum and reception of emissions from far away.

Solution: The measurement system has to select and change the measurement frequency automatically. Just before the actual measurement, a scan over the desired frequency range is done and the frequency with lowest level is used for the following measurement.

b) Atmospheric noise such as from lightning as well as some intended emissions, received through skywave propagation, may have the same characteristics as MMN and are difficult to identify. However, if only MMN should be measured, it is necessary to separate atmospheric from Man-made Noise caused by local sources.

Solution: MMN measurements are performed at two locations simultaneously (measurement and reference location). The distance between both locations is between 0.5 km and 10 km. The equipment is exactly time-synchronized. Characteristic waveforms that are detected at both locations are assumed to be received over the skywave and deleted from the MMN result by a correlation process.

c) Due to propagation, emissions especially from broadcast transmitters produce received signal levels that are more than 100 dB higher than the current MMN level. This will overload the sensitive measurement equipment and produce false results.

Solution: Band pass filters are used before the first amplifying stage of the measurement equipment. Especially the broadcast bands are suppressed by at least 20 dB relative to the attenuation in the desired measurement range(s). This also implies that no active antennas with built-in preamplifiers can be used because the preamplifier is always subject to overloading as it would be in front of the filter.

d) Due to propagation, the WGN level in each frequency range will depend on the time of day. It is therefore not sufficient to average the WGN results gathered over a whole day in one figure.

Solution: The measurement is done over 24 h. The results are averaged over one hour only; resulting is 24 WGN figures for each measurement.

e) Due to the long wavelengths below 30 MHz, a tuned dipole in a free space environment or any other lossless antenna as assumed in Recommendation ITU-R P.372 cannot be realized. A practical measurement antenna will not be able to transfer all available energy from the field into the receiver.

Solution: The average antenna factor is determined and used to correct the measurement values before the external noise figure is calculated.

4 Measurement equipment and setup

The following equipment is needed for MMN measurements in the frequency range below 30 MHz including IN.

TABLE 1

Basic measurement equipment and requirements

Part of equipment	Important requirements, remarks
HF antenna	Horizontal pattern: ND Example: short monopole on the ground with mounted radials Antenna factor at 5 MHz: ≤ 35 dB (1) Antenna factor between 12 and 30 MHz: ≤ 20 dB Feeder cable fitted with ferrites to suppress sheath waves
HF band pass to suppress broadcasting bands	Suppression ≥ 20 dB between 9-5 000 kHz, 5 600-12 000 kHz, 13 600-19 000 kHz, 21 500-30 000 kHz Passband attenuation ≤ 4 dB
Low noise amplifier	Minimun frequency range: 3-30 MHz Gain: ≥ 15 dB Noise figure below 10 MHz: ≤ 6 dB Noise figure above 10 MHz: ≤ 3 dB
Measurement receiver	FFT analyser or sweeping analyser Sampling speed: ≥ 20 kHz (2) Acquisition/sweep time: ≥ 1 s (3) Interface for live data transfer to computer RBW: 10 kHz (2)
Computer with control software	Set and control the measurement receiver Store data Provide time synchronization of equipment (4)

(1) The antenna factor denotes the conversion factor to be applied when converting antenna voltage to field strength.

It is usually given in dB and used as follows:

$$E = U + AF$$

where:

E : electrical field strength (dB(μV/m))

U : antenna output voltage (dB(μV))

AF: antenna factor (dB)

Note that for directive antennas only the average antenna factor, integrated over any possible azimuth and elevation angle, has to be used. When the noise sources are uniformly distributed, the noise power received by a directive measurement antenna and by a theoretical isotropic antenna will be the same. In this context, the average antenna factor is obtained by applying an appropriate correction for the antenna gain in the specific direction.

(2) The measurement bandwidth is oriented on the broadcast radiocommunication system below 30 MHz and its channel spacing which is DRM with a spacing of 10 kHz and a maximum bandwidth of 20 kHz. Using a wider RBW would reduce the chance of finding a free frequency for the measurement. The shortest pulse that can fully be captured by an RBW of 10 kHz is 2/20 kHz = 100 μs. In order to capture every pulse, the sampling speed has to be at least twice the RBW.

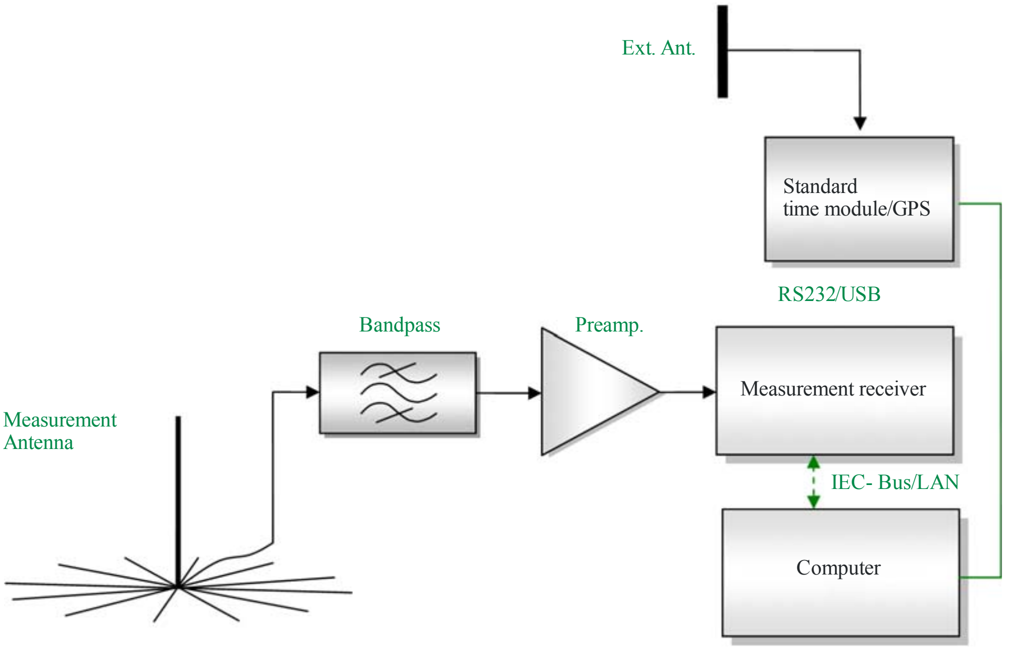
(3) The acquisition or sweep time of 1 s allows detecting pulse/burst repetition frequencies down to 2 Hz. Periodic emissions with lower repetition frequencies are assumed to be slower than the maximum frame rate of any digital transmission. The disturbing effect of these signals will therefore only be like that of a single impulse event.

(4) Time synchronization of the equipment at measurement and reference location can for example be achieved through connection of external devices such as DCF77- or GPS-Modules.

The following measurement setup is used:

FIGURE 2

Basic measurement setup



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5 Measurement procedure

As mentioned earlier, the system has to find a suitable free frequency before each acquisition of data. This can be done in a "pre-run" which is a sweep over the whole passband range of the filter, preferably with the same RBW as for the actual measurement and an RMS detector. The frequency with the lowest level is the candidate for the following final measurement of WGN and IN.

The WGN level is measured in a second run with an RMS detector, narrow RBW (e.g. 100 Hz), zero or narrow span (e.g. 100 kHz), and an integration time of at least 1 s.

The IN level is measured in a third run with a sample detector, zero span and 10 kHz RBW over an acquisition time of 1 s or more. During each second, at least 10 000 samples have to be taken and stored.

It is sufficient to repeat these measurements on each frequency range every 5 min.

The time synchronization process has to ensure that the third run at both the measurement and reference location is always done exactly at the same time with a maximum offset of about 100 ms. This will ensure sufficient (90%) time overlap of the IN acquisitions from both locations.

To characterize the MMN, it is recommended to measure in at least 3 different frequency ranges, evenly spread over the whole HF range from 3 to 30 MHz. Broadcast bands should be avoided as they are heavily occupied by high power transmitters resulting in high received signal levels. Mobile bands with only short-time occupancies should be preferred (e.g. 4-5, 12-13 and 19-20 MHz).

6 Measurement evaluation

6.1 WGN

Recommendation ITU-R P.372 suggests to present the WGN result as an external noise figure F_a. It can be derived from the noise level that would be received from a matched lossless isotropic antenna by normalizing it to 1 Hz bandwidth and present it in dB above thermal noise (*kTB*, usually set to −174 dBm/Hz).

Example: If the (corrected) MMN level is −120 dBm measured in 100 Hz RBW, this would correspond to −140 dBm in 1 Hz RBW which is 34 dB above *kTB*.

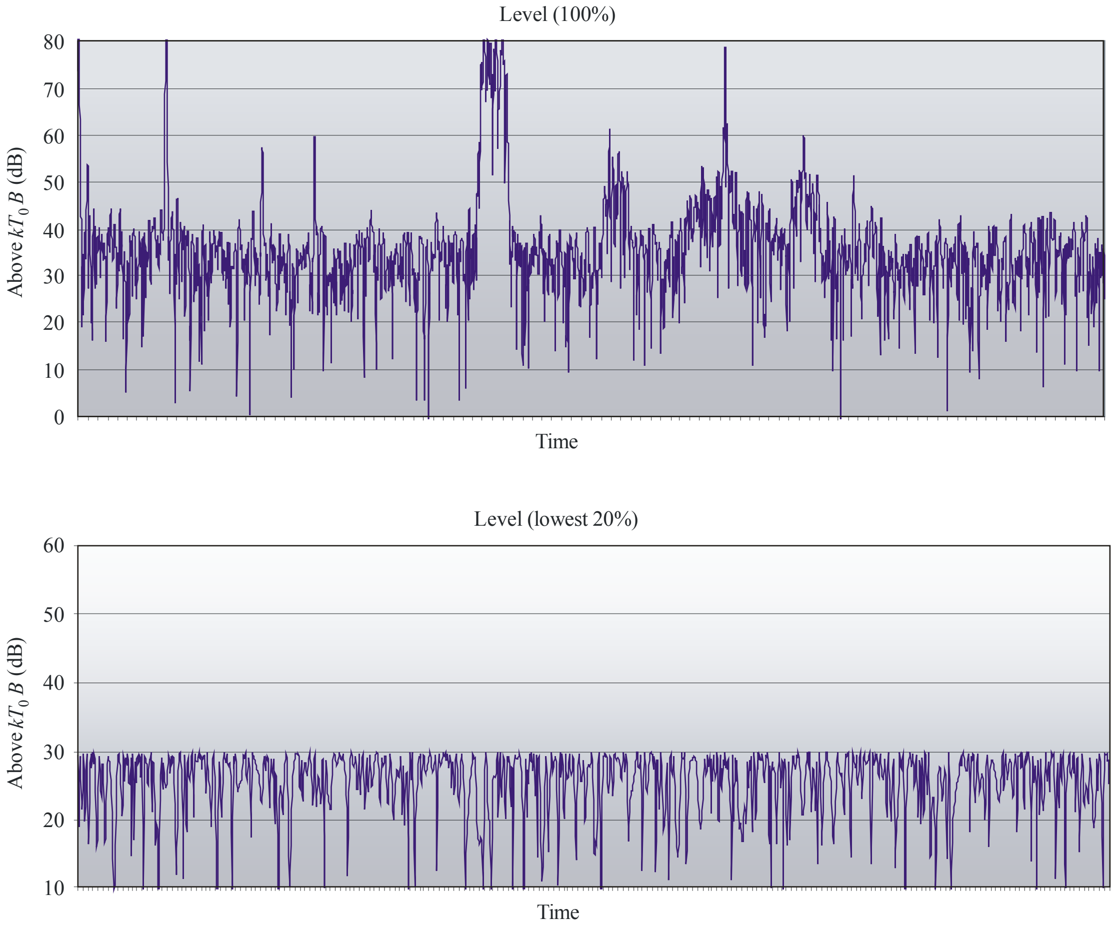
If, like in most cases, the measurement antenna cannot be assumed lossless, a correction has to be applied. This is described in detail in Recommendation ITU-R SM.1753.

When it can not be assumed that the whole measurement range is free of intended emissions, the WGN level has to be determined out of all RMS samples by using the 20%-method described in Recommendation ITU-R SM.1753: From all measurement values 80% of the samples representing the higher levels are truncated, leaving only 20% of the samples representing the lower levels (see Fig. 3). This will delete the intended emissions from the result. The remaining values are averaged linearly. However, by cutting 80% of all measurement samples, also some higher levels of the WGN are deleted. Therefore, a correction has to be applied to the averaged result. This correction is determined by applying pure WGN to the measurement system (e.g. from a noise source) and recording it for a while with the same settings as used for the actual MMN measurement. The correction to be applied is the difference of the linear average of all (100%) samples and the lowest 20% samples from the measurement with the noise source.

NOTE 1 – This method will also eliminate any impulsive atmospheric noise such as from lightning from the F_a result, leaving a fair estimate of the MMN only.

FIGURE 3

Level vs. time for one acquisition



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Example: MMN including some intended emissions is measured with a resolution bandwidth (RBW) of 100 Hz. The average of all samples, corrected for the used antenna, is –100 dBm. The average of the lowest 20% of all samples is −120 dBm. Measurement of true WGN from a noise source results in an average of all samples of −60 dBm and an average of the lowest 20% values of –70 dBm. The correction to be applied is 10 dB which has to be added to the 20% figure from the actual MMN measurement (−120 dBm). So, the correct level of the WGN is −110 dBm, measured in 100 Hz RBW. Reduced to 1 Hz RBW this would be −130 dBm. With an assumed thermal noise level of −174 dBm/Hz, the final result of the WGN will be 44 dB above *kTB*.

6.2 IN

Other than with WGN, the level of the measured IN does not scale linearly with bandwidth. This is because the emitted bandwidth of the very short impulses must be regarded as wider than the measurement bandwidth, causing the measured level to be reduced. To have a bandwidth independent result, the measured values are presented as a level density and given in (dB(µV/MHz)). To arrive at the final result presentation of the IN, four evaluation steps are required:

a) separation of IN samples from WGN samples;

b) burst detection;

c) comparison between measurement and reference location (measurement type 3 only);

d) computation of level/density, length, repetition time and total burst time.

6.2.1 Separation of IN and WGN

Separation of IN samples from WGN samples is necessary for the following reasons:

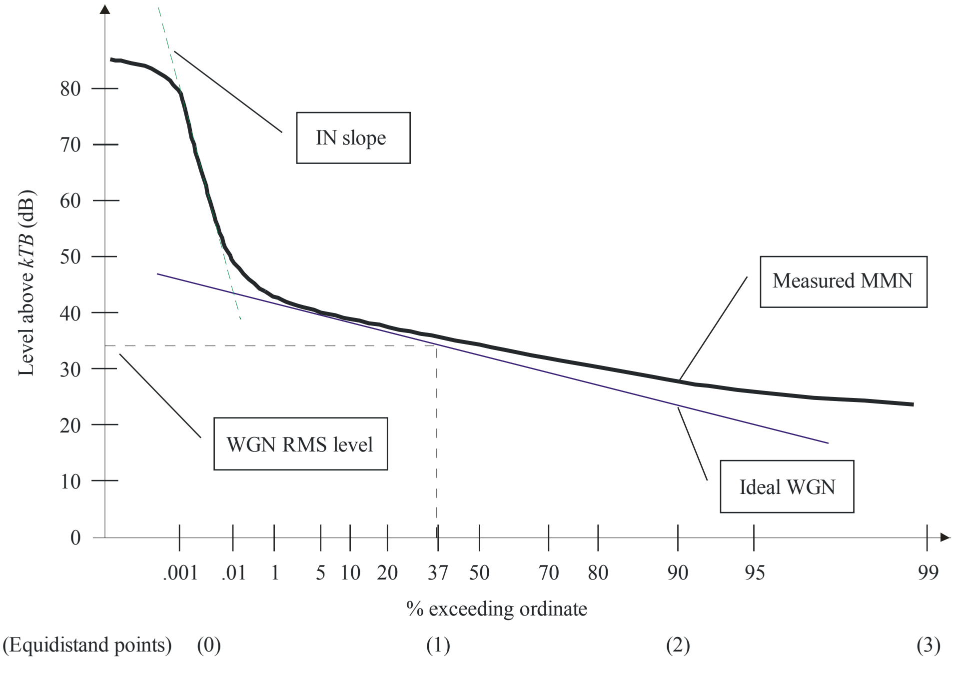
- Impulses will only be present at a very low percentage of the time. Without separation of IN and WGN, results will vastly be dominated by the ever present WGN and the characteristics of the few impulses will not be seen.
- strictly speaking WGN can also be seen as a series of very short pulses, but the presentation of IN statistics should apply to those peaks that originate from IN emitting sources only.

In the absence of a theoretical method based on a mathematical approach, it is suggested to separate IN from WGN samples by placing a level threshold high enough to suppress all (or nearly all) of the peaks from WGN. All samples exceeding the threshold are defined as being IN. A practical value for the threshold is the CREST factor (difference between peak and average power level) of pure WGN which is 13 dB (a practical value that is also to be seen when switching between peak and RMS detector). It is therefore necessary to determine the average power level (RMS) of the WGN samples in each acquisition. The IN level values have been taken with a sample detector. Because we have used fast data sampling, the WGN level can be calculated using the so-called APD-method.

First, all measurement samples are sorted in ascending order. Then, for each measured level in the list, it is counted how many samples exceed that level. Then, a graph is made showing the number of samples exceeding a certain level against that level (see Fig. 4). This graph is called the Amplitude probability distribution (APD).

FIGURE 4

Typical amplitude probability distribution (APD)



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The central part of he APD characterizes the WGN. The following facts can be mathematically proven (however that proof is outside the scope of this Report):

a) The APD of pure WGN is a straight line with a slope of 1/10 when the x-axis is Rayleigh scaled.

b) The numerical slope of the WGN line of 1/10 applies to the linear equivalent of the Rayleigh scaling. Examples of equidistant points on the x-axis are 0.0045%, 36.5%, 90.5% and 99% which correspond to the linear values of 0, 1, 2, and 3 (see bottom of Fig. 4). These values can be used to draw the WGN line into the APD graph: the level rises by 10 dB from 99% to 90.5% and 90.5% to 36.8% and 36.8% to 0.0045%.

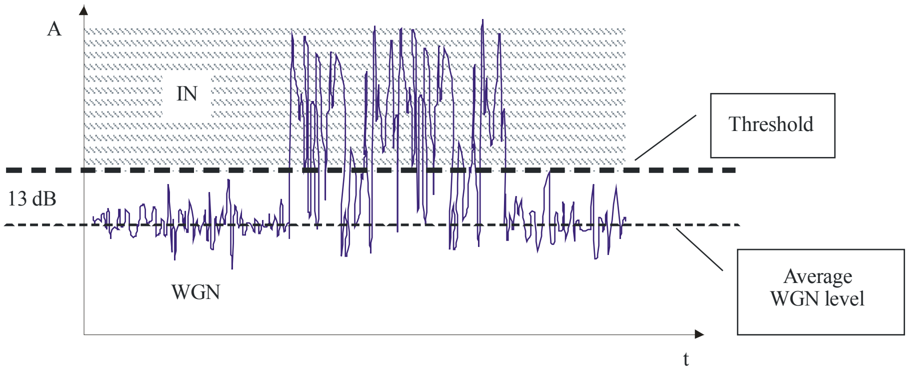
c) The RMS value of the WGN is the level where this line crosses the 37% probability point.

If, like in most cases, the measurement results also contain IN and SCN, the APD turns from a straight line into the typical shape shown in Fig. 4. A more accurate way of determining the RMS level of the WGN part only is to shift a straight line with the slope of pure WGN from the bottom up until it just touches the measured APD curve. The WGN RMS value is then obtained by reading the level where this line crosses the 37% probability point (dotted lines).

The threshold for the separation of IN from WGN is this RMS value plus 13 dB (see Fig. 5).

FIGURE 5

Separation of IN from WGN with threshold



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The subsequent evaluation steps are applied only to those measurement samples that exceed the threshold.

The major disadvantage of this separation method as opposed to pure mathematical approaches is a certain loss of sensitivity: An impulse can only be detected if its level is at least 13 dB higher than the average WGN level. Weaker impulses are lost. However, this disadvantage is acceptable for the following reasons:

– Modern digital radiocommunication systems are relatively immune against IN interference. Its level has to be very strong in order to disable reception.

– The WGN level of the MMN is also given as a separate figure. In order to function properly, a radiocommunication system must cope with this constant MMN level at any time. This already includes the short “peaks” in the WGN that are up to 13 dB above average.

6.2.2 Burst detection

In most cases it is the average disturbing RF energy that produces interference to radiocommunication receivers. When a noise source emits a series of very short pulses having a high RF bandwidth, the victim receiver integrates them over the burst time. It seems logical to do the same when evaluating IN and its interference potential to radiocommunication systems.

It is therefore suggested to combine short IN samples to bursts in such a way that each resulting burst within an acquisition meets all of the following conditions:

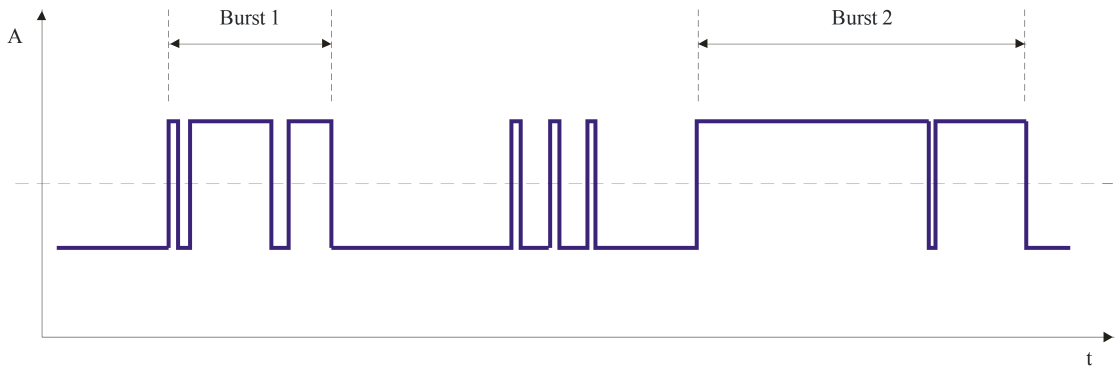
a) At least 50% of all samples in a burst must exceed the threshold.

b) No sample within 25% of the total burst time before the start and no sample within 25% of the total burst time after the end of the burst may exceed the threshold.

The first condition ensures that the majority of samples within a burst lie above the threshold. The second condition establishes a minimum "clearance area" around each burst that is half of its length, equally split on each side of the burst. The following figure provides some examples with simplified rectangular pulses.

FIGURE 6

Principle of the burst detection



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The first three and the third two impulses are merged to bursts. The impulse series in the middle could not be merged because the resulting burst would have less than 50% samples above the threshold. For the same reason the first burst could not be extended to cover the three short impulses in the middle. They could also not be included in the second burst because the resulting longer burst 2 would not have enough clearance from burst 1. Instead, they will remain as separate impulses.

The Figure 7 shows the result of the burst detection applied to a real acquisition in an MMN measurement.

FIGURE 7

Practical example of burst detection

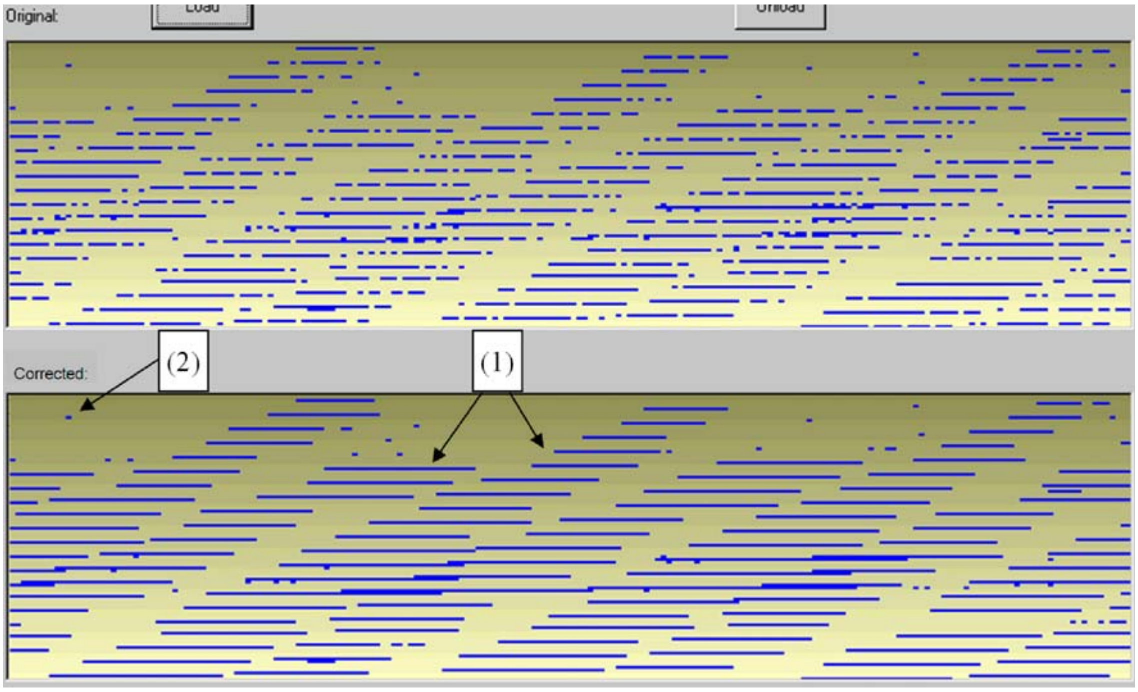

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Figure 7 shows the level vs. time of a whole acquisition block of 1 s length. To provide enough resolution, it is drawn in multiple lines and stacked below each other, just like the electron beam in an analogue TV set writes a frame line by line on the screen. Blue pixels indicate levels exceeding the threshold. The upper window shows the original data, the lower window shows the result of the burst detection process. The major noise source, a device with a certain burst length and constant repetition frequency, can clearly be seen (1). Still, some additional short pulses in between are retained with the full time resolution (2).

6.2.3 Computation of the IN parameters

The process of determining level, duration and repetition time described here is applied to each burst formed according to § 6.2.2 and each remaining impulse that is not part of a burst. For simplification, the following text uses the word "burst" for both.

The burst level is the linear average of all samples between burst start and burst end, regardless of whether they are above or below the threshold. This method reveals the average integrated RF level (RMS) being present over the whole burst time as this value determines the interference effect on radiocommunication receivers.

As mentioned earlier, the measured burst level does not scale linearly with bandwidth. It is therefore desirable to state it as a density rather than absolute levels. The recommended unit is (dB(µV/MHz)). This figure can be obtained from the measurement results as follows:

$$Wg = U + 20*\log(1\ \text{MHz}/Bw)$$

where:

Wg : spectral density (dB(µV/MHz))

U : measured voltage at receiver input (dB(μV))

Bw : measurement bandwidth (MHz).

Another parameter relating to the burst level is the function with which the burst level rises towards the highest bursts measured. This can be described with the angle or slope with which the IN hump in the APD graph rises towards the left hand side (see Fig. 4). The impulse slope is the slope of an auxiliary line that is fitted to the steepest part of the impulse "hump" in the APD. It is computed relative to the linear x-axis like the slope of the WGN line (see Fig. 4). The IN slope values of all sweeps are averaged over the whole registration time.

The burst duration is the time difference between the first and the last sample of a burst that exceed the threshold.

The burst repetition frequency is the inverse time difference between the centre (or middle) samples of any two pulses in one acquisition/sweep. The result will be a time of arrival difference histogram. In the case where multiple bursts are captured in one acquisition, the time for each possible combination has to be determined, resulting in multiple repetition frequencies (see Fig. 8)

FIGURE 8

Principle of burst repetition time determination

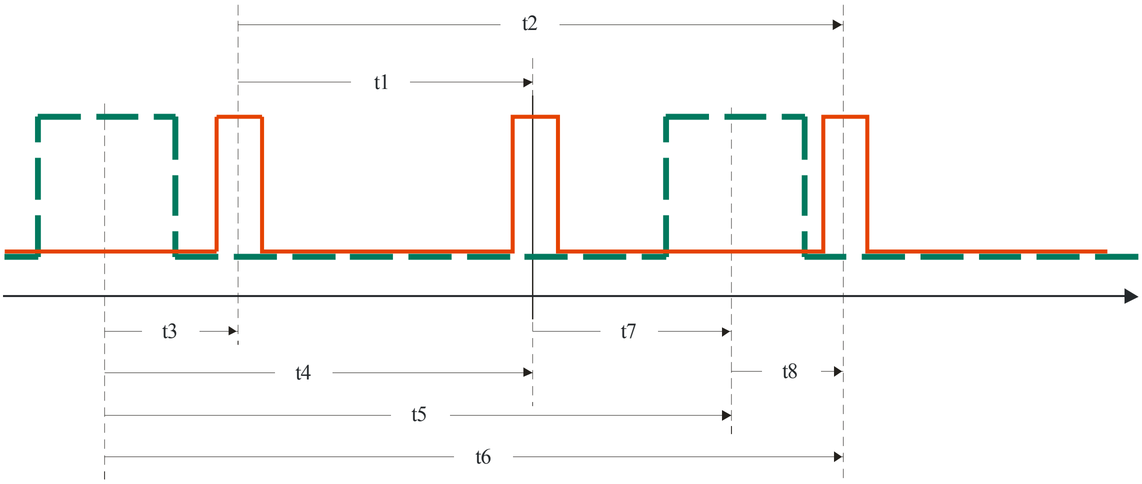

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Figure 8 shows signals from two sources emitting impulse trains at a certain repetition rate. The red (solid) signal results in the repetition times t1 and t2. The reason for giving both repetition times in the result presentation lies in the typical behaviour of a digital radiocommunication service: it is only sensitive to impulse noise with a certain pulse repetition frequency, usually matching the frame rate. When the frame duration happens to be t2, the system is disturbed because always the same bits inside a frame are interfered. The occurrence of this time (t2) has to be shown by the IN result presentation (see Fig. 31).

The green (dashed) line in Fig. 8 is the signal of a second source having a different repetition frequency. Calculating all combinations will result is 8 different repetition times for this acquisition.

The total burst time says something about the amount of impulses or bursts occurring during a whole day. It is computed by dividing the number of measurement samples belonging to bursts (including those samples inside bursts that lie below the threshold) by the total number of samples in the whole registration.

6.2.4 Comparison between measurement and reference location

As mentioned earlier, especially atmospheric noise like lightning that is received over the skywave may be eliminated from the MMN samples to a certain extent. These are the impulses and bursts received simultaneously at both locations. MMN from local sources will not be received at a location that is many kilometres away.

Propagation and receiving conditions can be different at the measurement and reference location. To identify a signal that was received at both locations, it is therefore not sufficient to evaluate only the signal level. Instead, the identification algorithm has to look for simultaneous sudden increases and/or decreases of the receive level, allowing some tolerance in terms of level and time.

The demand for a time synchronization accuracy of 100 ms between both locations and a recommended sweep time of 1 s means that we would have at least 900 ms of overlapping sweep time. The first step of the evaluation has to be the determination of the exact offset between measurement and reference location. As described in Recommendation ITU-R SM.1753, this is done by correlation. The following text, illustrated by Fig. 9, describes a practical way of calculation:

Step 1: Calculate the median level of a sweep from the reference and measurement location. Independent of the total received level, 50% of all samples in both sweeps lie above, and 50% below this median level.

Step 2: Each sample of a sweep that is above the median is assigned an autocorrelation index of +1. The value –1 is assigned to each sample below the median. The sum of all these assigned for each scan should be 0.

Step 3: Now, only the assigned correlation indexes are compared between a scan from the reference and measurement location. If both correlation indexes are equal, the resulting cross-correlation index is +1, if they are unequal, it is –1 (logical function “exclusive OR”). The sum of all these results is the cross-correlation figure.

Step 4: Now the scan from the measurement location is shifted in time by one sample and the cross-correlation figure is calculated again. This process is repeated for all possible time offsets inside the 900 ms overlap time. The offset with the highest cross-correlation figure is fixed as this is assumed to be the exact synchronization between both scans.

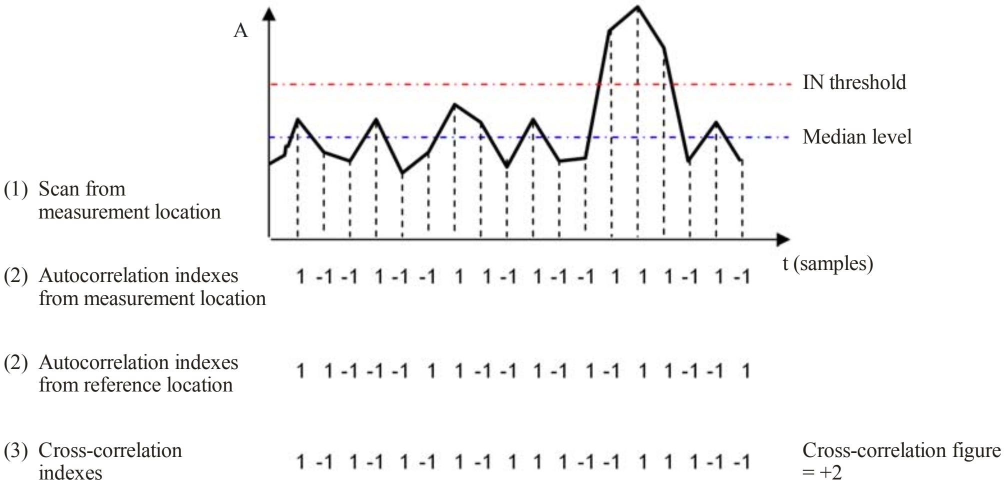
Step 5: The start and end sample of the first burst from the measurement location are identified (in the example from Fig. 9 the start would be at sample 13 and the end at sample 16). It is then determined whether for more than 50% of the burst length a burst also shows up at the reference location. If this is the case, the burst is assumed to be received via the skywave and eliminated. Otherwise, the burst is assumed to be of local origin (man-made) and kept.

In the example from Fig. 9, the burst is 4 samples long and starts at sample 13. So, if at the reference location at least 3 samples (> 50%) between position 13 and 16 are above the burst threshold, it is eliminated and not considered in the further evaluation process.

Step 5 is repeated for every burst in a scan. Then, Steps 1 to 5 are repeated for all remaining scans of the registration.

FIGURE 9

Correlation between measurement and reference location



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7 Result presentation

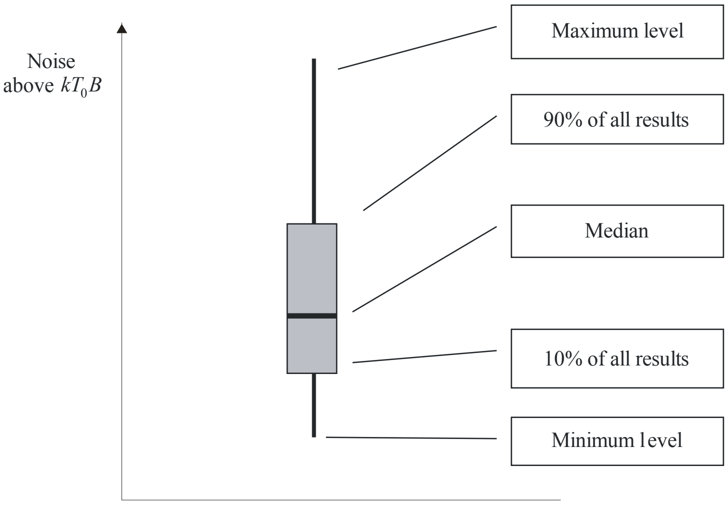
7.1 WGN

As mentioned earlier, the WGN figures in the HF frequency range will depend on the time of day due to different propagation conditions. It is therefore recommended to average the WGN levels over one hour and present 24 figures for F_a (dB above *kTb*).

However, the WGN figures at one location will also differ from day to day, and measurements taken at different locations, even of the same category, will also differ considerably. Therefore, the WGN figures are only of practical value when they are averaged over a lot of measurements made at different locations and different days. To give not only the average or median WGN values but also provide some information about the possible distribution, the so-called box plot is the recommended way of presenting the results. Each box indicates maximum, minimum, upper deciles, lower deciles and median values together (see Fig. 10).

FIGURE 10

Principle of a box plot



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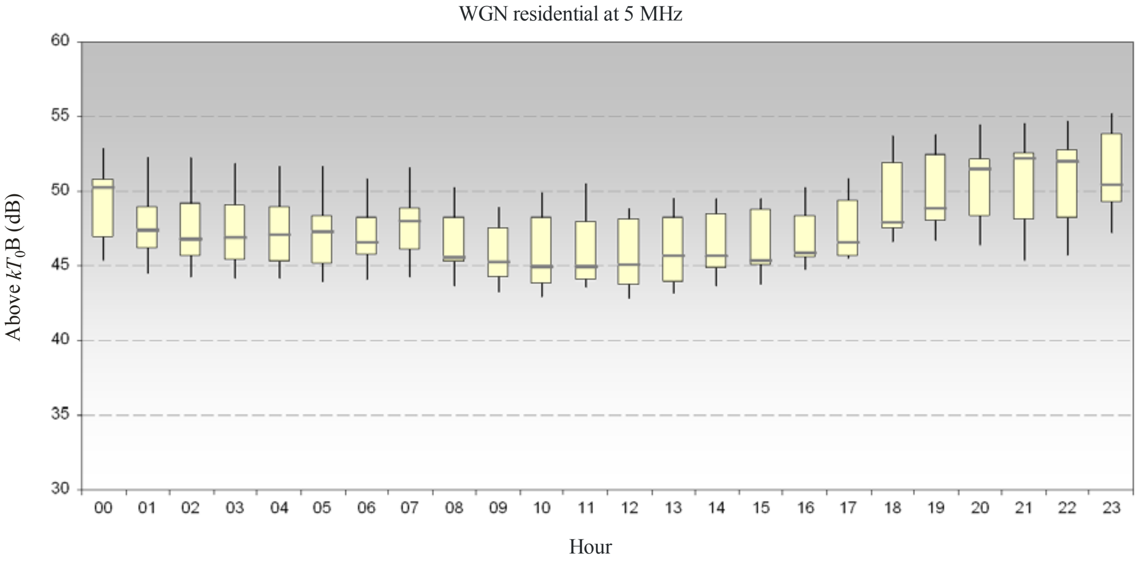
Care should be taken not to mix measurements from different location categories (e.g. city and residential) in one box plot.

Also, because the general MMN level is depending on the frequency, only results obtained in the same frequency range can reasonably be combined in a box plot.

FIGURE 11

Example of a typical box plot



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To develop a broad basis for the eventual revisions of the WGN values given in Recommendation ITU-R P.372, a databank for radio noise measurement results has been established by the ITU and made available at http://www.itu.int/ITU-R/index.asp?category=study-groups&rlink=rsg3&lang=en. Administrations performing MMN measurements according to Recommendation ITU-R SM.1753 and/or this report are invited to provide their results to be included in the databank. Information about the required data format is contained in Recommendation ITU-R P.311.

7.2 IN

In real environments the 24 h registration will include many impulses/bursts from many different sources covering a large range of values for the three main parameters level, length and repetition frequency. This makes it necessary to present the results as statistical distributions rather than giving a single figure for the average of each parameter.

After the comparison between measurement and reference location, only IN from nearby sources is considered. Since these sources do not depend on propagation conditions, it is not necessary to separate figures for each hour of the day. Instead, all values derived over the whole 24 h period can be summarized.

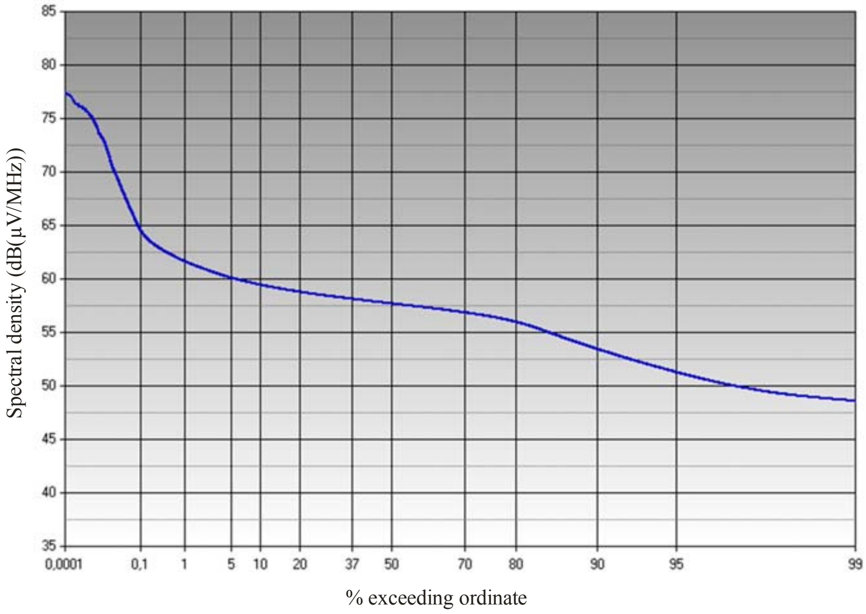
To also provide some information as to how often impulse noise appears, it is recommended to indicate the relative burst time (= relative number of IN samples in percent) in any of the presentations (see bottom of Fig. 13).

7.2.1 Burst level

The average burst levels and spectral densities calculated according to § 6.2.3 can be presented as the accumulated probability vs. spectral density. An example is given in Fig. 12. The value on the y-axis then indicates how many percent of all bursts reach or exceed a certain spectral density.

FIGURE 12

Example of a burst level distribution



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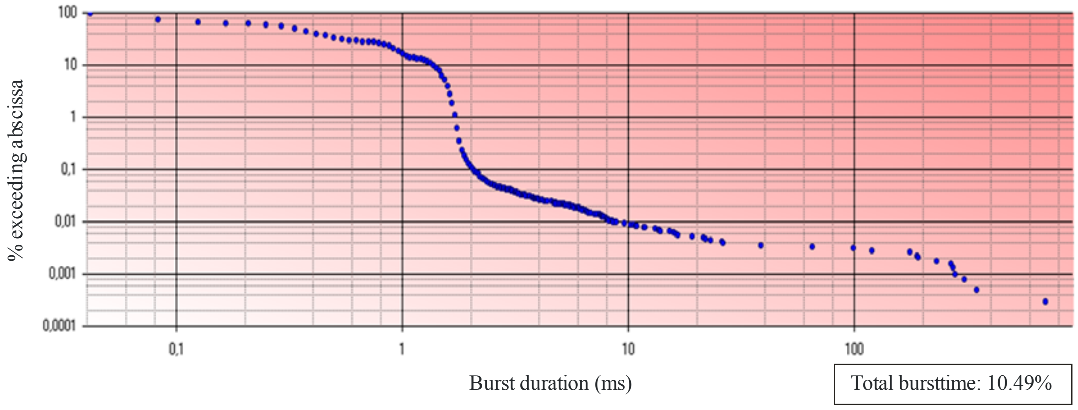
7.2.2 Burst duration

The burst durations calculated according to § 6.2.3 can be presented as the accumulated probability vs. time (length). The value on the y-axis then indicates how many percent of all bursts reach or exceed the length on the x-axis. For practical reasons it is recommended that the scaling of both axes is logarithmic. An example is given in Fig. 13.

FIGURE 13

Example of a burst duration distribution



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7.2.3 Burst repetition time

The burst repetition frequencies calculated according to § 6.2.3 can be presented as the probability vs. frequency. The value on the y-axis then indicates how many percent of all possible burst combinations have the repetition time on the x-axis.

NOTE 1 – Simply counting the occurrence of a certain pulse spacing can not directly be taken as the basis for the graph: In an acquisition of, say, 1 s, there can be 500 short bursts with a spacing of 1 ms and a corresponding burst repetition frequency of 500 Hz. At the same time there can be 2 bursts from another source having a spacing of 500 ms which correspond to 2 Hz burst repetition frequency. It would be incorrect to count the fast bursts 500 times more than the slow ones, because this would give the impression that burst repetition frequencies of 500 Hz are 500 times more likely than bursts of 2 Hz. To correct for this effect, the number of counts with a certain spacing has to be weighted before the probability graph is drawn. This is done by dividing the number of counts by the number of maximum possible occurrences of this spacing in the acquisition.

Example: The acquisition time is 1 s during which 10 000 samples were taken. So the time between two samples is 100 µs. We count 1 500 bursts with a spacing of 300 µs (3 samples between the bursts), and we count 2 bursts with a spacing of 500 ms (5 000 samples between the bursts). If the first source with 300 µs repetition time were continuously present, we would count 3 333 bursts in every acquisition. The value on the graph of burst repetition frequency distribution is calculated as follows:

For the repetition time of 300 µs: A = 1 500 bursts/3 333 bursts = 45%

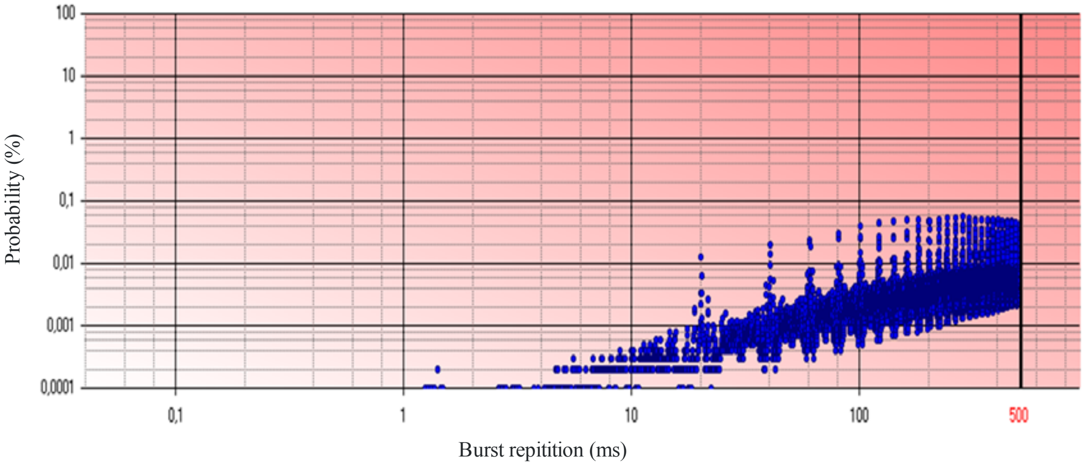
For the repetition time of 500 ms: B = 2 bursts/2 bursts = 100%

This is done for all detected burst repetition times. The total number of all different times, for example 25, in the result corresponds to 100%. Then the probability (= value on the y-axis) for the repetition time 300 μs is 45%/25 = 1.8% , and for 500 ms it is 100%/25 = 4%.

An example of a burst repetition time distribution is given in Fig. 14.

FIGURE 14

Example of a burst repetition time distribution



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The right end of the x-axis is determined by the acquisition time of 1 s that results in a slowest detectable burst repetition time of 500 ms. The example in Fig. 14 shows a dominant impulse noise source with a repetition time of 20 ms. Due to the principle described in section § 6.2.3, there are also peaks at multiples of 20 ms (40, 60, 80 ms …).

7.2.4 Total burst time

All statistical diagrams so far only contain relative probabilities of the IN parameters. In Fig. 13, for example, 0.1% of all bursts are longer than 40 ms. This, however, may be 100 or millions of impulses per hour. Therefore, another interesting parameter is how much of the total measurement time was occupied by IN. The total time of all impulses and bursts relative to the total observation time can be stated as a single figure (%) and is best placed next to any of the timing graphs. In Fig. 13, for example, 10.49% of all measurement samples were bursts or impulses (see text box at the lower right).

8 German MMN measurements

Starting 2007, a large scale campaign of MMN measurements in the HF frequency range is carried out at different locations in Germany. The WGN results will be published in the ITU radio noise databank.

NOTE 1 – Since the antenna factor of the measurement system used has not yet been established, the results presented in this version of the Report have to be regarded as preliminary. The estimated measurement uncertainty due to this circumstance is ±5 dB.

8.1 Measurement equipment properties

The following measurement equipment is used:

TABLE 2

Measurement equipment used in Germany

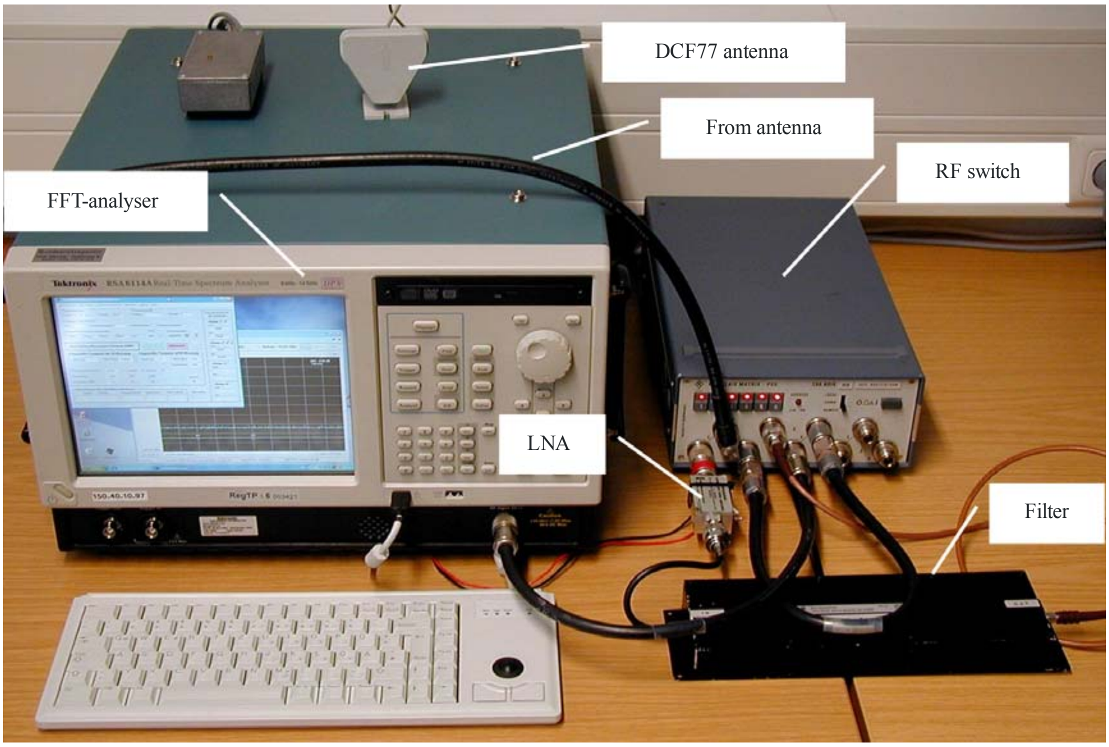
Part of equipment	Important properties, remarks
Passive HF antenna	Vertical dipole Length: 5 m Height above ground: 8-10 m (centre) Antenna factor at 5 MHz: 22 dB Antenna factor at 12 MHz: 28 dB Antenna factor at 20 MHz: 15 dB
HF band pass	Customized, especially manufactured Suppression ≥ 22 dB between 9-5 060 kHz, 5 600-12 100 kHz, 13 570-19 020 kHz, 21 540-30 000 kHz Passband attenuation ≤ 2.5 dB 3 passbands: 5 210-5 470 kHz, 12 410-13 240 kHz, 19 490-21 070 kHz
Low noise amplifier	Frequency range: 5-1 500 MHz Gain: 20 dB Noise figure: 1.2 dB
Measurement receiver	FFT analyser Sampling speed: 2 × 24 kHz (I/Q) Acquisition time: 1 s Built-in computer running control software Internal I/Q data storage capacity RBW: 100 Hz (WGN), 20 kHz (IN)
Control and evaluation software	Own development (Visual Basic, Excel)
Time synchronization	DCF77 module attached to analyser via RS232
RF switch	2 IEC-bus controlled switching circuits

The measurement equipment is fitted into a measurement vehicle. The antenna is mounted on the built-in retractable mast. In most cases, external 220 V power supply is provided. For remote locations, two measurement vehicles were fitted with 1260 AH battery capacity and a sinusoidal d.c/a.c converter that allow to run the equipment for 24 h without external power supply.

The RF switch in Fig. 15 can be used to bypass the filter if no external DCF77 antenna is available. In these cases the software also supports direct reception and evaluation of the DCF77 signal by the FFT analyser using the measurement antenna. In this mode, the actual noise measurement is suspended every few minutes, the analyser is set to 77 kHz for a certain time and the data telegram transmitted by DCF77 is evaluated through software to determine the exact time. Since 77 kHz is not inside one of the passbands, the filter has to be bypassed during these time synchronization phases.

FIGURE 15

HF MMN measurement equipment setup



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If the external DCF77 antenna system is present, the RF switch is not needed.

FIGURE 16

HF MMN measurement vehicle

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8.2 Measurement procedure

The following three frequency ranges are measured:

TABLE 3

Frequency ranges measured

Range (MHz)	Centre frequency (kHz)	Span (kHz)
5	5 331	288
12	12 820	795
20	20 220	1 430

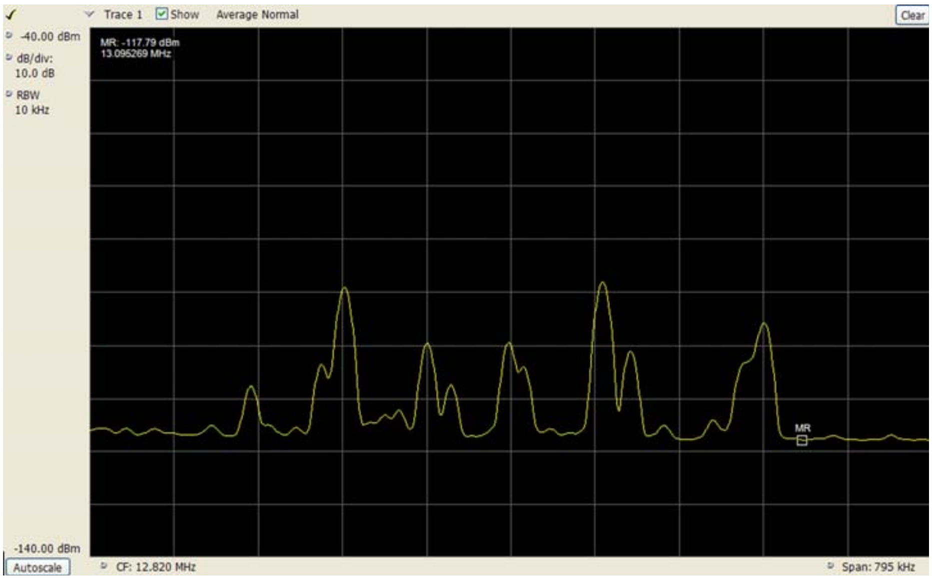
The following measurements are automatically done for each of the above mentioned frequency ranges subsequently and repeated for 24 h:

1 Pre-run to determine frequency with lowest MMN level. Settings:
Centre frequency: from Table 3;
Span: from Table 3, RBW: 10 kHz;
Acquisition and integration time: 1 s;
Detector: RMS.

An example is shown in Fig. 17. The marker denotes the frequency with the lowest level on (or around) which measurements are continued.

FIGURE 17

Pre-run to determine suitable measurement frequency



-40.00 dBm
dB/div: 10.0 dB
RBW 10 kHz
MR: -117.79 dBm
13.095269 MHz
-140.00 dBm
CF: 12.820 MHz
Span: 795 kHz

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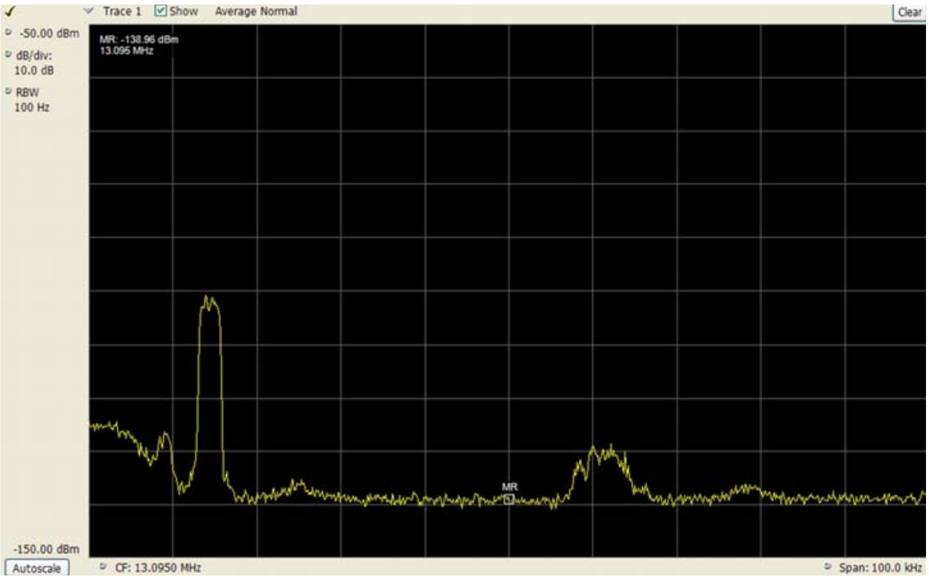
2 WGN measurement run. Settings:
Centre frequency: frequency with the lowest level from pre-run;
Span: 100 kHz;
RBW: 100 Hz;
Acquisition and integration time: 1 s;
Detector: RMS.

An example is shown in Fig. 18.

FIGURE 18

WGN measurement run to determine the RMS MMN



-50.00 dBm
dB/div: 10.0 dB
RBW 100 Hz
MR: -138.96 dBm
13.095 MHz
-150.00 dBm
CF: 13.0950 MHz
Span: 100.0 kHz

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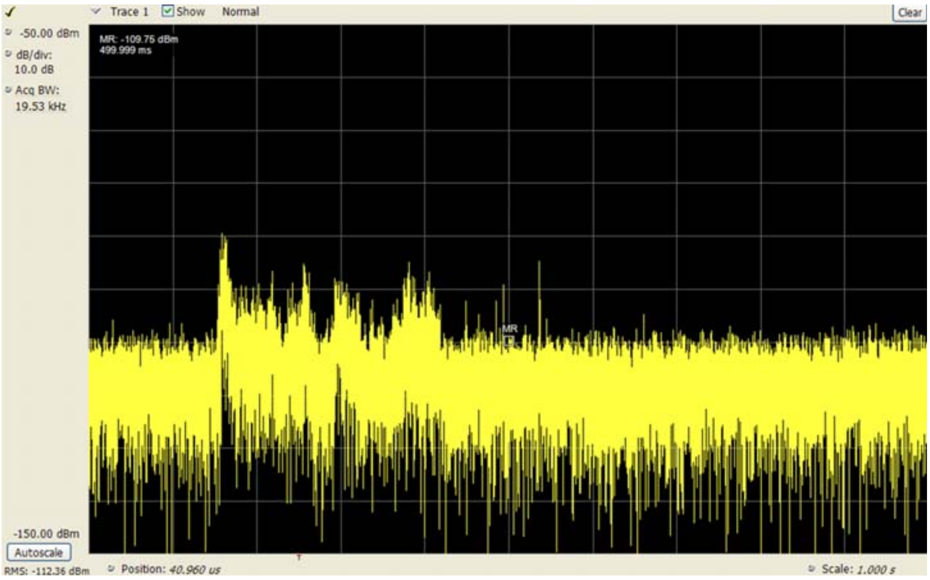
3 IN measurement run. Settings:
Centre frequency: frequency with the lowest level from pre-run;
Span: zero span (amplitude vs. time);
RBW: 20 kHz;
Acquisition time: 1 s;
Detector: sample.

An example containing several bursts is shown in Fig. 19.

FIGURE 19

IN measurement run (amplitude vs. time)



-50.00 dBm
dB/div: 10.0 dB
Acq BW: 19.53 kHz
MR: -109.75 dBm
499.999 ms
RMS: -112.36 dBm
Position: 40.960 us
Scale: 1.000 s

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Time synchronization is established about every 7 min by decoding the DCF77 signal via an external interface module and comparing it to the current system clock of the computer. The time difference is stored as an "offset" and used to synchronize the subsequent measurement runs accordingly. The achieved accuracy in synchronization between measurement and reference location is better than 100 ms.

8.3 Measurement results

Until the year 2009, measurements were done at over 100 locations in Germany. The following box plots summarize the WGN results obtained so far for each location category.

FIGURE 20

WGN city 5 MHz (box plot)

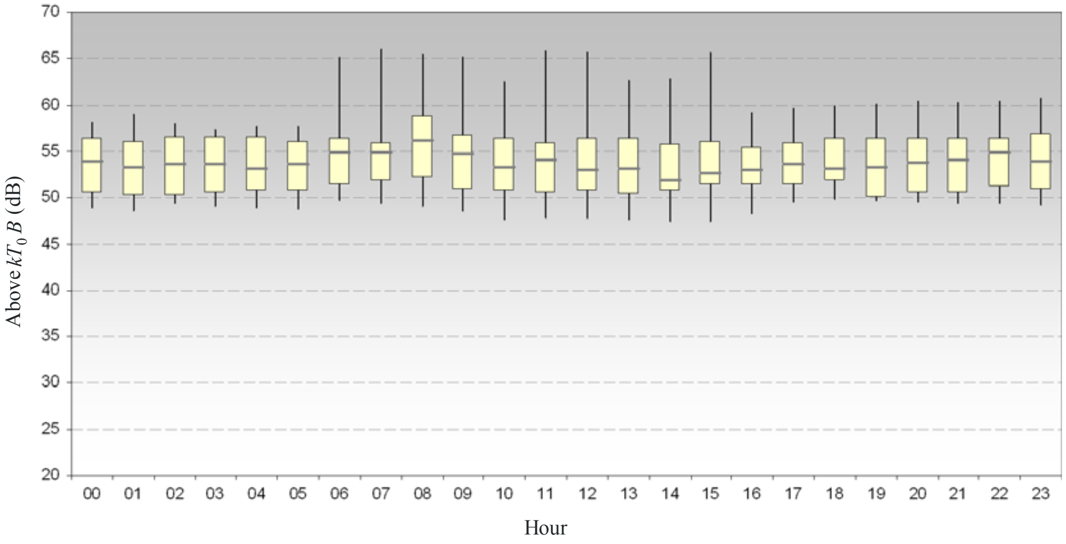

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FIGURE 21

WGN city 12 MHz (box plot)

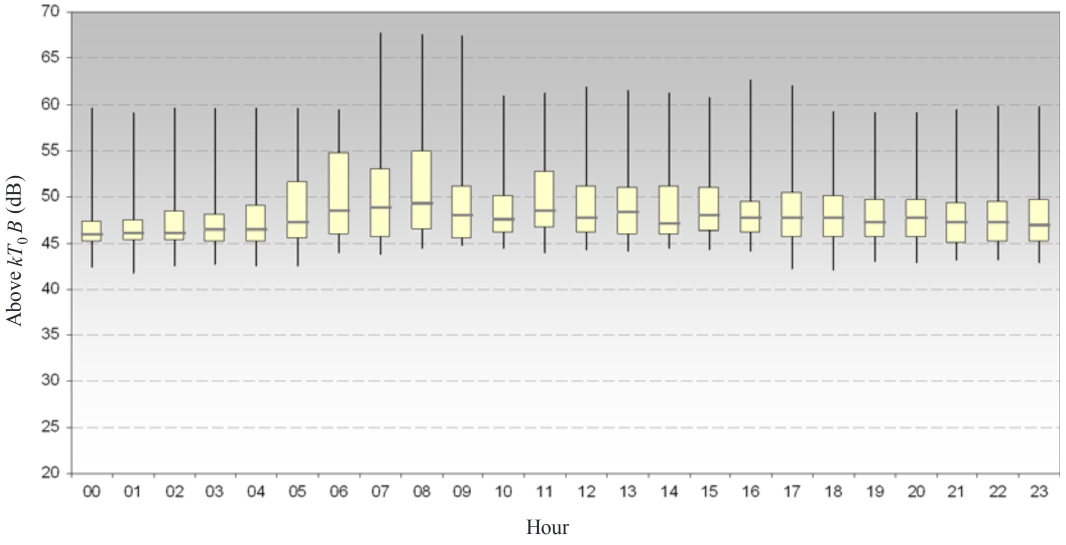

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FIGURE 22

WGN city 20 MHz (box plot)

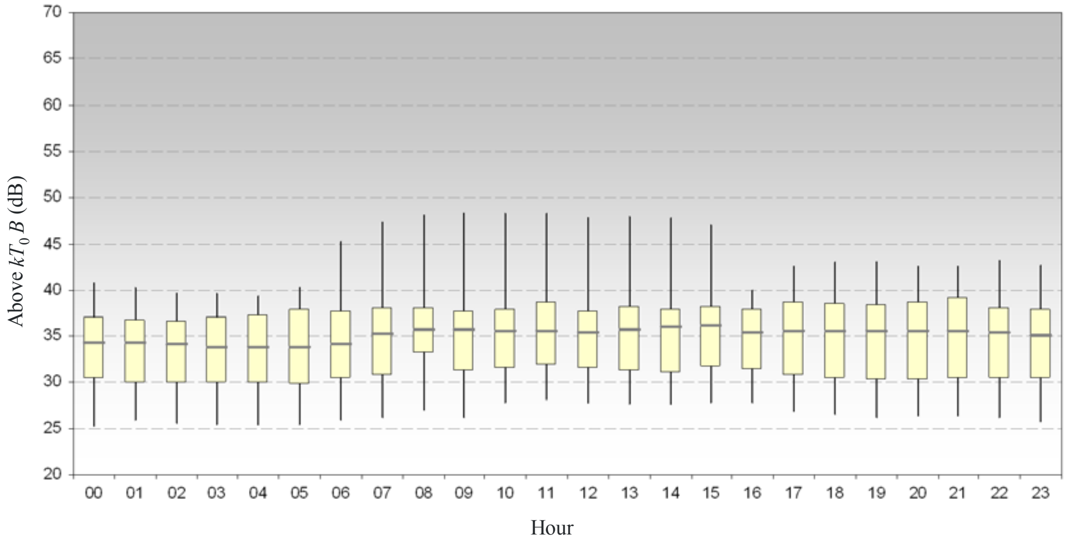

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FIGURE 23

WGN residential 5 MHz (box plot)

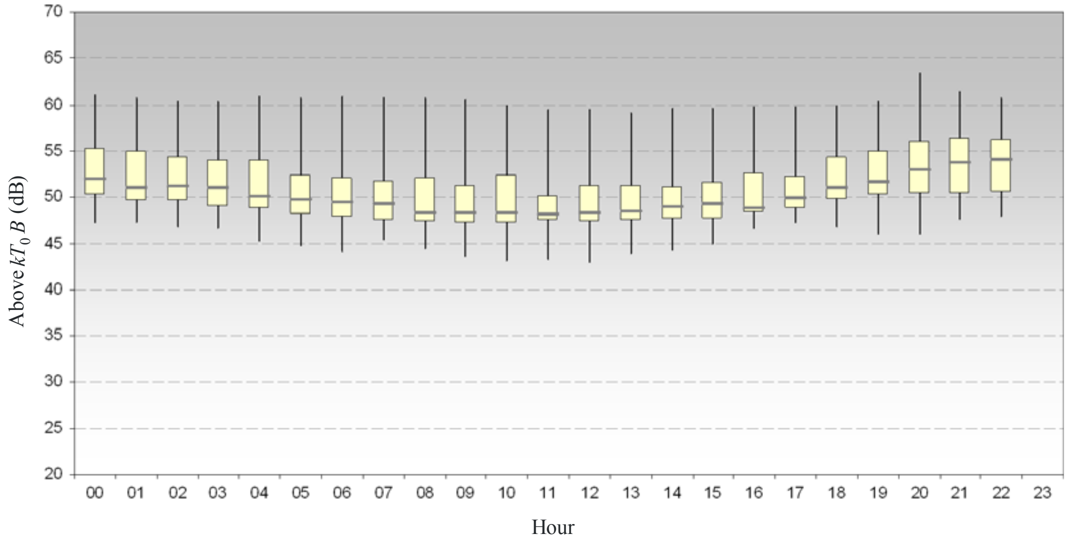

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FIGURE 24

WGN residential 12 MHz (box plot)

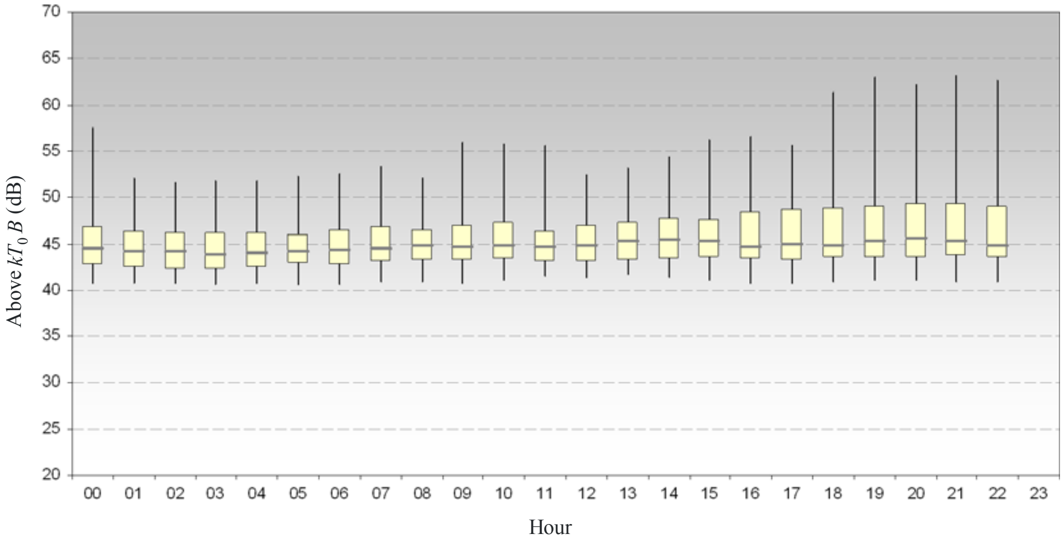

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FIGURE 25

WGN residential 20 MHz (box plot)

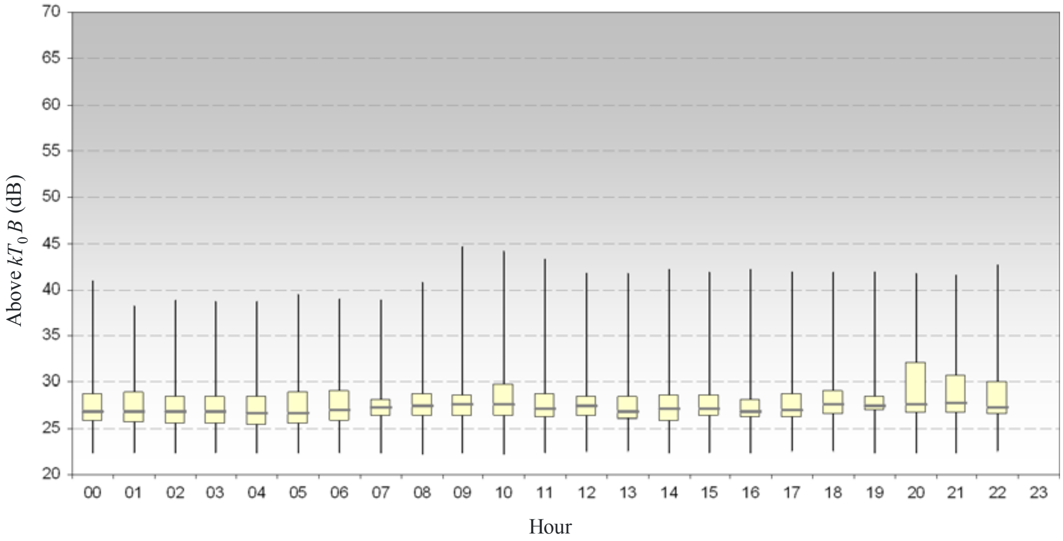

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FIGURE 26

WGN rural 5 MHz (box plot)

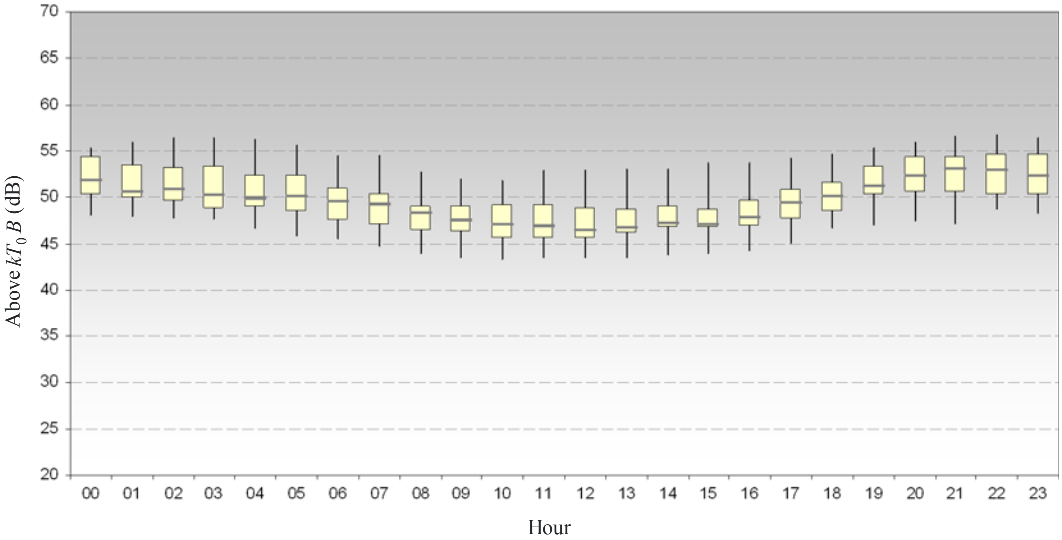

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FIGURE 27

WGN rural 12 MHz (box plot)

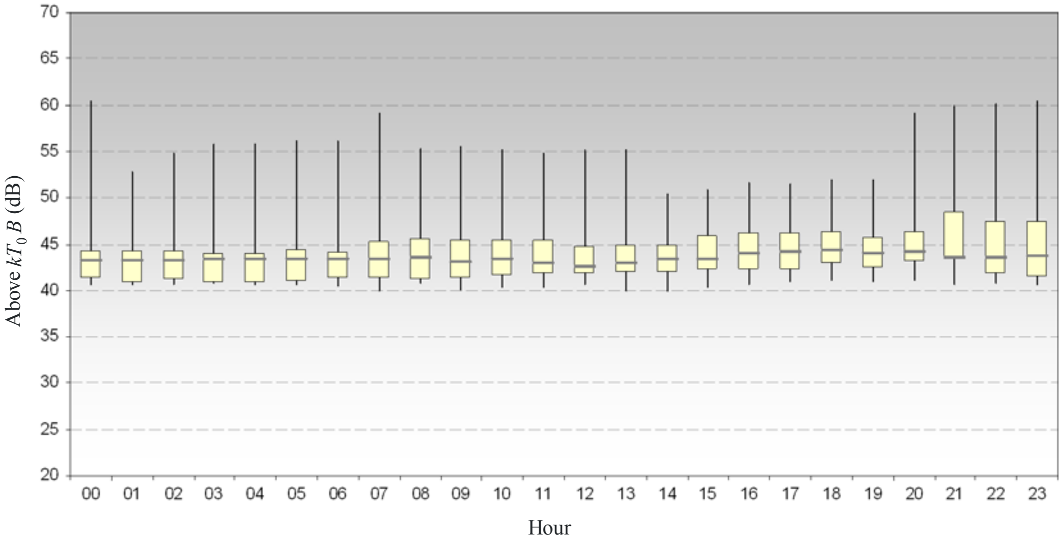

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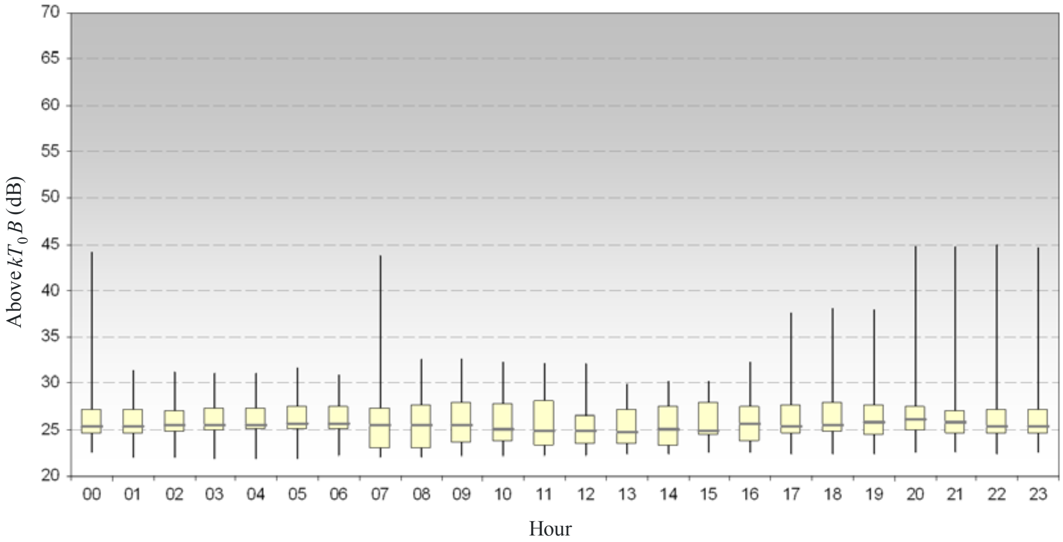
FIGURE 28

WGN rural 20 MHz (box plot)



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The evaluation of the measurements indicates that the WGN values are mostly lower than current figures given in Recommendation ITU-R P.372. Table 4 compares the median results over the whole day and all German measurements done so far with the values of Recommendation ITU-R P.372.

TABLE 4

Comparison of German (GER) WGN measurements with Recommendation ITU-R P.372

Frequency (MHz)	City		Residential		Rural	
	P.372	Measurements GER (max/med/min)	P.372	Measurements GER (max/med/min)	P.372	Measurements GER (max/med/min)
5	56.5 dB	59.6 / **53.6** / 49.6 dB	52.2 dB	60.5 / **49.9** / 45.7 dB	46.9 dB	54.3 / **49.5** / 45.8 dB
12	46.1 dB	59.5 / **47.2** / 43.2 dB	41.8 dB	52.8 / **44.7** / 41.0 dB	36.5 dB	55.2 / **43.4** / 41.0 dB
20	40.5 dB	40.2 / **35.2** / 26.3 dB	36.2 dB	40.8 / **27.1** / 22.5 dB	30.9 dB	31.3 / **25.3** / 22.6 dB

The following figures show some examples of the IN evaluation.

FIGURE 29

Typical IN level distribution

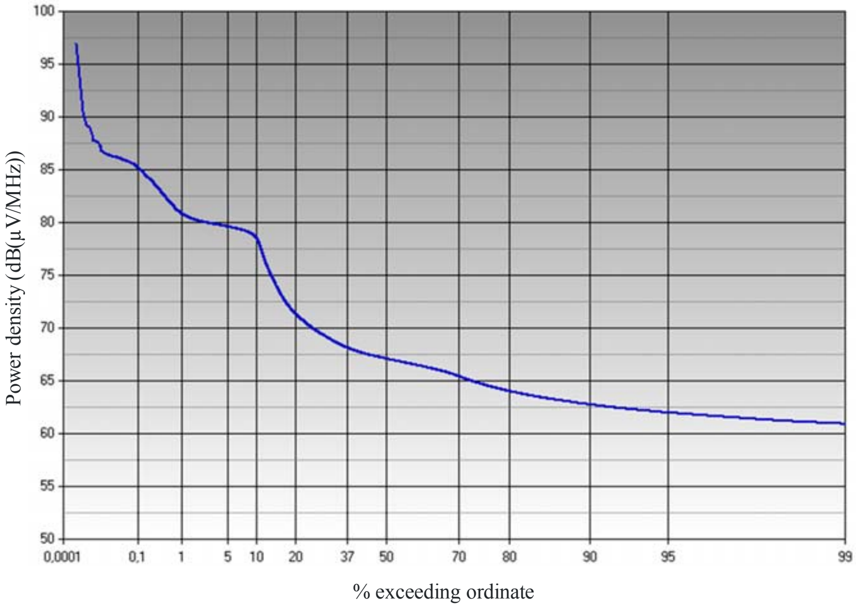

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FIGURE 30

Typical IN pulse length distribution

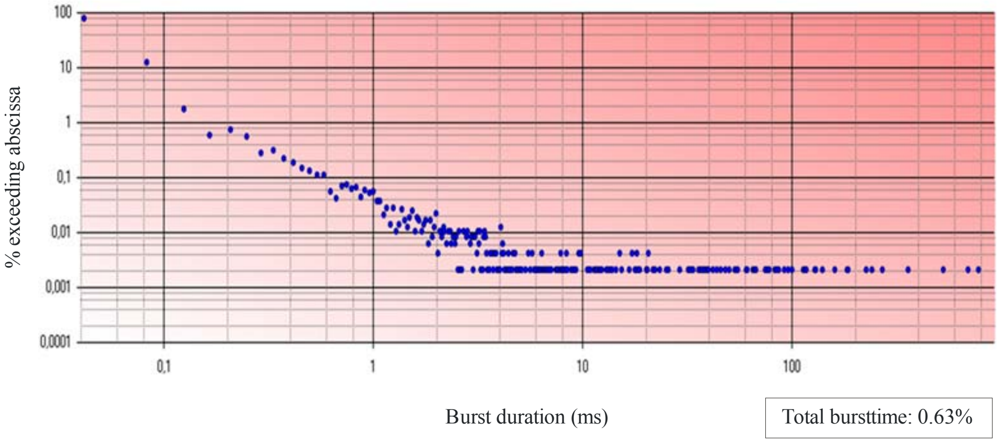

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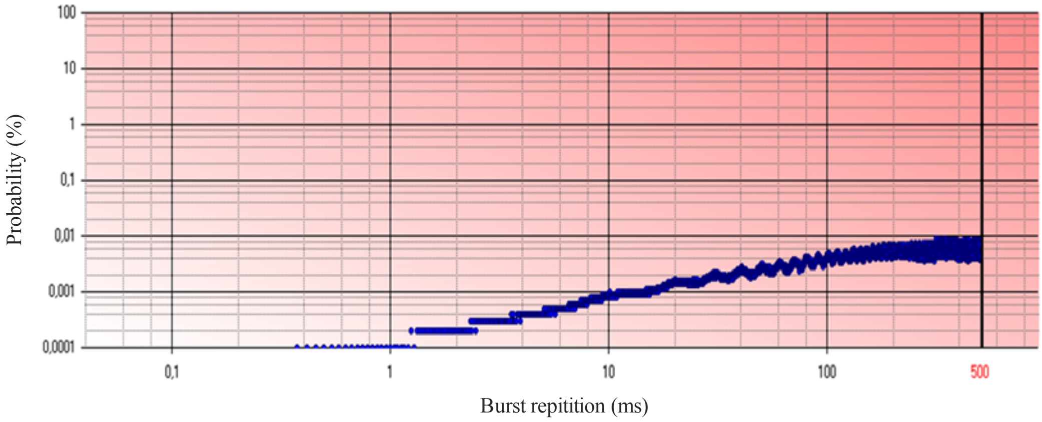
FIGURE 31

Typical IN pulse repetition distribution



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The German MMN measurement campaign is planned to continue for several years and the WGN results will continuously be provided to the ITU radio noise databank.