

# MAN-MADE NOISE MEASUREMENTS CONSIDERING DIGITAL COMMUNICATION SERVICES

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**Abstract:** In the design phase for wireless communication services the only support regarding noise is the ITU-R recommendations. These recommendations are intended for analogue systems and are based on 20 to 30 year-old measurements. Furthermore, the ITU-R recommendations presume the use of Gaussian noise characteristics and an omnidirectional antenna. Thus, there is an increased need to investigate the validity of these assumptions regarding the levels, distribution and dependence of direction. As a first step to increase the knowledge of man-made noise with respect to digital communication systems, a series of measurements was carried out. The result showed that the levels are within the range of the ITU-R recommendations. We also found that there is a large dependence on direction. The assumption that the noise has Gaussian distribution is not valid for all environmental categories.

## 1 Introduction

Military tasks, such as peacekeeping operations, involve cooperation with civilian society and are dependent on wireless communication services. Major restrictions on the performance of such systems are caused by man-made noise. In the design phase for these systems the only support regarding noise is the ITU-R recommendations [1]. These recommendations are intended for analogue systems and are based on 20 to 30 year-old measurements. Furthermore, the ITU-R recommendations presume the use of Gaussian noise characteristics and an omnidirectional antenna. In many cases the noise characteristics are of vital importance for modern digital communication systems. Moreover, future systems will also include advanced antennas, making the spatial distribution of the noise interesting. Thus, there is an increased need to investigate the validity of the fundamental assumptions concerning man-made noise levels, distribution and dependence of direction in the ITU-R recommendations.

As a first step to increase the knowledge of man-made noise with respect to digital communication systems, a series of measurements was carried out. This paper presents a summary of the results from 1999. So far, measurements were made at three sites in Sweden, representing rural, suburban and residential environments. The noise at each site was measured for two months with a specially designed measurement system.

## 2 Methodology

The system was designed to measure noise levels, dependence of direction and to analyse the amplitude distribution in the frequency range 30 – 2000 MHz. Furthermore, the effects of bandwidth and polarisation were investigated. Calibrated logperiodic antennas and calibrated measurement receivers were used to guarantee for the measured levels. An increment of 60° for

the rotation of the antennas was selected, based on the antenna lobe of 120°. Twenty frequencies, not allocated to transmitters, logarithmically distributed over the frequency range were chosen. We made measurements on two bandwidths, 10 kHz and 120 kHz. Most of the results in this paper are based on the measurements with a bandwidth of 120 kHz. Three different measurement sites were chosen. Site one is located in a rural area outside Linköping, site two in a suburban area north-west of Stockholm and site three in a residential area two kilometers from the city center. An rms detector in the receiver gave us the noise level in dBμV. This was then converted to antenna noise factor  $F_{am}$ , referred to as noise value, or value. The ITU-R noise levels are referenced to a vertical short monopole. To make our measured levels comparable we adjust them for the differences in antenna characteristics. This was done in the following way. Consider the incoming intensities from a number of emitters  $S_1, S_2, \dots, S_n$ . If the antenna sweeps continuously around the horizon, 0 to 360°, the average value of the signal power from the logperiodic antenna will be:

$$\langle P_{SLP} \rangle = q\eta D_{LP} \frac{\lambda^2}{4\pi} \left\langle \sum_{i=1}^n S_i \right\rangle \frac{1}{2\pi} \int_0^{2\pi} \left| F\left(\frac{\pi}{2}, \varphi\right) \right|^2 d\varphi, \quad (1)$$

where:

$q$  = Mismatch loss

$\eta$  = Efficiency

$D_{LP}$  = Max. directivity of the logperiodic dipole

$F(\theta, \varphi)$  = Normalised directivity

From a lossless short monopole (gain = 3) we would get:

$$P_{SMP} = 3 \cdot \frac{\lambda^2}{4\pi} \left\langle \sum_{i=1}^n S_i \right\rangle. \quad (2)$$

From this we can calculate the antenna noise factor

$$f_a = \frac{P_{SMP}}{kTB} = \frac{3}{q\eta D_{LP} \frac{1}{2\pi} \int_0^{2\pi} \left| F\left(\frac{\pi}{2}, \varphi\right) \right|^2 d\varphi} \frac{\langle P_{SLP} \rangle}{kTB}. \quad (3)$$

We measured the gain of the logperiodic dipole as a function of the azimuth,  $\varphi$ . The radiation diagrams are of similar form for the frequencies above 40 MHz with a main lobe 120° wide and a front to back ratio of about 10 dB. The integral in the denominator was calculated from these data, which gives the adjustment factor shown in Figure 1. The bandwidth adjustment was done using the data from the receiver handbook. At the

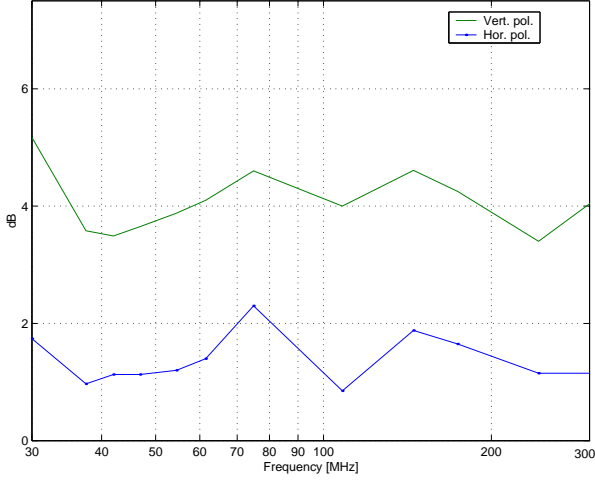


Figure 1: Adjustment factor for the logperiodic antenna.

receiver video output,  $V_{rms}$  and  $V_{avg}$  were measured. From these the ratio [2]

$$V_d = 20 \log \frac{V_{rms}}{V_{avg}} \quad (4)$$

was calculated. The parameter  $V_d$  provided a measure of the impulsive nature of the noise. We have chosen to call this parameter the impulsiveness ratio. If both the in-phase (I) and quadrature-phase (Q) components are Gaussian distributed, then the measured signal will be Gaussian. This system calculates histograms of the I and Q output from the receiver. Based on measured standard deviation a theoretical Gaussian distribution  $p(x)$  is calculated. This distribution is compared to the measured distribution  $q(x)$ . As a test for the equality between the distributions, we use the Kullback Leibler distance, [3]

$$D(p \parallel q) = \sum p(x) \log \frac{p(x)}{q(x)}. \quad (5)$$

Imperfections in the measurement system give deviations from the theoretical values. Therefore, a calibrated noise source is used as reference for the test.

### 3 Results

We found significant differences in the noise levels for the different sites and for the two polarizations. From the measurements at the two bandwidths we have found that the noise power is directly proportional to the bandwidth. As expected, the lowest levels can be found at site 1 and the highest at site 3. We have also found that the median levels and the variation with frequency for the measured values correspond quite well with the values from the ITU-R recommendation. First we will study the level of the noise factor  $F_{am}$  for the horizontal and vertical polarization as a function of frequency for the three different sites. To make this comparison with the ITU-R levels, which are given for an omnidirectional antenna, we have added the correction factor described above.

#### 3.1 Polarization

The largest difference between the polarization can be seen at site 1, with the horizontal polarization always having the highest level, see Figure 2. At site 2, see Figure 3, the horizontal polarization gives somewhat higher values than the vertical for most of the measured frequencies, although the difference is not large. At site 3, see Figure 4, the vertical polarization gives higher values for the lower frequencies and the horizontal for the higher frequencies. The relative high values for the frequency 108.1 MHz, which is in the FM BC band, can be caused by high sideband levels from an FM radio station.

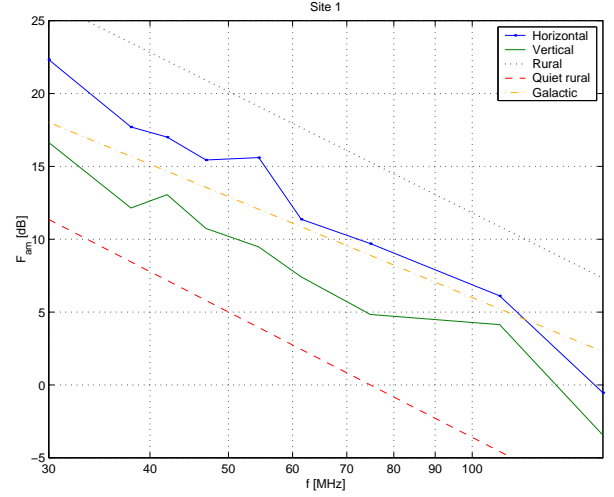


Figure 2: Median levels for horizontal and vertical polarization at measurement site 1 compared with ITU-R levels.

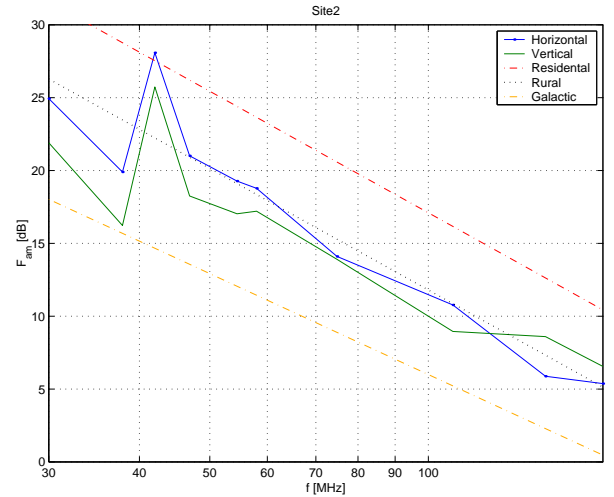


Figure 3: Median levels for horizontal and vertical polarization at measurement site 2 compared with ITU-R levels.

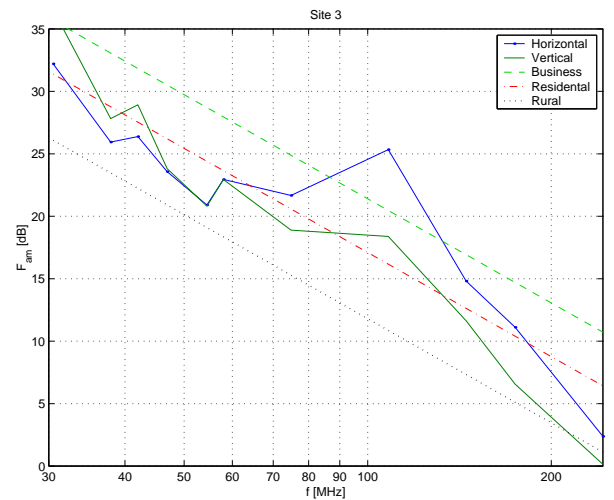


Figure 4: Median levels for horizontal and vertical polarization at measurement site 3 compared with ITU-R levels.

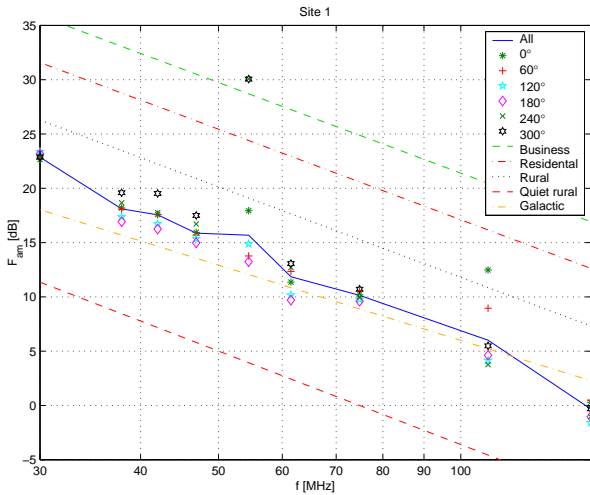


Figure 5: Median values for the different directions and the total median for site 1 compared with the ITU-R levels.

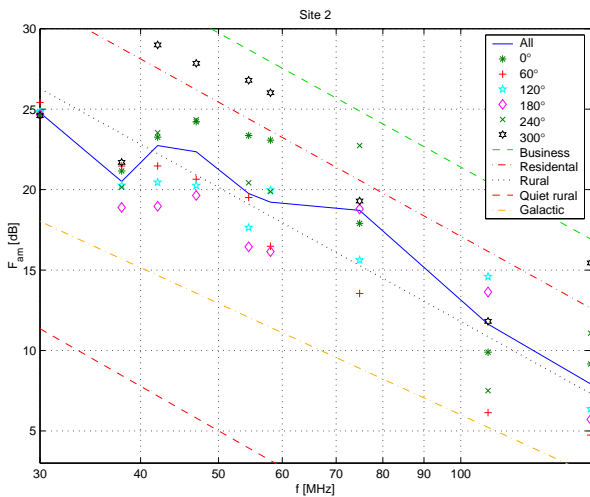


Figure 6: Median values for the different directions and the total median for site 2 compared with the ITU-R levels.

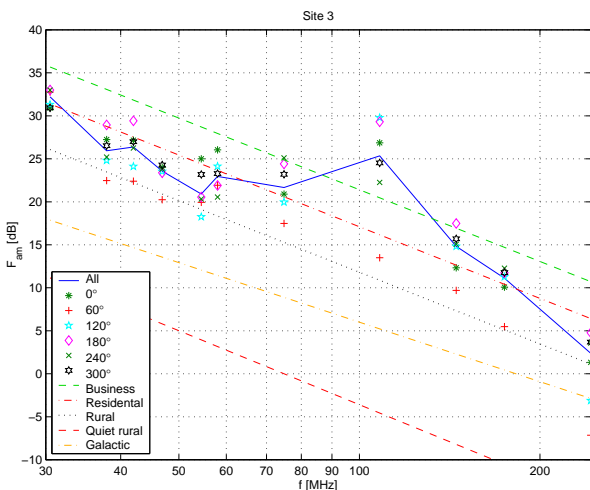


Figure 7: Median values for the different directions and the total median for site 3 compared with the ITU-R levels.

### 3.2 Direction

We have also found that the noise levels are dependent on the direction of the antenna. This can be seen in Figure 5 - 7. At the lowest measured frequency the antenna directivity is small. All of the sites have a relatively high dispersion of the noise levels at the frequency slightly above 100 MHz. The phenomenon is probably traceable to the fact that this frequency is in the FM BC bandwidth. There is no FM station at the measured frequency that should be within range to be detected. However, the measured frequency is probably contaminated by sidelobes from adjacent stations. The difference between the directions for site 1 is about 1.5-3 dB. Two relatively high values can be found for the frequency 54.5 MHz, which can be seen in Figure 5. They probably originate from a TV station situated at some distance. The highest dispersion depending on the direction can be seen at site 2, Figure 6, where it is 5-10 dB. It can also be seen that one of the directions represents the highest values for most of the frequencies. In that direction there are traffic lights at a busy road. At site 3 there is one direction that always has the lowest value, see Figure 7. In that direction it is quite far to the nearest building, except for a house with a tin roof which is placed below the height of the antenna.

### 3.3 Amplitude distribution

We have not evaluated the tests fully, but we did a straightforward comparison between the test variables of the measured noise and the noise generator. An example of the result of the Kullback Leibler distance test can be seen in Figure 8, where we show the frequency 42 MHz, 120 kHz bandwidth, vertical polarisation and the inphase signal component. Measurements on the noise generator give values in the range 60 - 140, with most of the measured data for the example at site 1 (the histogram at the top of Figure 8) falls within the same interval. Site 2 has the lowest measured data within the interval, whereas site 3 has a little more data in the interval. Note that the y-axis scale for site 1 is three times the scale of the others.

By these calculations on the results from the tests, we get an indication of how much of the data that could be assumed to have Gaussian distribution and how much that had a low extent of impulses. About 95% of the data from site 1 passes the test for Gaussian distribution. At site 2, not much of the data will pass the test; only about 40%. Site 3 is, as expected, in the middle concerning passing the test, with about 65%. Table 1 shows the percentage for the different sites and frequencies passing the test. The first measured frequency at site 3 is totally jammed,

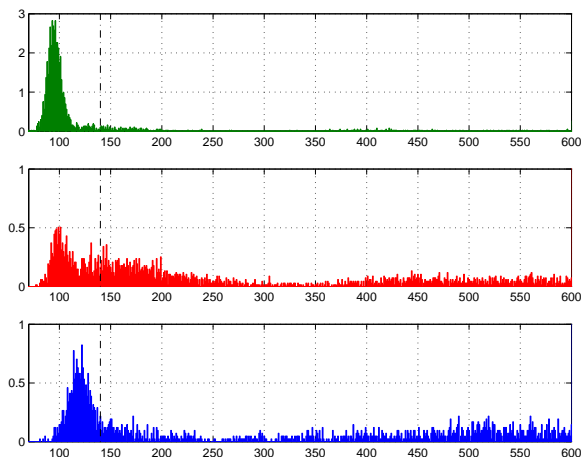


Figure 8: An example of the inphase component of the information divergence test for the three sites. Site 1 at the top, Site 2 in the middle and site 3 at the bottom.

Table 1: Percentage of the data passing the test both for in-phase and quadrature phase. The — marker indicates that the measurement was buried in noise from the measurement system. This is also the case for all higher frequencies.

Frequency MHz	Site 1	Site 2	Site 3
30	89.59	45.41	0.14
37.9	89.33	41.60	25.42
42	92.72	43.32	37.09
46.9	90.41	28.02	65.11
54.5	97.26	21.63	66.75
58	96.83	19.81	79.75
74.85	96.42	40.82	81.01
108.1	98.71	47.78	97.27
145	—	38.93	73.04
174.5	—	—	98.46

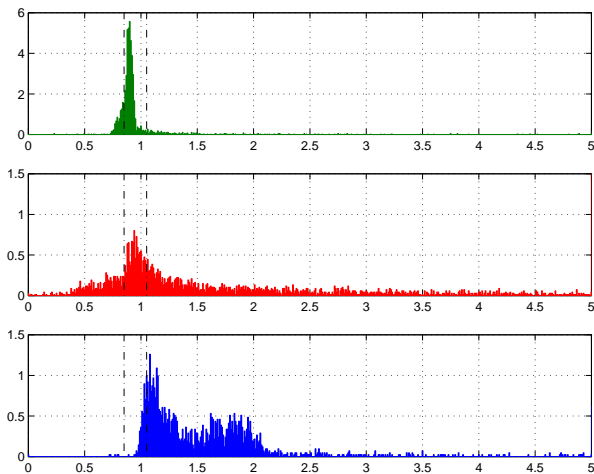


Figure 9: An example of the impulsiveness ratio for one frequency at the different sites.

Table 2: Percentage of the data passing the test both for in-phase and quadrature phase. The — marker indicates that the measurement was buried in noise from the measurement system. This is also the case for all higher frequencies.

Frequency MHz	Site 1	Site 2	Site 3
30	95.15	47.11	2.73
37.9	90.91	44.07	30.39
42	95.15	52.86	53.52
46.9	92.21	36.62	81.69
54.5	98.85	23.78	68.31
58	98.85	21.46	86.08
74.85	99.41	36.30	80.82
108.1	99.7	45.83	97.22
145	—	70.51	98.06
174.5	—	—	99.23

giving that only about 0.1% of the data can be assumed to be Gaussian.

An example of the distribution of the impulsiveness ratio can be seen in Figure 9. We have used the same parameters as for the previous example when making the histograms. Measurements on our noise generator give values in the range of 0.85 - 1.05. The theoretical value for a Gaussian distribution is 1.04, but the measurement system gives values that differs from this. In the example the histogram for site 1 shows a cluster slightly below 1, which indicates that there are not many impulses in the noise. At site 2 the cluster is widely spread, indicating that the noise is rich in impulses. At site 3 the data is mostly concentrated below 2 that indicates that most of the noise has small impulses. Summing the impulsiveness gives that site 1 has about 3% noise that is rich in impulses, site 2, more than half, and site 3, about one third. Table 2 shows the percentage for the different sites and frequencies that are not rich in impulses.

#### 4 Conclusions

The overall conclusion is that the level of the noise in our measurement is within the range of the ITU-R recommendations. The site assumed to be rural has noise levels a little bit higher than the ITU-R recommendation for quiet rural areas. The suburban site has noise levels that could be compared with rural areas in ITU-R. The residential site has noise levels which corresponds well with the ITU-R recommendations for residential areas. The noise levels show significant variations according to the direction for the suburban and residential sites. The magnitude of the variations is 6-15 dB. At the rural site, the majority of the measurements can be assumed to be Gaussian distributed (approximately 90%). At the suburban site our tests indicate that less than half of the measurement can be assumed to be Gaussian distributed. At the residential site the tests indicate that approximately two-thirds of the measurements can be assumed to have Gaussian distribution. Concerning impulsiveness, we have found that at the rural site about 3% of the noise is rich in impulses, whereas at the suburban site more than half of the noise is rich in impulses. At the residential site about one third of the noise is rich in impulses.

#### 5 Acknowledgements

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#### References

- [1] "Recommendation ITU-R PI.372-6," Tech. Rep., Geneva, 1994.
- [2] A. D. Spaulding, et al., "Urban residential man-made radio analysis and predictions," Tech. Rep., OT Telecommunications Research and Engineering Rep., US Govt. Printing Office, Washington, DC 20402, 1971.
- [3] S. Kullback and R. A. Leibler, "On information and sufficiency," *Ann. Math. Stat.*, 1951.