REPORT ITU-R SM.2055*

Radio noise measurements

(Question ITU-R 231/1)

(2006)

TABLE OF CONTENTS

Page

* Radiocommunication Study Group 1 made editorial amendments to this Report in the year 2023 in accordance with Resolution ITU-R 1.

1 Summary

This Report describes a new, general, measuring technique for determining radio noise in practical radio applications. This proposed technique is not equipment-specific; critical elements of the method will be described in detail. The proposed method is mainly useful for measurements where no statistical processing of raw sampled data is necessary. To cope with the fact that the method should work with different measurement receivers and analysers, a post processing method is developed that works with both scanning and single frequency devices. This method, which will be described in § 4, should yield comparable results for both types of devices. Although some examples in the Report are based on HF (< 30 MHz) measurements, the method is frequency-independent. Fast raw data sampling methods are not described here but many of the post processing items can also be used with this method. Administrations are invited to update this Report in the future with additional processing and data collection methods.

2 Introduction

In 2002 CEPT decided to conduct a measurement campaign in the LF, MF and HF bands to evaluate the radio noise levels given in Recommendation ITU-R P.372 to assist a project team on spectrum engineering in its technical work concerning the compatibility between cable transmission systems and radio services.

Recommendation ITU-R P.372 was updated in 2001 but the radio noise figures are still based on the results of man-made measurements made in the 1970s. Due to the introduction of new radiocommunication systems the radio noise levels stated in this Recommendation may have changed. For efficient spectrum management administrations need to know the exact noise levels. After having completed a measurement campaign it became clear that obtaining comparable results was much more complicated than it seemed at the start of the campaign.

As the measurement method and procedures in the 1970s could not be reproduced for various reasons, a properly described new measuring method should be developed. Therefore the Netherlands group of experts from scientific bodies, defense, industry, radio amateurs and the Radio Communication Agency initiated a relevant study.

It was to develop a frequency independent measuring method that should also be in line with the technical properties of modern equipment and software for post processing. For instance, in the monitoring campaigns as conducted in the past, the frequencies were manually observed to avoid that strong signals would interfere the calculation of the radio noise levels. Nowadays computers and software can do the same task faster and better, leaving the time for detailed analysis of the end result.

3 Properties of noise to be measured

The definition of noise depends on the branch of technology we are working in. For example in radio broadcasting, noise is the pulse-shaped ignition type interference or power leaking from the adjacent channels of a wanted broadcasting system. In radio astronomy it is the always present noise from cosmic origin. When we speak about *radio noise* in this Report we do not mean noise from a single specific origin, but the sum of the low level (almost statically present) noise types affecting the investigated communication systems. This type of noise is assumed to be Gaussian, not deterministic, and has a normal amplitude-time distribution. The noise signals impinging on the receiving system are assumed to have a smooth spatial distribution, and are also assumed to be spatially uncorrelated. In other words, it is not possible to point out a single noise source by observing the angle of arrival of the received signal within the aperture of the receiving antenna (array) or observing the amplitudes of the received signal in the observation time window. Only the statistical properties of a large number of cumulated sources can be analysed.

The most important classes of noise we have to take into account in our measurements are listed below. As the choice of the proper antenna depends on the type of noise to be measured, we included a detailed description of this in the antenna section.

– *Atmospheric noise*

  Sky wave signals are dominant here; ground wave propagation only occurs at LF and MF frequencies. Signals from all azimuth direction are present, but a direction dependency, strongly influenced by time, season, frequency and weather conditions should be taken into account. The same is true for the elevation angle, which is also frequency dependent.

– *Cosmic noise*

  Ionosphere penetrating sky wave signals are dominant here. This limits the occurrence to the higher frequencies, above f_0. Signals arrive from all elevation angles with stronger signals from high elevation angles.

– *Thermal noise*

  There are two different kinds of this type of noise. The noise from the Earth and noise from large stellar bodies like the sun and the moon. Effects are season and time dependent but are most of the time reasonably predictable. Propagation is ground or direct wave.

– *Equipment noise*

  This is a constant noise produced by the low noise amplifier (LNA) receivers and antenna-amplifiers. In particular setups even the antenna itself can produce noise. It is a factor that can be "nulled" out easily.

– *Man-made noise, cumulated sky wave signals*

  The occurrence of this type of noise strongly depends on ionospheric propagation conditions like D-layer absorption. The azimuth direction and elevation angle are the same as for atmospheric noise.

– *Man-made noise, cumulated ground wave signals*

  An uneven distribution of azimuth directions is probable.

– *Man-made noise, cumulated local coupled signals*

  Short-range E-field/ground wave and near field coupling occurs.

– *Man-made noise, single source local coupled signals*

  This type of noise is outside the scope of the radio noise measurements described in this Report and should be excluded.

4 Measurement method/algorithms

This section describes a way to select only those types of signals representing the definition of *radio noise* as described in § 3. All steps to accomplish a usable measurement are presented sequentially. The goal was to develop a simple method not incorporating expensive digital signal processing (DSP) and hard disk recording systems. However it is advisable to use such systems to determine the statistical properties of the noise present in different environments. This way correction factors and percentages can be determined more correctly.

The crux of the proposed radio noise level measurement method is to find regions in the spectral-time domain which are not occupied or which are only partially occupied with (distinguishable) transmitters. After finding such a region, the radio noise power level can be estimated by analysing the lowest measured signal power values. The high power values are discarded because these values may contain (distinguishable) transmitter signals. As the probability density function (pdf) of the noise is known, the measured lowest power values can be extrapolated, yielding an estimate of the radio noise power root mean square (r.m.s.). This method involves a correction factor measurement which is needed to compensate for the radio noise power estimation bias.

In this method it is assumed that the radio noise is Gaussian, and that a certain fraction of the time-frequency window does not contain distinguishable transmitters. The latter can easily be verified by inspecting time-frequency spectrograms, assuming that transmitter bandwidths are smaller than the spectrum range under consideration. An additional verification that a region does not contain transmitter signals is to apply higher order statistics, but this requires a non-standard signal processing mode, and is not discussed great detail.

4.1 Receivers and detectors

For measuring noise in the first place we need a receiver or analyser with a bandwidth limiting filter. Over a short time period noise is an unpredictable random phenomenon so for a correct measurement of the noise power density we need an r.m.s. detector. The r.m.s. detector needs to be a true r.m.s. detector. In order to limit the power measurement uncertainty the sampling rate of the level sampler should be at least twice the IF filter bandwidth. These requirements apply for both analogue single channel systems and digital single channel or multichannel fast Fourier transform (FFT) systems but in this section a single channel system is considered. The time between each sample is called the sampling period of the detector. Do not confuse this with the sample period of the samples from the detectors A/D converter from which the r.m.s. value is calculated. After a certain time the logic circuitry of the detector calculates the r.m.s. value over a certain time period, this is called the integration time. So when we measure noise the actual measured value depends on the chosen IF filter bandwidth. But because we know the properties of the measured noise, which in our case has a normal distribution, we can correct the values for the chosen filter bandwidth.

NOTE 1 – Old equipment sometimes contains r.m.s. detectors that are not true, these detectors only apply a fixed correction factor to the measured peak value. This works only for sinusoidal signals and not for noise. Its is possible to use an external r.m.s. detector, or a peak envelope detector, see Note 2.

NOTE 2 – When no r.m.s. detector is available it is possible to use the peak envelope detector of the analyser or receiver with some restrictions. Two additional errors are introduced that have to be compensated for.

Error 1: The envelope of a narrow-band Gaussian process is Rayleigh distributed. Measuring with a peak envelope detector means in fact that the noise signal envelope is averaged prior to detection. The Raleigh distribution has the pdf $P_{RAYLEIGH}(R)=\frac{R}{\sigma^2}e^{\left(-\frac{R^2}{2\sigma^2}\right)}, R\geq 0$. The standard deviation σ is the r.m.s. deviation from the average. The average value is $\sigma\sqrt{\frac{\pi}{2}}$ and the r.m.s. value is $\sigma\sqrt{2}$.The ratio r.m.s./average is $\sqrt{\frac{4}{\pi}}$ or 1.05 dB in power which has to be added to the measured results.

Error 2: When the signal is compressed logarithmically before it is averaged (detected) as stated in error 1 there is an additional error caused by the fact that the average is less influenced by the larger noise samples/perturbations. For Gaussian noise this error is 1.45 dB in power that also has to be added to the measured results. This is for example the case when an external r.m.s. detector is connected to the log amplifier of a measurement receiver.

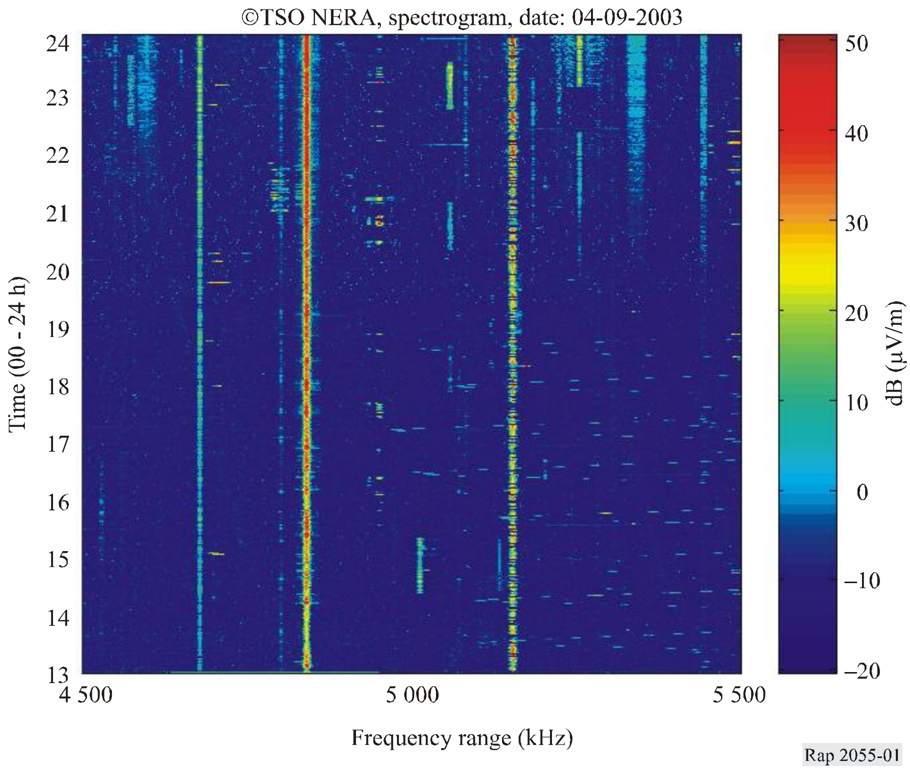
This only works when the noise has a normal distribution and the overall measurement accuracy is less than with a true r.m.s. detector.

4.2 Selecting a frequency

When measuring noise the choice of frequency can be a problem because strong carriers or high average occupation can limit the usable observation time. We first need to investigate (scan) a frequency band which is larger than the frequency band or frequencies to be observed in the final measurement period. Our goal is to end up with for example an 100 kHz band or a single frequency without too much interference. This can be done with a relative large IF filter and high attenuator setting. Of course the measurement has to be representative for the future so the process might be repeated a few times.

FIGURE 1

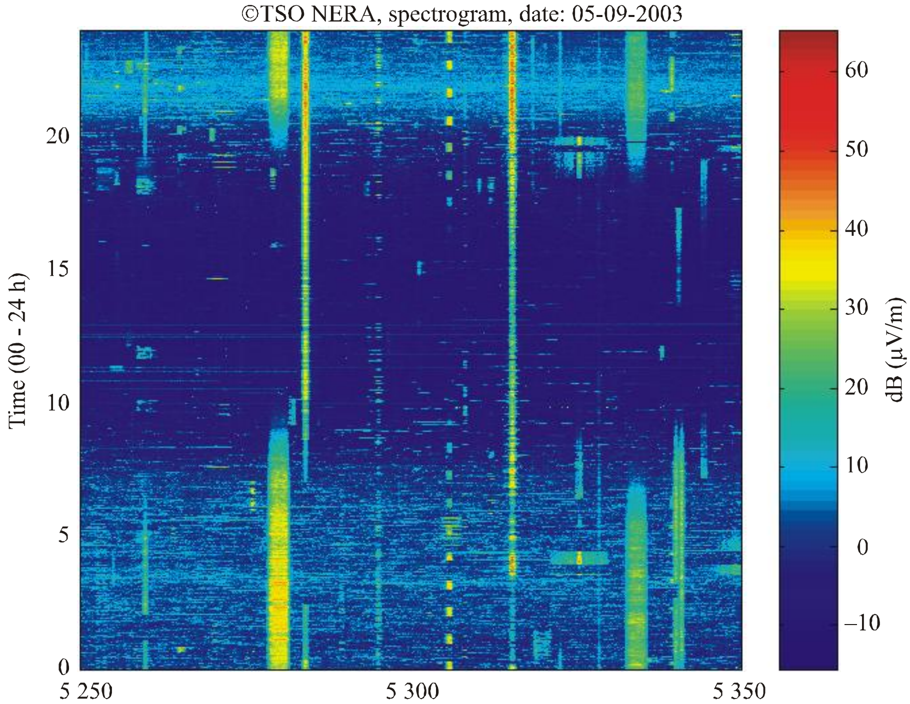
Pre-scan to determine usable frequency slots



The next step is to scan the frequency band with a spectrum analyser or scanning receiver. The number of frequencies to be scanned should not be too low because we want to apply some selection criteria on the obtained results. Typically a value between 10 and 1 000 can be used. Single frequency measurements are possible with some limitations. Figure 1 below show scans frequency versus time on the selected frequency of 5 300 kHz. The number of frequency steps is 500 in this case.

FIGURE 2

Select frequency slot



Rap 2055-02

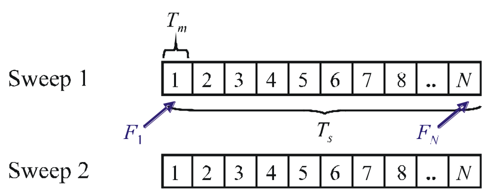
4.3 Collecting the noise containing samples (swept or single frequency measurement)

To keep our methods as equipment independent as possible two methods of collecting noise samples are described here. One method uses a receiver and the other a swept spectrum analyser.

Using an analyser: Scan a small section of frequency band from frequency F_1 to F_n, representative for the frequency range in which the noise has to be measured. This will result in a range of N samples taken in the sweep time T_s of the analyser. The measurement time T_m is [$T_m = T_s/N$]. Note that the integration time per sample usually is less than the measurement time.

FIGURE 3

Two frequency scans (sweeps) using a spectrum analyser

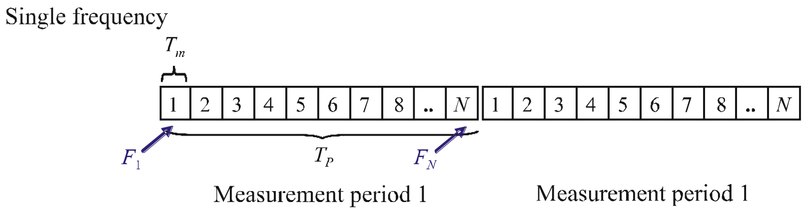


Rap 2055-03

Using a single channel measurement receiver: Record N samples on a single frequency for a time period T_p. The measurement time T_m is [$T_m = T_p/N$].

FIGURE 4

Two frequency scans (step ranges) using a single frequency channel device



Rap 2055-04

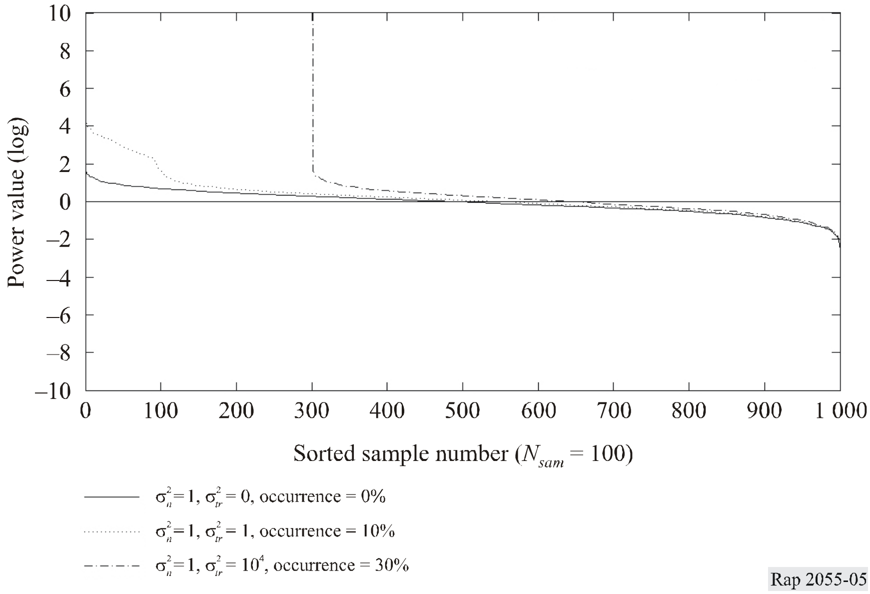
For measuring noise power densities in a small frequency range there is no difference in scanning a small section of frequency band or sampling on only one frequency as long as we take the measurement period of the receiver equal to the sweep time of the analyser. Only when strong constant signals are present at the single frequency bin, those periods are unusable making the analyser method more efficient than the single channel instrument. Here we assume that there is no "dead-time" between taking successive samples or scans, and that the measurement time is the same for both types if instruments. Please note that the integration time per sample usually is smaller than the measurement time, so that this has to be corrected for when calculation the variance of the power estimate. It is also assumed that the successive data samples are independent. If this is not the case (over-sampling) than this has to corrected as well. Spectrum analysers usually apply such a correction factor.

4.4 Selecting the noise containing samples

Connecting an antenna to a receiver means that we always measure a combination of noise and non-noise signals. A way to filter is to eliminate those signals that are not continuously present in the frequency band. In fact it is nothing more than sampling/measuring the field strength over a relatively long period and eliminate those samples that do not confirm to the definition of noise (i.e. a random process with a normal amplitude distribution). We can use a measurement receiver or spectrum analyser and record the field strength using a computer. It is assumed that the samples containing unwanted signals are stronger than samples only containing the wanted signals, of course only over a short period. In practice we found that for short wave between 3 and 20 MHz for example 20% of the samples with the lowest value can be used to estimate the noise levels in these short-wave bands. For other frequency bands and applications we can use another percentage value. As an illustration, Fig. 5 shows an estimated power distribution simulation for a receiver/spectrum analyser system. A situation is considered where there is only noise present and two situations are considered in which there are also transmitters present. The background noise power s_n^2 can be estimated by taking the value corresponding to the middle (sorted) sample number (number 500 in this Figure). The observed power estimate s_n^2 will lie close to the true value when the transmitter occupies less than 50% of the time-frequency space. There is a small bias which can be measured using a noise source. In case the transmitter occupies more than 50% and less than 80% of the time-frequency space the 20% criterion is preferred. The 20% criterion corresponds to power values belonging to the 20% lowest samples (sample number higher than 800 in Fig. 5). The average value of these data points lies a few tenths of a dB below the true value, but this offset can be calibrated as well by using noise sources, as will be explained in § 4.6

FIGURE 5

Simulation of a receiver system



Rap 2055-05

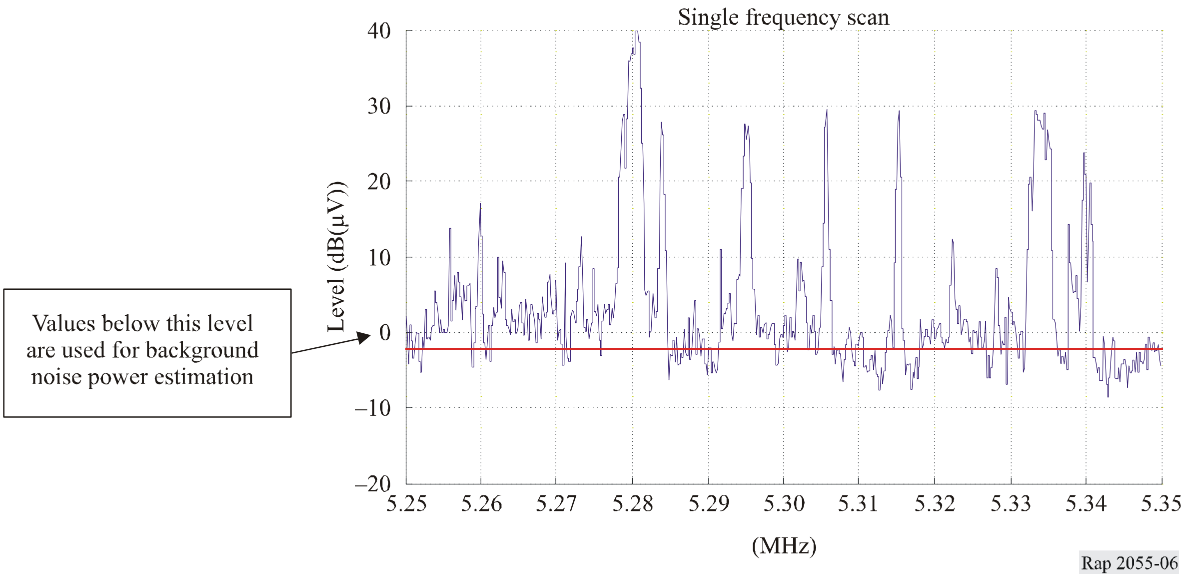
Figure 5 is the result of the simulation of a receiver system showing the (sorted) received power for 1 000 frequency bins and 100 time samples per bin, N_{sam}. The solid curve represents the noise-only situation, with noise power $s_n^2 = 1$. The dotted curve represents a situation in which also a transmitter is present with a bandwidth which fills 10% of the band under consideration, and which has a signal power $s^{tr2} = 1$. The dash-dotted curve represents noise plus a transmitter with $s^{tr2} = 10^4$, which is present in 30% of the band.

4.4.1 Determining the percentage

The choice of 20% in the following example is made by analysing the distribution of level values present in some randomly chosen scans representative for the total set. Figures 6 and 7 show one of these distributions. In Fig. 6 we see a scan with a threshold level of −2 dBμV, all values above this line are considered non-noise, in other words unwanted signals.

FIGURE 6

Randomly chosen scan

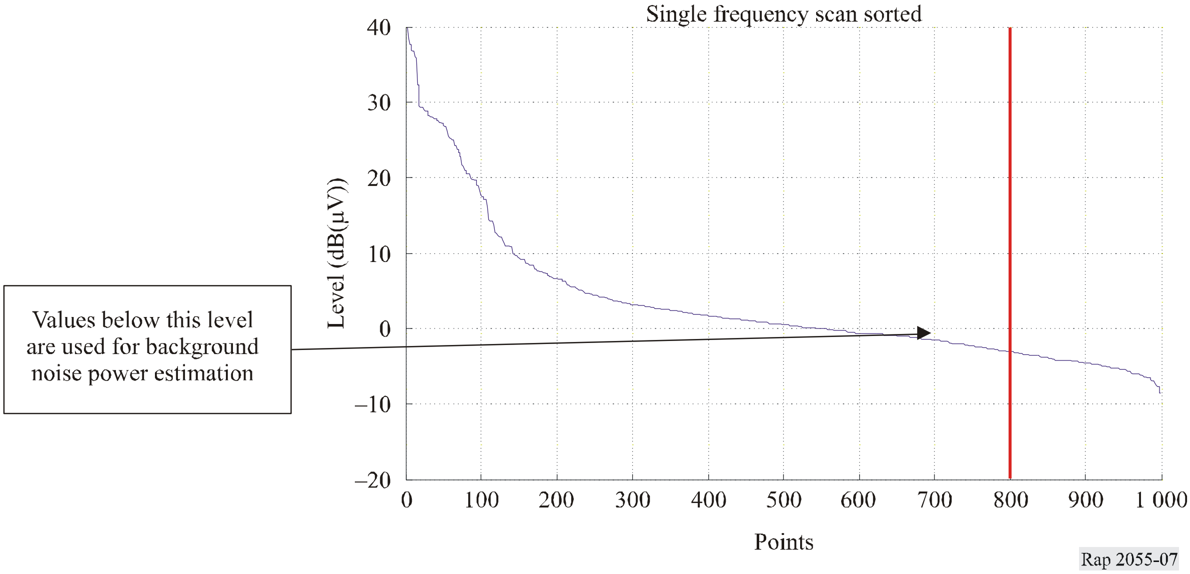


Rap 2055-06

Figure 7 shows the same scan but with all the values sorted. By setting the same level of −2 dBμV we can choose the percentage, in this case 20%.

FIGURE 7

Randomly chosen scan with sorted values

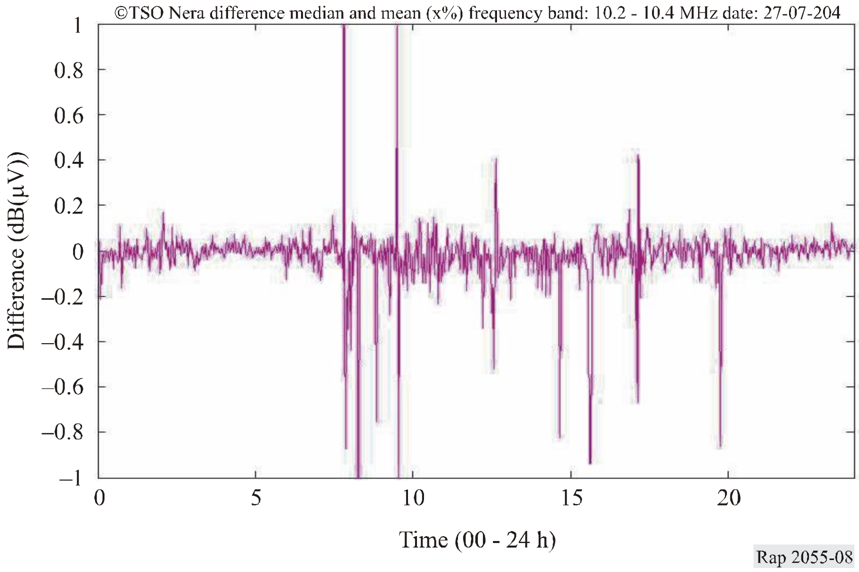


4.4.2 Validation of the chosen percentage

In reality a fixed value of for example 20% can be used for a relatively short measurement period (1 h-1 day). It is better to use a dynamic value or a value optimized for a specific frequency band or application. Initially we can use the method described before with an extra test to guarantee that even with small percentages the samples are not too much affected by strong transmitter signals. A practical test is the difference between the mean and median value, which is obviously influenced by transmitters. Another test would be to check whether the curve at the right side of the "20%" point is smooth and has a small slope. Both test methods require some a priori calibration. Also a meaningful number of samples needs to be used in the calculation, for example a single sample cannot be used in this type of test.

FIGURE 8

Difference between mean and median values (20% selection)



Rap 2055-08

As an example the graph above shows the difference between mean and median values with a fixed percentage of 20% for all scans. The observation period is 24 h (0000 to 2359). During the hours 0700 till 2000 thunderstorms cause the distribution of the 20% selection to have large slopes and thus large differences between the median and mean power values.

4.4.3 Calculating the average noise level

After the selection of noise containing samples the average of these is calculated and the number of used samples is stored with this value to determine the correction factors.

4.5 Correcting for equipment noise

The signals we measure with a measurement receiver or spectrum analyser are in fact signals superimposed on the equipment noise. For normal measurements the error caused by this noise is negligible but for low level noise measurements its not. The way for correction is as follows. Measure for a short period without connected source (passive antenna) but with connected and properly terminated low noise amplifiers and the same settings as the original measurement. Now select the samples with the lowest value using the same method and same percentage as during the original measurement and subtract this value linear from the measured average level value.

NOTE 1 – If the antenna is active this procedure should be performed with connected antenna in an anechoic chamber (Faraday cage with wall-absorbers).

4.6 Correcting for 20% or *x*% values

The unwanted noise components e.g. carriers are filtered out by the 20% method. However, as was mentioned before, the wanted noise is also filtered by this method. A correction factor needs to be applied to compensate for the introduced error. This error can be determined with a Gaussian noise source and the actual settings to be used in the measurements, both IF filter, video filter and wanted *x*% percentage.

For a specific noise type alternative noise sources can be used.

NOTE 1 – In fact the correction factor is not a constant but dependent on the actual number of filtered noise samples, however when the *x*% percentage is chosen correct and the number of noise samples does not change more than 50% the factor can be assumed correct for the whole registration period.

NOTE 2 – To prevent errors caused by the non-linearity of the receiver, the in-band generated power of the noise source needs to be equal to the total received noise power during the measurements.

4.7 Correcting for antenna (*K*) factor differences in scanning measurements

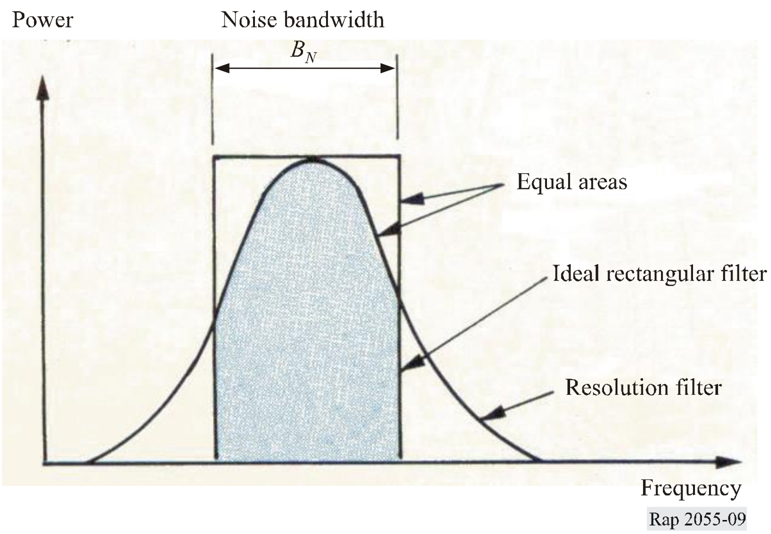
Each measured frequency point should be corrected with the right *K* factor, especially for narrow-band antennas used in semi-wideband measurements. Keep in mind that narrow-band antennas should not be operated outside their frequency range because of the changes in the antenna diagram and impedance.

4.8 Correcting for filter shape/bandwidth

Although, in spectrum monitoring, we like to speak about noise levels noise is almost always expressed as power/bandwidth. For such an expression the filter bandwidth needs to be integrated and basically presented in a rectangular form.

FIGURE 9

Rectangular presentation of filter bandwidth



If we want to compare measurements made with two different receiver bandwidths (RBWs), we have to apply a correction factor to one of the results that is equal to the ratio of the two RBWs. So, to convert measurements made with RBW_1 into measurements made with RBW_2, a correction of

$$10 \log (RBW_2/RBW_1) \tag{1}$$

has to be applied to the measured values (dB).

In order to get bandwidth-independent results, the measured values are normalized to the thermal noise level which can be calculated as follows:

$$P_0 = K\, T_0\, B \tag{2}$$

where:

- K: Boltzmann’s constant 1.38×10^{-23} (W/Hz)
- T_0: ambient temperature (K)
- B: noise equivalent bandwidth of the measurement filter.

Of course this only works well when the noise spectrum of the calibration source is reasonably flat.

4.9 Plotting the results

The result can now be plotted in a time amplitude diagram, smoothing the result by averaging over a 100 s period makes it easier to compare results.

The 100 s period has proven to produce useful results in combination with a sweep time of 10 s. When we use an analyser that produces frequency scans of 500 data points with a sweep time of x s, $100/x$ scans are needed to produce the average over the desired 100 s period. Over this 100 s period the maximum, minimum and mean value are calculated.

At least 10 scans are needed to obtain meaningful maximum, minimum and mean values.

Examples of plots and a common data format are described in § 8.

4.10 Alternative method

During the initial tests an alternative method was developed that produces acceptable results under controlled conditions. This method was not adopted as the standard measurement algorithm but can be an alternative in situations where limited storage capacity for measurement data is available or where immediate results over a short period of time are needed. The sampling time of the receiver should be in the same range of the one used in the other method. However the samples are grouped in blocks of 10 samples for which the mean is calculated providing an update every 0.5 s. Calculate out of every block of 240 values the lowest highest and the mean value. Output these three values related to 2 400 samples. Using this method means that manual filtering of non-noise signals is necessary.

5 Required equipment specifications

In selecting measuring receivers or spectrum analyser to be used, account should be taken of the need for adequate sensitivity, high overload capability (i.e. high second and third order intercept points) and for frequency and gain stability including self-calibration.

Measurement bandwidth should be the minimum required for satisfactory reception of the signal to be measured, while at the same time excessive bandwidth should be minimized to avoid adjacent-channel interference. For field-strength measurements measuring receivers shall be equipped with the necessary calibration and detector functions. Modern, fast measurement equipment makes use of digital recording media, especially where more than one channel is measured automatically. Measurement results are secured on mass storage devices and graphic representations of measured data may be obtained at any time.

5.1 Receiver specifications

The measurement receiver can be a standard measurement receiver or spectrum analyser with some additional requirements like a low equipment noise floor and high stability which are essential for the performance of noise measurements. Table 1 does not describe a new set of measurement receiver specifications but only points out the additional or specific requirements necessary for a receiver used for radio noise measurements. Also the frequency band designations are based on the practical implementation of a noise measurement system and do not point to a specific receiving system.

TABLE 1

Function	Frequency range		
Frequency range	9 kHz – 30 MHz	30-500 MHz	0.5-3 GHz
Input (antenna input) VSWR	50 Ω, nominal < 1.5		
3rd order intercept (dBm)	≥20 (>3 MHz)	≥10	≥0
2nd order intercept (dBm)	≥60 (>3 MHz)	≥50	–
Preselection	Set of suboctave band filters or tracking filter	Tracking or fixed filter Low pass/high pass filter	
Noise figure	15 dB (>2 MHz)		
Sensitivity (500 Hz bandwidth)	−10 dBμV	−7 dBμV	−7 dBμV
LO-phase noise	–120 dBc/Hz in 10 kHz offset	–100 dBc/Hz in 10 kHz offset	–100 dBc/Hz in 10 kHz offset
IF rejection (dB)	>80	>90	>100
Image rejection (dB)	>80	>90	>100
Automatic gain control	Measurement outputs should have no agc applied		
Electromagnetic compatibility of the measurement setup including computers and interface	All interference produced and received by the setup should be >10 dB below the average noise to be measured		

VSWR: voltage standing wave ratio.

The intermediate frequency (IF) selectivity between 60 and 6 dB should be accurately known to calculate the equivalent noise bandwidth when measurements with different IF filters have to be compared.

5.2 r.m.s. or average detector

In § 4.1 is concluded that a measurement using an r.m.s. detector is needed. A simultaneous operating average detector would be a useful addition. One of the advantages of the r.m.s. detector in correlation work is that for broadband noise the output obtained from it will be proportional to the square root of the bandwidth, i.e. the noise power is directly proportional to the bandwidth. This feature makes the r.m.s. detector particularly desirable and is one of the main reasons for adopting the r.m.s. detector to measure noise. Another advantage is that the r.m.s. detector makes a correct addition of the noise power produced by different sources, for example impulsive noise and random noise, thus for instance allowing a high degree of background noise.

r.m.s. detector

The r.m.s. detector calculates the true power over each measurement interval. The result corresponds to the signal power within the chosen bandwidth. For the r.m.s. calculation, the samples of the envelope are required on a linear level scale.

The following applies:

$$V_{r.m.s.} = \sqrt{\frac{1}{N} \cdot \sum_{i=1}^{N} v_i^2} \tag{3}$$

where:

$V_{r.m.s.}$: r.m.s. value of voltage (V)

N: number of samples allocated to the pixel concerned

V_i: samples of envelope (V).

Average detector

An average detector is designed to read the mean value of the envelope of the signal passed through the pre-detector stages. The average detector calculates the linear average over each measurement interval. For this calculation the samples of the envelope are required on a linear level scale.

The following applies:

$$V_{AVG} = \frac{1}{N} \cdot \sum_{i=1}^{N} \nu_i \tag{4}$$

where:

V_{AVG}: average voltage (V)

N: number of samples allocated to the pixel concerned

V_i: samples of the envelope (V).

Depending on the type of input signal, the different detectors partly provide different measurement results.

5.3 Sensitivity

The measured uncorrected noise signals (no correction factors applied) should be at least 10 dB above the equipment noise floor to guarantee sufficient measurement accuracy. When the measured values are less then 10 dB below the equipment noise floor the r.m.s. detector requires a custom calibration. Other methods like raw data sampling method have to use a sample detector because the processing includes r.m.s. calculations that are done afterwards.

5.4 Input impedance

The typical input return loss of a receiver is $\Gamma_{RX} > 13$ dB with the internal attenuator switched off. The receiver will be used with an external attenuator of at least 3 dB, the lower the attenuation the better.

5.5 Spurious radiation

Spurious radiations from the receiver are components at any frequency, radiated by the equipment/cabinet. This radiation must be as low as possible. Computers used in automated measurement setups not specifically designed for measurements radiate wideband noise. The computer itself and the switching power supply can be placed in an RF shielded enclosure. The radiation of cabling and interfaces should be measured and adequately shielded cables should be chosen.

5.6 LNA and preselectors

These devices are different, but serve overlapping functions so are considered together. An LNA is a wideband RF amplifier that is positioned between the receiver and the antenna. In some cases, the LNA is mounted at the antenna and is used to overcome transmission line losses. In other cases, it is positioned right at the receiver antenna input. A *preselector* is a tuned circuit that passes the desired frequencies. As the name implies, a preselector preselects the RF signals that will be applied to the receiver input. The typical installation of a preselector is right at the antenna terminals of the receiver, or by means of a short piece of coaxial cable to permit operator access.

Some preselectors are manually tunable and need proper calibration before use.

Preselectors should be used when overloading of the receiver/analyser front-end is suspected and there is no other possibilities to prevent the overload. These preselectors have a negative effect on measurement accuracy unless they are included in the receiver/analyser and calibrated as part of the total receiver calibration. LNAs introduce noise and should be avoided unless needed to overcome cable loss or compensate for relatively small antenna structures. An LNA should be used when the received noise is less than 10 dB above the equipment noise floor. The requirements for such an amplifier are given in Table 2 which does not describe a new set of measurement receiver or LNA specifications but only points out the additional or specific requirements necessary for an LNA used for noise measurements.

TABLE 2

LNA recommendations

Function	**Frequency range**		
Frequency range	20-50 MHz	50-500 MHz	0.5-3 GHz
Input (antenna input) VSWR	50 Ω, nominal <1.5		
Gain (dB)	≈ 18	≤25	≤25
Gain stability	≤0.1 dB at 10-30° C		
Noise figure (dB)	≤2		
Gain flatness over the frequency range of interest (dB)	<0.1	<0.2	<0.5

Care should be taken not to overload the receiver when using an LNA. An external band filter can be applied to prevent overloading.

5.7 Cables, cable routers and connectors

It is recommended that wherever possible, solid, semi-rigid or double-screened cables should be used for all RF connections. This is to ensure maximum screening between adjacent cables and feeders and to reduce coupling between equipment. Solid outer conductor cables have superior passive intermodulation performance than braided screen cables but double shielded braided cables like RG223 and RG214 can be used without problems. Single screened cable (e.g. UR67, UR43, RG58) should not be used. The direct and shortest route is always the best for minimum radiation and minimum insertion loss. It is often convenient to break down very large feeder cables to a more convenient size and there is a tendency to place connectors just inside the equipment room when reducing the main incoming feeder to a more manageable size. It is best, however, to take the main feeder as close as possible to the equipment to which it is to be connected before interrupting its outer conductor.

The only exception to this rule is to provide an Earth connection for lightning conductor purposes. This should be carried out by means of an external clamp on the outer copper conductor and this should be taken via the most direct route.

Incoming feeders must not be interconnected by a “patch panel”, as used in conventional setups. The “patch panel” is a source of Earth current coupling and intermodulation and should be avoided.

It is also recommended that high quality connectors be used and a minimum standard would be type N. Only stainless steel or at least nickel plated connectors should be used, silver plated connectors should be avoided since the material scraped off causes connector contamination. All connectors must be fitted in conformity with manufacturers' instructions to ensure proper sealing and electrical uniformity and should be tightened to the manufacturer's recommended torque settings to guarantee measurement reproducibility.

5.8 Feeder identification, terminations and grounding

Feeder cables should be uniquely and permanently identified at each end and at the point of exit from the structure. More frequent identification may be advisable when cables are buried in a duct.

Connectors and grounding kits should be fitted in accordance with manufacturers' instructions. Connector fitting should be carried out under laboratory condition and feeders should be installed in accordance with manufacturers' recommendations, with connectors already fitted to their upper ends and suitably protected from water ingress.

5.9 Sealing

On completion, connectors should be wrapped with PolyIsoButylene (PIB) self-amalgamating tape. Over-wrapping with petroleum jelly impregnated waterproof tape should be avoided since PIB is attacked and gradually dissolved by petroleum based products. Where PolyVinylChloride (PVC) covers are provided for connectors, they should be removed and the connectors taped as described.

Feeder and cable entries, external cable or feeder terminations, and Earth connections to feeders on towers or gantries should be suitably sealed or protected against the ingress of moisture using non setting pastes, self amalgamating tapes, neoprene paints as appropriate and in accordance with manufacturers instructions. Particular attention should be paid to the shedding of surface water.

5.10 Inspection for moisture

In cases where the mast is exposed and there is a possibility of moisture gathering at the outer jacket of the copper case of the incoming cables, it is wise to remove the outer insulating jacket at a point well inside the equipment room where it can be inspected for traces of moisture.

6 Antenna systems

6.1 Introduction

Noise received by an antenna is generated by a large number of sources, coming from a large number of directions. The noise power, measured at the connector of an antenna, is the sum of all received powers from independent noise sources with their own directions. Each received noise power component has its own pointing vector, and coupled to this pointing vector a free-space E and H field strength and polarization plane. This makes that the received power at the antenna connector cannot be correlated to a field strength in a deterministic physical sense as we use to do for a single radio signal.

Thus in a true scientific approach only a noise power at an antenna connector can be defined and measured, and for example expressed in a noise figure or noise temperature as is done in the relevant ITU documents.

However, in the application field of radio engineering, the relevance of noise measurement lies in the comparison between a radio signal and the background noise level. As we express the signal strength of the radio signal in a field strength (generally for frequencies below 30 MHz), we can also express the background noise power in an equivalent field strength, assuming all the noise power at the antenna connector is received from the same direction (azimuth and elevation) as the radio signal was coming from.

It is this approach that gives us opportunities to describe antennas properties, used for noise measurements.

6.2 Antenna properties

The antenna used for noise measurements in a particular frequency range should be fit for the purpose of receiving radio signals in that frequency range.

This means that the directivity is matched to the radio signals to be received. For example in a frequency range used for near vertical incident signal (NVIS) communications the directivity of the antenna shall be optimized for the reception of high elevation angle signals. The *K*-factor can be derived from a antenna gain value averaged over the relevant elevation angles. Another example is the use of a beam antenna for long range communication. As we can assume that this antenna will be directed at the source direction of the radio signal to be received, we can use the antenna gain in the optimal direction to calculate the *K*-factor.

We can conclude that there is no universal antenna for all type of noise measurements as well as for all frequency ranges. The radiation pattern of the antenna needs to have a relationship with the type of noise to be measured. For antennas placed in an environment where noise sources are distributed evenly around the antenna, the antenna pattern is less relevant than in cases where the noise is received from a defined angle. In the first case only the antenna efficiency or average gain over the total antenna aperture needs to be used as a correction factor. This is particular the case with VHF and UHF measurements. The lower the frequency the more relevant the 3D properties of the antenna diagram are.

The same is valid for polarization, an ideal antenna for this type of measurement is polarization independent or is sensitive in all relevant polarization planes at the same time.

6.2.1 Calculation of the antenna factor (*K*-factor)

There is a direct relationship between the antenna gain of a passive and loss-free antenna (in a certain direction), G_i, and the antenna factor K (see also Annex 1):

$$\begin{aligned} \boldsymbol{K} \equiv \frac{\boldsymbol{E}}{\boldsymbol{V_{rx}}} &= \frac{4\pi}{\lambda} \cdot \sqrt{\frac{30}{\boldsymbol{g} \cdot \boldsymbol{R_{rx}}}} \\ &= \frac{4\pi \boldsymbol{f_{MHz}}}{300} \cdot \sqrt{\frac{30}{\boldsymbol{g} \cdot \boldsymbol{R_{rx}}}} \end{aligned} \tag{5}$$

In dBs:

$$\begin{aligned} \boldsymbol{K} &= 20\ \log(\boldsymbol{f_{MHz}}) - \boldsymbol{G_i} - 12.8 - 10\log(\boldsymbol{R_{rx}}) \\ &= 20\log(\boldsymbol{f_{MHz}}) - \boldsymbol{G_i} - 29.8 \qquad\qquad R_{rx} = 50\Omega \end{aligned}$$

Losses in the antenna have to be subtracted from the antenna gain.

6.2.2 Gain versus frequency (bandwidth and compensation)

Loss-free antennas are in general tuned antennas, for example a dipole or inverted V antenna. The antenna bandwidth reduces progressively, where the antenna dimensions decrease with wavelength.

In case of swept measurement the sweep width can be wider than the bandwidth of the antenna. The measurement result should corrected for the resonance curve of the antenna. The measurement of the resonance curve can be done using a small auxiliary antenna, a non resonant small dipole or a magnetic loop, fed by the tracking generator output of a spectrum analyser or a noise source. It may be necessary to insert an amplifier between the tracking generator or noise source output and the auxiliary antenna. The coupling to the measurement antenna may be in the near field.

6.2.3 Measurement sensitivity matters

What are the minimum required physical dimensions versus frequency and when do we need a low noise amplifier? The noise spectrum density for most types of noise decreases with frequency. At the same time the effective aperture of antennas tend to decrease with frequency. Table 3 illustrates this in the frequency range 10 kHz to 30 MHz. As an example a loss-free half-wave dipole is used in the Table. It becomes clear that for frequencies of 1 MHz and below a smaller or less effective antenna may be used. For the higher frequencies and the common noise figure of measurement receivers (12-13 dB) a low noise amplifier is necessary. Even for the highest frequencies an antenna with some more gain may be advisable.

TABLE 3

Frequency (MHz)	**Minimal noise field strength (dBμV/m) according ERC Report 69 (2.7 kHz bandwidth) target spec.**	***K*-factor dipole antenna in free space**	***K*-factor dipole antenna above ground (+5 dB)**	**Minimal signal level (dBμV)**	**Noise floor Rx (2.7 kHz) NF = 12.7 (dBμV)**	**Minimal gain LNA for 10 dB *S*/*N***
0.01	48	−72	−77	125	−20	
0.05	27	−58	−63	90	−20	
0.1	13	−52	−57	70	−20	
0.5	−23	−38	−43	20	−20	
1	−30	−32	−37	7	−20	
5	−30	−18	−23	−7	−20	
10	−21	−12	−17	−4	−20	
15	−25	−8.5	−13.5	−11.5	−20	1.5
20	−30	−5.9	−10.9	−19.1	−20	9.1
30	−30	−2.4	−7.4	−22.6	−20	12.6

Another solution is the use of an active antenna with incorporated LNA.

In general this has to be tuned for sufficient sensitivity too.

6.3 Required properties of LNAs

When the noise level at the output of the LNA exceeds the input noise level of the receiver with 10 dB, the increase of the total noise due to the receiver noise is less than 0.5 dB. Knowing this we arrive at a minimal gain $G_{LNA} \geq 13$ dB. A low noise figure is also important, but has to be combined with other relevant factors as front-end filtering and sufficient dynamic range. A realistic noise figure: $NF_{LNA} = 2 - 3$ dB. A front-end band filter is required to avoid intermodulation noise from signals at lower frequencies, and to avoid intermodulation products from strong VHF signals.

In the post processing algorithm the (known) noise contributions from the receiver and from the LNA should be subtracted. The total instrumental noise voltage (dBμV) based on an impedance of 50 Ω, is:

$$\begin{aligned} V_{n,instrumental} &= 10\log(10^{V_{n,RX}/10} + 10^{V_{n,LNA}/10}) \\ &= 10\log(BW/(10^{(NF_{RX}-67)/10} + 10^{(NF_{LNA}-67+G_{LNA})/10})) \end{aligned} \tag{6}$$

The corrected noise voltage is: $V_{n,corrected} = 10\log(10^{V_{n,indicated}/10} - 10^{V_{n,instrumental}/10})$

6.4 Methods of calibration of the antenna factor

Basically there are two ways to determine the antenna factor of an antenna:

– by comparing with a laboratory calibrated measuring antenna;

– by determine the gain of the antenna by using simulation tools.

Both methods can be used but there are some essential differences.

6.4.1 Using a laboratory calibrated measuring antenna

This method makes use of an intermediate measuring signal which is measured as well as with the antenna under test as with a laboratory calibrated measuring antenna (for example the Rhode & Schwarz loop antenna HFH 2-Z2 and rod antenna HFH 2-Z1). This measuring signal can be generated on purpose or an existing radio signal can be used. There are some restrictions:

– The field of the measuring signal must be homogeneous over the whole antenna structure.

– For a simultaneous measurement on both the devices under test (DUT) and calibrated antenna, both antennas must not influence each other. This means that they have to be separated in space, so they do not share near field areas. It will be clear that at both positions the field-strength levels must be equal. Be aware of reflections from objects in the neighbourhood and other inhomogeneities.

– For a sequential measurement the same antenna position can be used. However, an essential requirement is that the signal strength is sufficient stable during the measurement sequence. Due to fading effects this requirement is generally not met when measuring skywave radio signals.

  In general this method is only useful when a controlled calibration signal is used. This signal can be generated locally by means of a small electrical dipole or magnetic loop antenna. As a source a comb generator or a noise source can be used. Due to the small distance between the transmit antenna and the antenna under test/measuring antenna, homogeneity is only guaranteed over a very small area, so the method is only useful for small, especially active, antennas like active rod and loop antennas.

6.4.2 Using simulation tools

For larger, low-frequency, antenna structures such as half-wave dipoles, inverted Vs, German quad, etc., it is not possible to generate locally a homogeneous measuring field over the whole of the antenna structure. So for the comparison method only far off generated radio signals can be used. Due to fading effects, often accompanied by spatial effects, the comparing measurements are difficult to perform and would require longer measurement periods combined with statistical methods. Besides that the elevation angle of the incoming radio signal is not controlled. So in a different approach the antenna gain of an antenna structure, including the effect of the real ground, can be found by using a simulation program able to calculate with real, Sommerfeld, ground models like NEC-2 or NEC-4. From this antenna gain above an isotropic radiator the antenna factor K can be calculated, see equation

(4). As not only the gain in the main antenna lobe but in all directions can be calculated, so the antenna factor can. This means an antenna factor depending on azimuth and elevation angle can be established.

Which directions are relevant is depending on the main purpose of the antenna as a receiving antenna for radio signals. For a high elevation angle receiving antenna for NVIS signals, by example a German quad antenna, a mean *K*-factor can be found by averaging the *K*-factor over a vertical cone, covering the elevation angles from 45° to 90°, thereby assuming that the relevant radio signal to be received will have elevation angles between 45° and 90°.

Another example is that of an directional beam, log period or conventional. In this case it can be assumed that the antenna will be directed to the transmitting station. Only the *K*-factor in the direction of the main lobe is relevant. The elevation angle can eventually be corrected for the ground reflections or an integration over a relevant range of elevation angles can made.

NOTE 1 – The elevation angles at which signals and also noise are arriving at an antenna are a function of frequency and time. It is also a function of the gain of the antenna which is elevation dependent. If for example one is interested in the noise arriving around noon on the lower HF bands from high angles, the amount of noise received is dependent on the path loss encountered by the noise to arrive at the antenna and on the gain of the antenna for the angle at which this noise is received. There is an upper limit on the amount of noise that can be received by a given antenna system, because the contribution of say angles from 50°-75° at noon will be very low due to the absorption of the ionosphere. The exact *K*-factor to be used therefore is an implicit function of the noise contribution.

When using modern propagation simulation tools, it is possible to calculate the total contribution of noise from an area around the receive antenna. Carrying out this simulation, one sees that there is a lower limit on the elevation angle for NVIS-noise that contributes to the amount of noise received. This may help in establishing the correct *K*-factor (one can see this as the effective observation area of the antenna).

6.5 Field strength over ground or free space field strength

We have to realize that the field strength that is measured by a small active antenna, positioned over ground, is the sum of the incoming radio signal and its reflection against ground, at least for the vertical polarized components of that signal. The vertical rod antenna only measures this vertical component of the electric field strength. The loop antenna when positioned vertically measures the horizontal component of the magnetic field. For a low elevation angle incoming signal this can be related to a nearly vertical electric field, and doubling of the field strength occurs. For high elevation the accompanying electrical field is nearly horizontal directed, so that the doubling does not occur. In fact the horizontal component of the E-field will be reduced near ground. The data, given in Recommendation ITU-R P.372, has been derived from measurements using vertical rod type of antennas. So these data are related to measured field strength over ground.

In the cases where the antenna is calibrated by means of simulations the calculated *K*-factor is related to the field strength in free space. The eventual reflections against ground are already incorporated in the calculation of the antenna gain. This means that a calibration by simulation, directed on the free space field strength, results in a lower *K*-value (maximal 6 dB) than by the comparison method based on the field strength near ground.

6.6 Stability (dependency on ground properties)

It is well known that when applying vertical rods over real ground, the impedance seen at the antenna terminals may change with the moisture content of the ground in the direct vicinity of the antenna. The antenna appears to be less sensitive on dryer ground, meaning that the *K*-factor increases. The effectiveness of the system goes down. The *K*-factor changes for the frequency the antenna was indicated to operate on. This results in miscalculation of the level of the noise. There are also indications that the impedance varies as a result of the moisture content of vegetation. Another effect is the obstruction of antennas by structures, either man-made or natural. In order to have reliable measurement results, the above described effects should be minimized or stabilized. The reception of low elevation signals depends on the properties of the surrounding ground many wavelengths away from the antenna. So when having a good electrical ground below the antenna, this in no way means that reception of low elevated signals will improve. This is only the case if the ground well away from the antenna has the right properties for reflection.

The application of a so called impedance ground screen for vertical antennas or the use of elevated feed vertical antennas readily diminishes the effects of changing environmental conditions. These screens normally exist of radial wires just above or buried in the ground extending up to 10 m typically for a vertical receiving antenna of say 8 m high, terminated by ground rods. Such screens are readily made so that they may be installed quickly when moving around with the measurement system and guarantee stable impedance matching.

When using horizontally polarized antennas, the effects of changing ground conditions below the antenna are of much less importance. It is of some effect when using very low wavelength elevated horizontal antennas above good to excellent ground.

The location of a measurement system should not be influenced by buildings or natural structures, as this immediately will have an effect on the properties of the antenna. The effects are difficult to model and are therefore an extra uncertainty in the measurements. It is therefore advised to use a clear site (simple triangular mathematics will give the maximum height of structures at a given distance from an antenna in order not to blank reception). When using loop antennas, these considerations play a much smaller role. Small loop antennas can be used very well in business environments as they are also external noise limited in such areas.

As for all antennas, the antennas should be galvanically separated from the coaxial feedline. Ferrite sleeves shall be used on the feedline to minimize common mode currents.

6.7 Long-term stability

Long-term stability depends on two factors, the stability of the environment and the stability of the antenna structure. The first factor has been paid attention to in § 6.6, where the conclusion was that a clear site well away from vegetation and man-made structures and good impedance matching will guarantee stability. The second factor depends on the mechanical properties of the antenna structure, see § 7.

6.8 Integrity testing

After installation and deployment of the system it is advised to regularly evaluate the system. This serves to confirm proper performance of the system and installation.

Elements to verify continued performance of the system may include:

– a visual inspection for condition of the installation, (including: cabling, guys, attachments, connections, grounding and protective provisions, equipment noise factor, etc.);
– a confirmatory system calibration; and/or
– a check on site calibration.

The latter can be a either a visual check for changes with respect to an earlier static site survey, or e.g. a spot check at selected key frequencies of the measurements which may use pre-arranged stimuli. Those signals may be coordinated with other and similar activities involving other sites.

6.9 Input impedance and measurement error

When a source and a load, such as an antenna and a receiver, are connected optimum power transfer takes place when both have the same impedance. In practice there is always a difference in source and load impedance causing a measurement error. This error is named mismatch error. The error can be calculated in absolute terms if we know the impedances and the exact electrical length of the interconnecting cables. Occurring mismatch losses are compensated for in the calibration of the whole system, see § 9. More useful is to calculate the mismatch uncertainty using the following formula.

Mismatch uncertainty $\boldsymbol{M_U} = 10\log_{10}(1 \pm \rho_{\boldsymbol{L}}\rho_{\boldsymbol{G}})$ (dB), where ρ_L ρ_G are the reflection coefficients of the load and the generator.

6.10 Wind loading

The structural design should take into account the wind loading of all the components on the structure, e.g. antennas, feeders and associated hardware. Twist and tilt limitations for parabolic antennas may also have a bearing on design or reinforcement.

The design or selection of a suitable support must be by qualified structural engineers. The design of new structures should where possible take into account the probability of future development.

6.11 Wind vibration

All antennas, mounting steelwork, feeders and ancillary equipment should be securely clamped to protect feeders and other semi flexible items from damage by vibration throughout the projected life of the installation. Manufacturers' recommended feeder clamp spacing should be observed, with particular attention to exposed areas and transitions from antenna to tower, tower to gantries and gantries into buildings. Feeders should not be laid loose on gantries. Where necessary additional protection should be provided.

6.12 Degradation of antenna performance

It is important to appreciate that the performance of an antenna is very dependent on the environment in which it is mounted. This is particularly true of many antenna types commonly used in the VHF and UHF bands. The data quoted by manufacturers will generally relate to parameters measured on a test-range in which the antenna is erected clear of all obstructions, using the optimum mounting arrangement. Such an environment will not normally apply at a typical user's installation, and inferior performance may result unless particular care is taken.

6.13 Examples (possible antennas for noise measurements)

The next four sections contain examples of antennas that can be used for noise measurements.

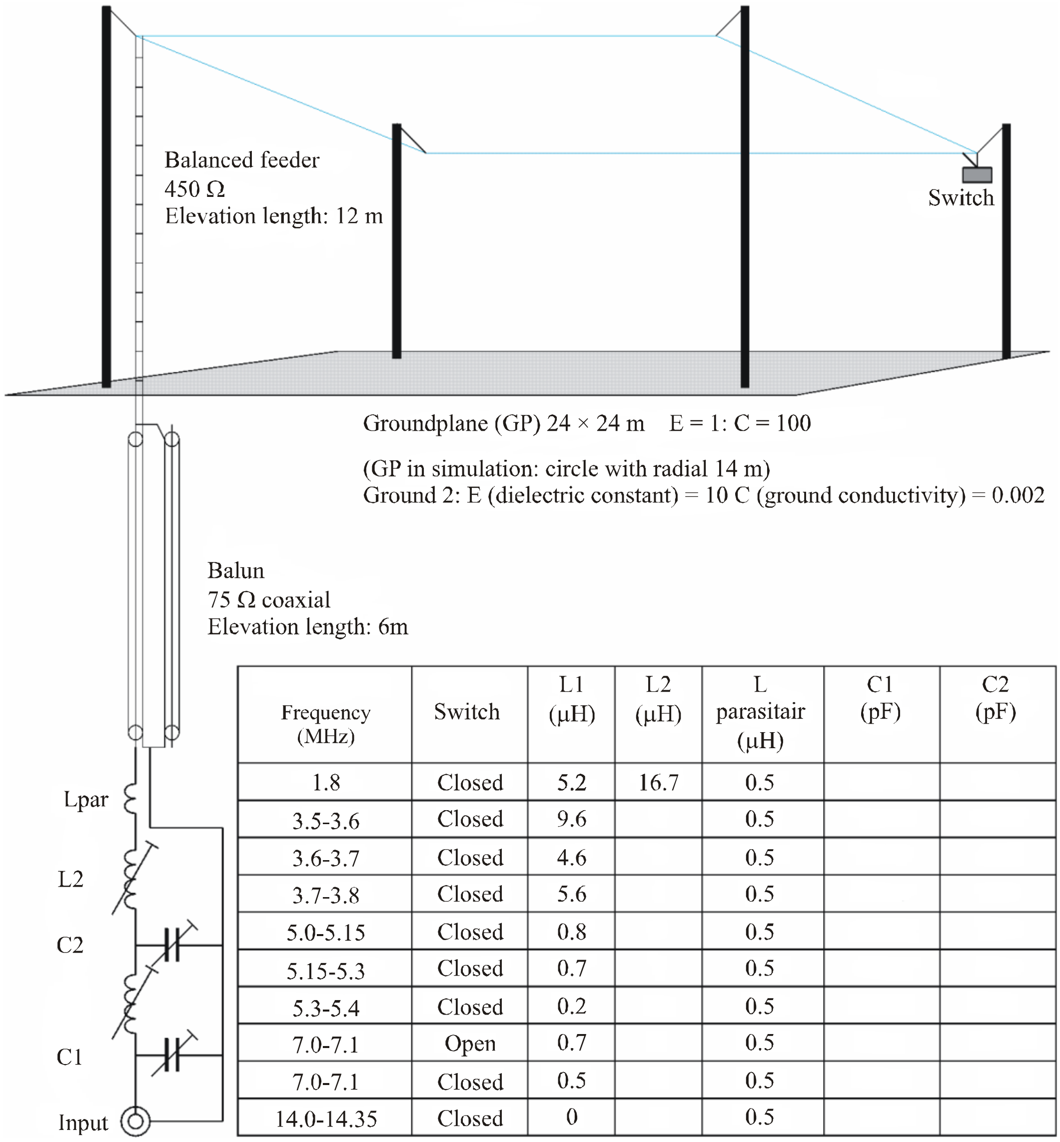
The first two described antennas (German quad and inverted V) are typical HF antennas (0-50 MHz) and rely on both the electrical properties of the antenna and the site's ground properties. The other two (monopole and loop antenna) can be applied for both HF and higher frequencies and mainly rely on electrical properties and not on the site's ground properties.

6.13.1 German quad

The German quad antenna has the shape of a square horizontal loop placed above a conducting ground. The antenna exhibits multi-band properties when for the lowest frequency band the circumference equals a half wavelength. Although it can be tuned and matched at any frequency, the desired radiation characteristics are obtained when the circumference equals whole multiples of a half wavelength.

FIGURE 10

Construction details of a German quad antenna



Frequency (MHz)	Switch	L1 (μH)	L2 (μH)	L parasitair (μH)	C1 (pF)	C2 (pF)
1.8	Closed	5.2	16.7	0.5		
3.5-3.6	Closed	9.6		0.5		
3.6-3.7	Closed	4.6		0.5		
3.7-3.8	Closed	5.6		0.5		
5.0-5.15	Closed	0.8		0.5		
5.15-5.3	Closed	0.7		0.5		
5.3-5.4	Closed	0.2		0.5		
7.0-7.1	Open	0.7		0.5		
7.0-7.1	Closed	0.5		0.5		
14.0-14.35	Closed	0		0.5		

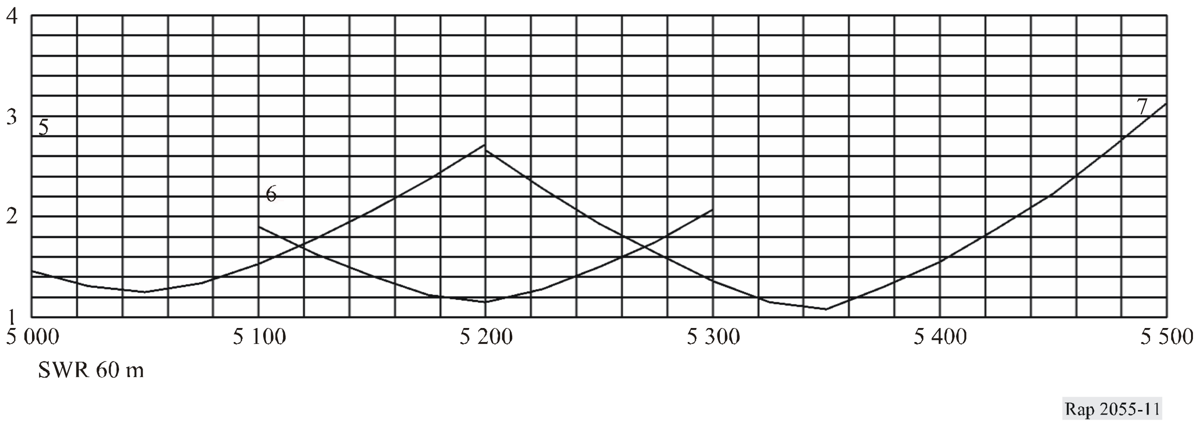
Rap 2055-10

Figure 10 shows a schematic drawing of a German quad. With a side length of 19 m the lowest frequency band is 1.81 to 1.88 MHz. The next band is 3.5-3.8 MHz, where the antenna's circumference is a full wavelength. On these bands the antenna has two radiation modes which are selectable by a switch. With the switch closed, the antenna has its maximum gain at 90° elevation. When the switch is open, the antenna has a null at 90° elevation, while its maximum gain occurs at an elevation angle of ≈ 60°. In general on frequencies with an odd number of a half wavelengths both modes are equivalent, although the impedance at the antenna's terminals still depends on the status of the switch. On frequencies with an even number of half wavelengths the antenna can operate in the two modes described above. In the band 7.0-7.2 MHz the operation of the switch is reversed.

The antenna is symmetrically fed using a balun transformer, and matched to 50 Ω coaxial cable by means of an antenna tuner. Since the behaviour of this tuner is narrow-band a preset mechanism needs to be implemented.

FIGURE 11

Input standing wave ratio (SWR) of a German quad antenna for the band 5.0-5.4 MHz



NEC2D simulations using a “Sommerfeld” ground model have been performed on each frequency band. The antenna gain has been calculated for series of elevation angles of 0° to 180°. This is repeated for a series of azimuth angles 0°, 45°, 90°, 135°, so obtaining a three-dimensional image of the antenna gain. The NEC output files are used to create the next two plots.

FIGURE 12
Radiation pattern at 5.25 MHz
(Antenna gain distribution German quad 5.25 MHz)

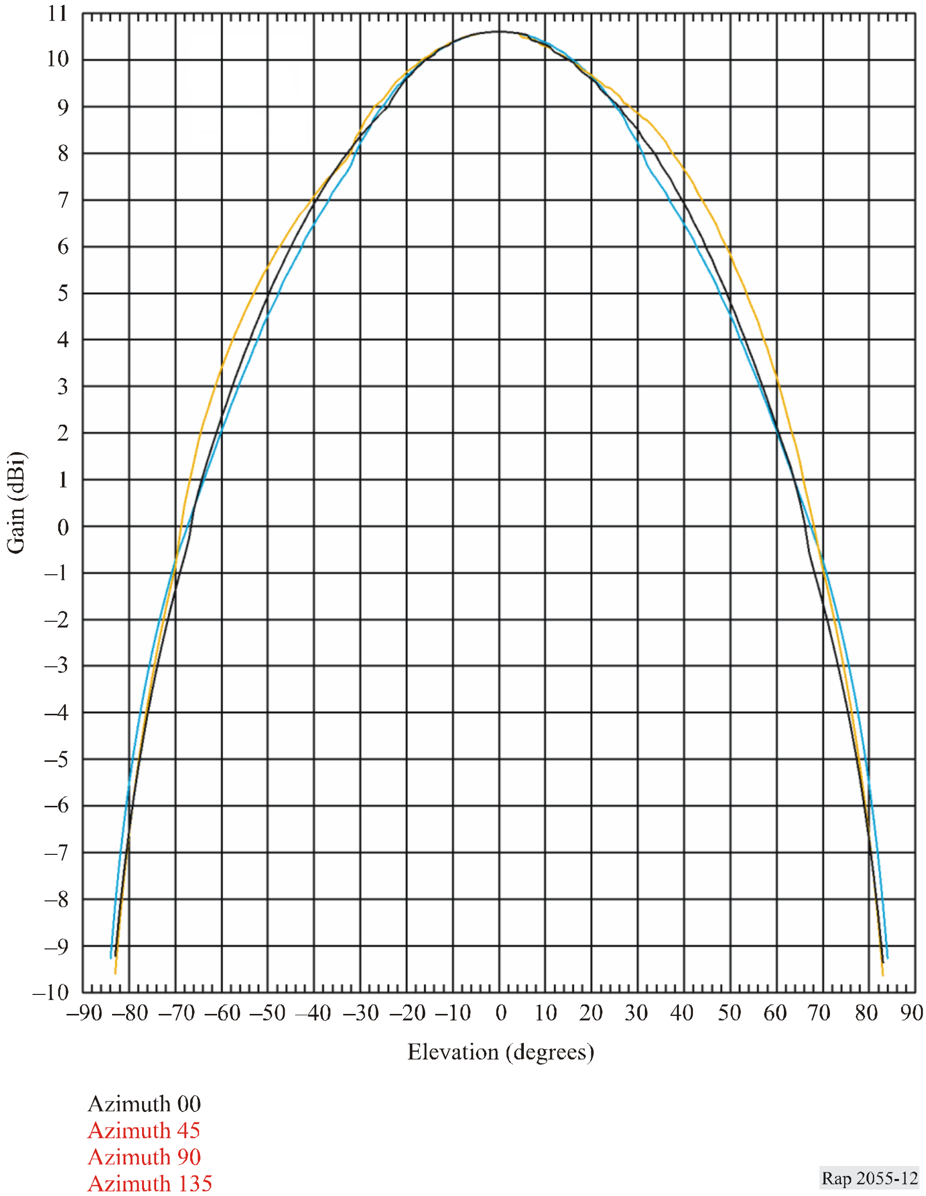
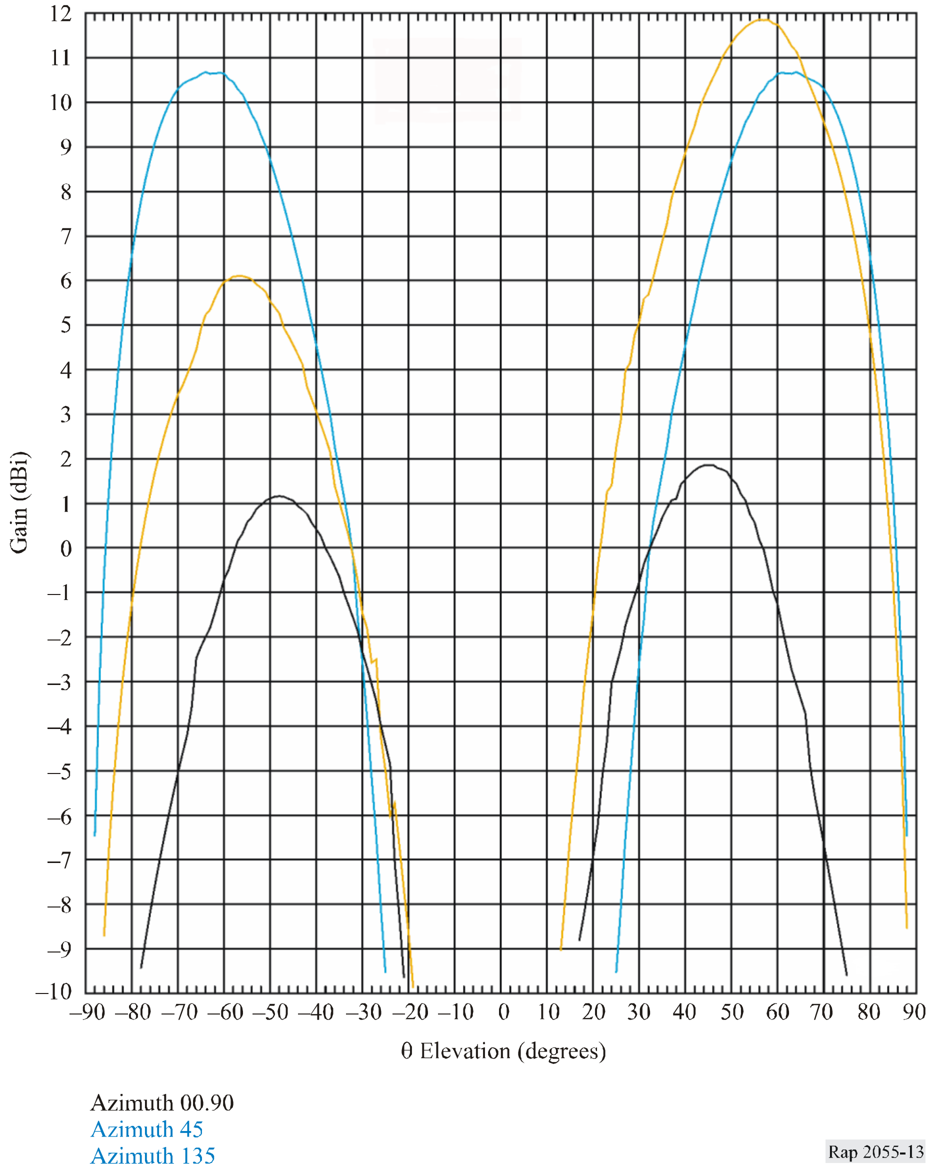


FIGURE 13

Radiation pattern at 14.1 MHz

(Antenna gain distribution German quad 14.1 MHz)



Also the gain has been (linearly) averaged over the hemisphere, resulting in a single average antenna gain number G_{av}. This gain number is the basis for calculating the antenna factor K, accordingly:

$$K_{av} = 20 \log f_{(MHz)} - G_{av} - 29.78 \text{ dB } (R_{RX} = 50\Omega) \tag{7}$$

In Table 4 the antenna gains and *K*-factors are listed, including values for the vertical direction and 45° elevation.

TABLE 4

_K_-factors for German quad antenna

Frequency (MHz)	Losses (dB)	Ground, external: Conductivity = 0.002 Siemens/m Rel perm = 10					
		G_{AV}(1) (dBi)	K_{AV}(1) (dB/m)	G_{VERT}(2) (dBi)	K_{VERT}(2) (dB/m)	G_{45}(3 (dBi))	K_{45}(3) (dB/m)
1.8	1	6.86	−31.3	9.62	−34.06	9	−33.44
3.5-3.6	1	7.19	−26.0	10.81	−29.62	7.6	−26.41
3.6-3.7	1						
3.7-3.8	1						
5-5.15	1						
5.15-5.3	1	6.83	−22.2	10.61	−25.98	6.5	−21.87
5.3-5.4	1						
7-7.1	1	7.18	−20	11.42	−24.24	7	−19.82
7-7.1(4)	1	3.66	−16.5				
14-14.35	1	3.4	−10.4				

(1) Averaged over the hemisphere above ground.

(2) In the vertical direction.

(3) At an elevation angle of 45°.

(4) With switch in closed position.

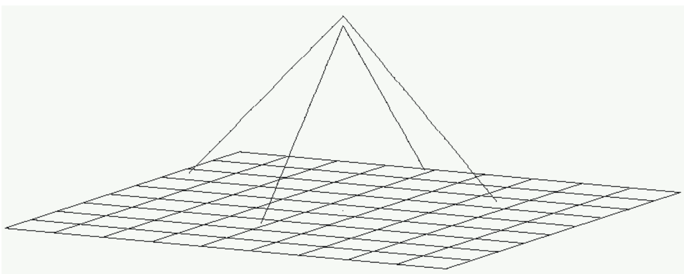
6.13.2 Inverted V

Inverted Vs are simple dipole style wire antennas that can be used for skywave signals with elevation angles as low as 5-10°. The antenna behaves like a dipole but can be placed low above ground to create a homogeneous gain characteristic in one direction in the vertical plane.

The antenna is directional in the horizontal plane for both polarizations (H and V with 90° difference in azimuth) but it is possible to make the setup omnidirectional and polarization independent when switching between two inverted Vs with 90° angles is performed.

FIGURE 14

Arrangement of two inverted Vs



Rap 2055-14

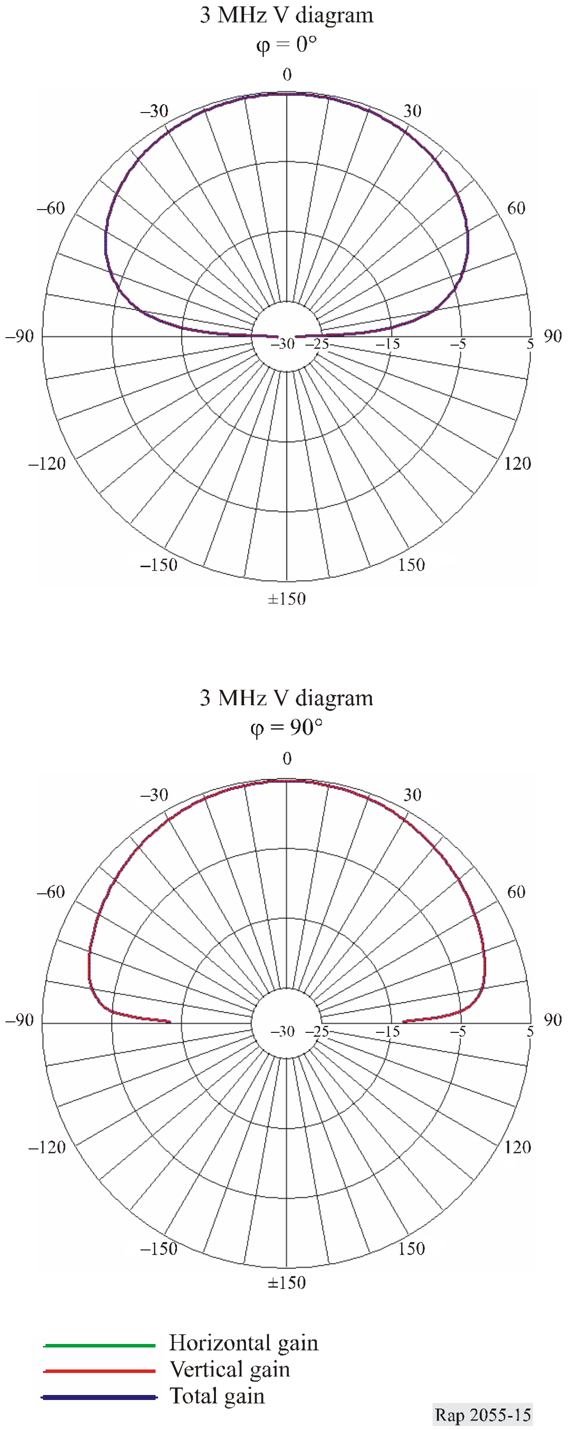
This antenna setup is unsuitable for use in urban environments due to the low ground clearing and possible direct coupling with underground structures. The setup is also not very sensitive for ground and direct wave signals. The antenna is narrow-band with constant gain over 50-100 kHz segments.

For low frequencies the antenna is quite large, centre loading of the antenna elements is possible. The diagrams are the same as of the full size versions but the gain is lower. The loaded antenna is even more narrow-banded than the normal inverted V but still usable in, for example, 50 kHz band segments. A multifrequency setup with just one pair of inverted Vs can be constructed when switchable loading coils are used. Coils are needed to give the antenna the constant feed point impedance required to obtain a constant measurement accuracy.

The antenna is efficient, low noise and easy to erect because it needs only one support mast. Placement in urban areas is difficult because of the dimensions and electrical properties. For measurements in rural environments however the antennas are very applicable. To determine the electrical properties of a stack of these antennas some NEC-2 simulations are performed from which the results are given in the following diagrams. These simulations are for one antenna.

FIGURE 15

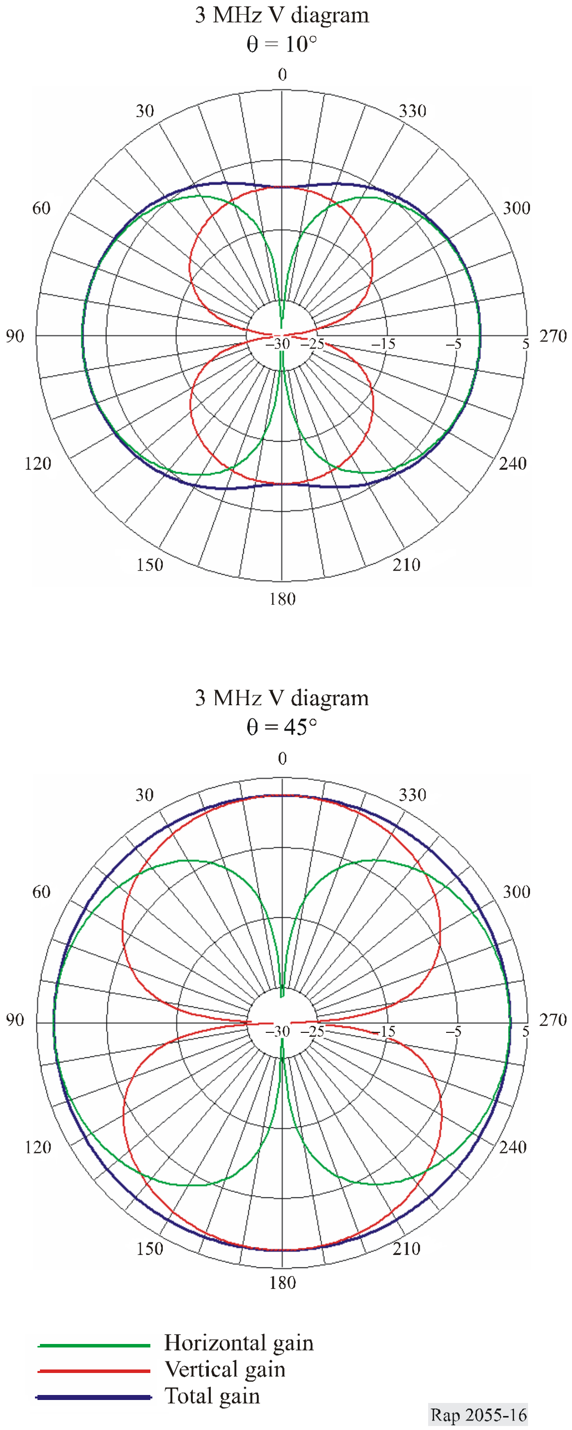
Vertical diagrams for elevation angles of φ = 0° and φ = 90°



As we can see the total average gain of the antenna does not change rapidly over large elevation ranges for azimuth angles above 10°.

FIGURE 16

Horizontal diagrams for azimuth angles of θ = 10° and θ = 45°



As we can see the total average gain of the antenna is constant for the whole azimuth range of 0-360° for elevation angles above 10°.

6.13.3 Monopole

The basic form of the monopole antenna is a quarter wavelength ground-dependent rod antenna.

The necessary ground can consist of a real ground with a coupling Earth net or an artificial ground consisting of quarter wavelength radials. In the last case the monopole can be used in an elevated way. The monopole is often used as a standard type for omnidirectional groundwave reception.

Monopole antennas are narrow-band resonant antennas but for use in broadband applications an active form of this antenna is often used. The active element in these antennas is mainly for controlling the output impedance of the antenna. Figure 17 shows a tuned active monopole mounted on PVC pipe. The sensitivity of an active monopole antenna can be improved considerably by adding an parallel tuned circuit at the base of the antenna. Not only the base capacitance and input capacitance are being compensated this way, it also can be shown that a voltage gain is obtained.

FIGURE 17

Monopole antenna

Rap 2055-17

6.13.4 Loop antennas

Loop antennas measure the horizontal component of the magnetic field perpendicular to the antenna loop. An advantage of these loops is that they can be made small and are only sensitive to magnetic fields when properly shielded. Therefore they can be used in areas where limited space is available and they do not couple to the electric field. The loop antenna is a directional antenna in the horizontal plane so for omnidirectional use two antennas are necessary.

There are two forms of the loop antenna, the active non-resonant type and the passive resonant type. Both can be built in shielded and non shielded form. The reason for making a loop antenna active is the same as for the active monopole antenna. The reason is mainly for controlling the output impedance of the antenna. In general a resonant loop antenna has better performance than a non-resonant loop antenna.

7 Measurement conditions and site survey

In order to guarantee reliable measurements, it is necessary to stabilize the measurement conditions or to qualify the dynamic behaviour of them. From § 6 we learn that the *K*-factor determines the transfer of noise energy to the measurement system. Any change in the effectiveness of the antenna system to transfer energy immediately effects this *K*-factor. It is therefore important to know by which internal and external parameters this *K*-factor is influenced at the antenna level. Ground conditions, vegetation and man-made structures are examples of external parameters, whereas mechanical robustness and connectors are internal parameters. An initial site survey characterizes the site. After the site has been chosen, a static site survey shall give information about the environment (ground conditions, buildings, vegetation, prevailing weather conditions). Calibration of the system then shall be done as has been pointed out in § 6. A dynamic site survey then regularly updates the static site survey and shall take into account new infrastructure, seasonal influences and changing ground conditions.

7.1 Initial site survey and antenna selection

The goal of an initial site survey is to characterize the site and to choose the proper antenna to be used for the measurements.

Business: Any area where the predominant usage throughout the area is of any type of business (e.g. stores and offices, industrial parks, large shopping centres, main streets or highways lined with various business enterprises, etc.)

Residential: Any area used predominantly for single or multiple family dwellings with a density of at least five single family units per hectare and no large or busy highways

Rural: Areas where dwellings are no more than one every two hectares

Quiet rural: Carefully selected quiet receiving site.

The characterization does not indicate *a priori* if one will measure the same noise figures as are given in the ITU Report over the whole HF.

The antenna to be used for the measurements shall be optimized for the noise source to be measured. For example, it is not advisable to use a vertical monopole for NVIS-noise. On the other hand, a vertical monopole is very well suited for man-made noise arriving by ground wave in, for instance, a business environment, but is not usable in the same environment for measuring sky wave atmospheric noise sources (see Note 1). The antenna shall always be external noise limited, meaning that ample sensitivity is available to measure the wanted noise source. The antenna type of course also effects the amount of work to be done in the follow-on process of static and dynamic site survey.

NOTE 1 – The elevation angles over which the noise is arriving at the antenna is a function of frequency and time. It is also a function of the elevation gain of the antenna. If for example one is interested in the noise arriving around noon on the lower HF from high angles, the amount of noise received is dependent on the path loss encountered by the noise to arrive at the antenna and on the gain of the antenna for the angle at which this noise is received. There is an upper limit on the amount of noise that can be received by a given antenna system, because contribution of angles ranging from 50°-75° at noon will be very low due to the absorption of the ionosphere. The exact *K*-factor to be used therefore is an implicit function of the noise contribution. When using modern propagation simulation tools, it is possible to calculate the total contribution of noise from an area around the receive antenna. Carrying out this simulation, one sees that there is a lower limit on the elevation angle for NVIS-noise that contributes to the amount of noise received. This may help in establishing the correct *K*-factor (one can see this as the effective looking area of the antenna). See also § 6.

7.2 Calibration and static site survey

A static site survey shall give information about the parameters that affect the *K*-factor. One important parameter is the type of ground. Another one is the surrounding environment. Calibration is necessary at the start of the static site survey to get a correspondence between a *K*-factor from mathematical modelling and from practical measurements. Modelling does not normally incorporate the effect of man-made structures and vegetation. The best thing to do would be to remain well away from such structures, but especially in business environments this is not always the case. One can also decide to work with small antennas (loops) in such environments as these are externally noise limited in such environments.

8 Format for the exchange of measurement data

Normally during the measurements the results obtained are stored in a database with a predefined structure. Although the type of information stored by the various bodies is broadly common the internal format in which measurement data is stored varies greatly between organizations and the different types of equipment used. The often incompatible data format makes data transfer very difficult.

Once the agreed measurements have been made, it should also be possible to send the results obtained from all the participating organizations to the coordinator in order to process the data on a common basis.

Although the type of information stored by the various organizations is broadly common, the internal format in which the monitoring data is stored varies greatly between the different types of equipment used. The often incompatible data format makes this transfer very difficult.

8.1 Common interchange format

The format described here is derived from the radio measurement data format (RMDF) format as used in the radio astronomy service, only some minor additions are applied. Both formats should be interchangeable.

To allow easy exchange and processing of the data, it should be stored in a relatively simple format. The header and data files should be readable by standard word processors, standard spreadsheets and by mathematical software such as Matlab. This leads to the requirement that the data file should be a rectangular ASCII text file conforming to the following format.

The data file should comprise two sections:

– A “Header” section containing the static information relating to the monitoring task such as the location used for monitoring, date and key monitoring parameters (see later).

– A “Data” section containing all the measured results during the period of observation.

In the original RMDF format the data and header are stored in two separate files.

8.1.1 Header section

The following fields and fieldnames should be used. All appropriate data fields should be included in the header area before the measured results are added.

The header section can contain two types of information – *Essential* or *Optional* (marked E or O in Table 5.)

TABLE 5

Type	Fieldname	Data format	Description
E	Data format	Text	RMDF noise
E	Monitoring station	Text	Antenna monitoring site
E	Latitude	Text	DD.MM.SSx where “x” is “N” or “S”
E	Longitude	Text	DDD.MM.SSx where “x” is “E” or “W”
E	FreqStart	Numeric (real)	Frequency (kHz)
E	FreqStop	Numeric (real)	Frequency (kHz)
E	AntennaType	Text	
E	FilterBandwidth	Numeric (real)	In kHz
E	LevelUnits	Text	dBuV, dBuV/m or dBm (note that “u” is used instead of “µ”)
E	Date	Text	Date of measurements in the format YYYY-MM-DD (start date if measurements span midnight)
E	DataPoints	Numeric (integer)	Number of data elements in the data row (analyser data points or receiver steps)
E	ScanTime	Numeric (real)	The actual time taken (in seconds) for the equipment to scan from FreqStart to FreqStop
E	Detector	Text	
O	Note	Text	General comments
O	AntennaAzimuth	Text	DDD.DD
O	AntennaElevation	Text	DD.DD
O	Attenuation	Numeric (integer)	Equipment attenuator setting in dB
O	FilterType	Text	e.g. “Gaussian 3 dB”
O	DisplayedNote	Text	A small remark of less than 40 characters containing essential information which could be displayed next to the data on any final report

Additional fields may be added to the header in order to provide further information however, these will not be automatically processed or recognized by the transfer software.

The header and data sections should be separated by ONE blank line.

8.1.2 Data section

The data area should consist of a separate line of data for each scan.

Each line should contain the start time of the measurement in HH:MM:SS format converted to Coordinated Universal Time (UTC) (or local time if requested by the coordinator) followed by a reading for each analyser data point or receiver step, all separated by commas.

Each signal level value should be rounded to the nearest integer value. If necessary, the coordinator will ask for an accuracy of one decimal place however this will increase the size of the resultant data file.

8.1.3 Example files

FileType	Bandscan noise
LocationName	Baldock
Latitude	52.00.00N
Longitude	000.08.00W
FreqStart	7000
FreqStop	7200
AntennaType	Inverted V
FilterBandwidth	0.5
LevelUnits	dBuV/m
Date	2004-04-18
DataPoints	501
ScanTime	7.5
Detector	Average
Note	This is a sample file of the data format.

00:00:00,65,56,64,54,23,29,32,43,54,25,29,25,36…etc…,43,59

00:00:10,64,53,65,59,42,37,35,34,64,25,26,36,63…etc…,54,61

00:00:20,62,57,64,59,41,36,26,42,53,62,16,52,24…etc…,52,66

etc

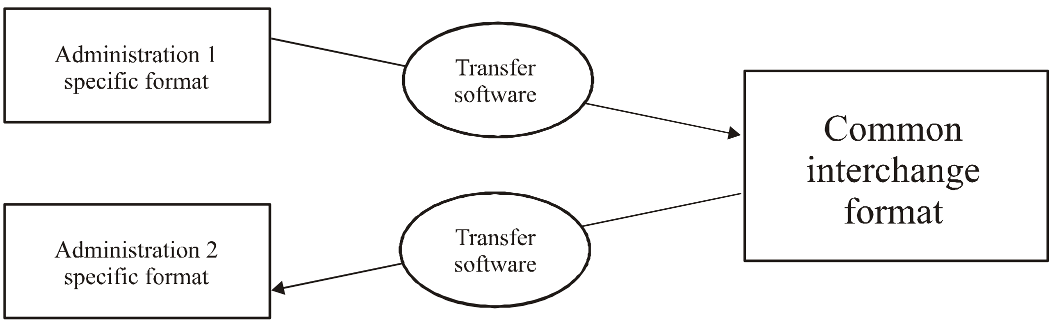
23:59:30,53,33,61,44,25,44,36,26,46,24,26,24,63…etc…,29,56

23:59:40,54,32,62,48,24,42,35,26,24,64,24,34,35…etc…,29,56

23:59:50,64,52,63,57,33,23,32,53,25,26,63,35,26…etc…,32,59

8.2 Transfer software

As various organizations use different data formats, they should therefore develop their own specific transfer software in order to translate their internal data layout to and from the common interchange format. Depending on the complexity of the internal design, this transfer software may be a simple macro file and could be shared between organizations using the same type of data acquisition equipment.



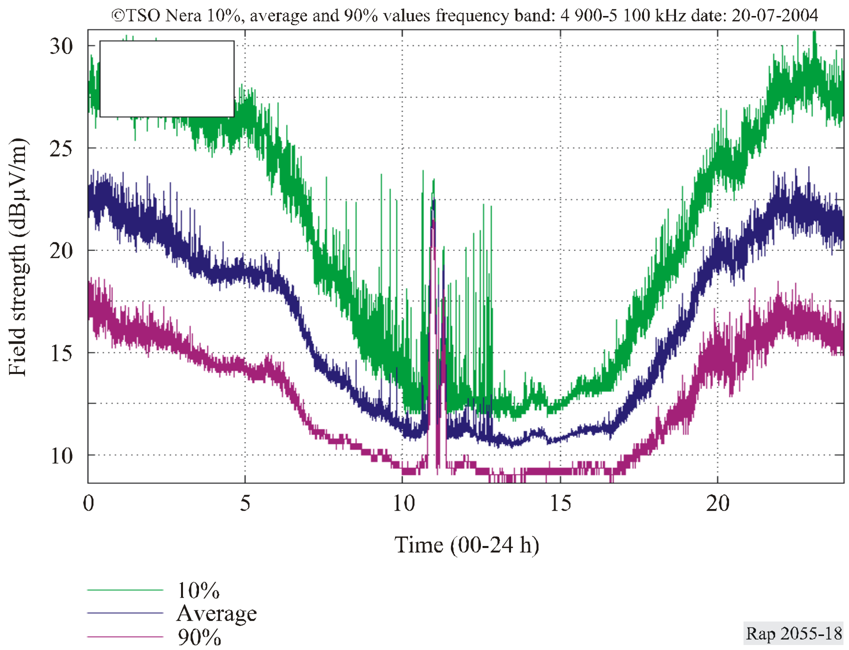
Rap 2055-17b

8.3 Presentation of data

The next picture gives an impression of the data before processing. The graph shows curves based on the occurrence of level values larger or equal then a certain value occurring for *x*% in a scan. The green curve shows the 10% value the blue curve the 50% or median value and the pink curve the 90% value. This is not the average of the 10%, 50% and 90% lowest values as calculated during processing. These curves give an impression about the distribution of the samples over the measurement period and can be used to determine the validity of a fixed chosen processing percentage for the total registration. In other words, the difference in amplitude in the 10% and 90% values gives information about the occurrence of strong signals and the percentage needed for processing.

FIGURE 18

10%, 50% and 90% values



The measurement data should be processed in accordance with the protocol in § 4.

FIGURE 19

Noise level

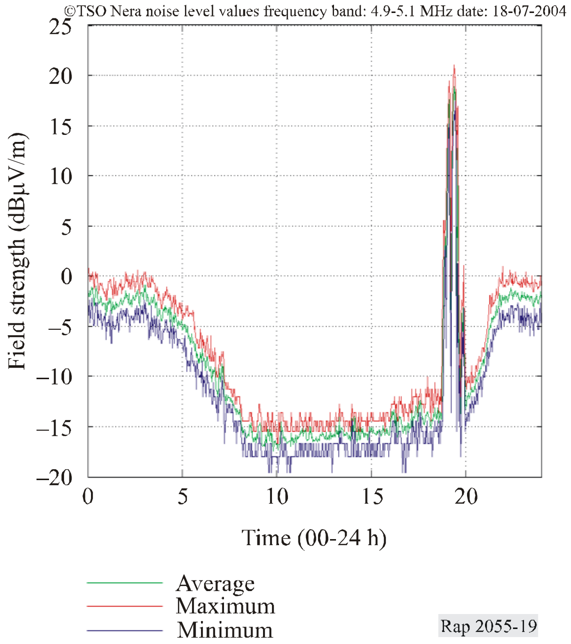


FIGURE 20

Spectrogram

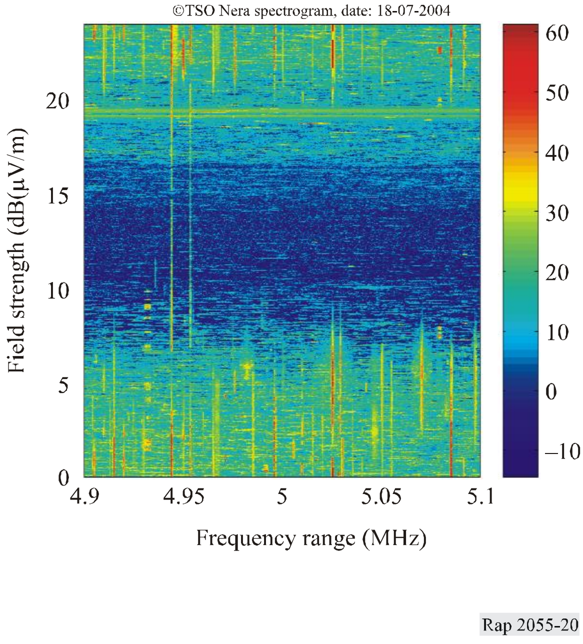


Figure 20 represents the 200 kHz (4 900-5 100 kHz) measured with 500 frequency bins or samples per scan and a scan time of about 10 s. 20% of the values per scan are used to calculate the minimum, mean and maximum values every 10 scans and are presented as in Fig. 19.

8.4 Correlation of multiple 24 h plots/periods

In most cases observations will have a time span of 24 h. Depending on the frequency band and application the measured noise values can change within periods of more than 24 h. For example on the HF bands the measured noise depends on the day of the week and if the day is a weekday or weekend day. A way to compare or correlate the measurements is to calculate an hour minimum, hour maximum and an hour standard deviation of 10% and 90% values. This way you can plot comparable curves for each hour. To ensure compatibility with other presentation methods other time periods, for example 4 h can be taken.

8.5 365 day plots

To compare the noise levels of different days over a longer period we can use the same procedure as in § 4.9. A day minimum, day maximum and a day standard deviation of 10% and 90% values can be calculated.

9 Measurement accuracy

In a measurement like this the overall absolute and relative accuracy depends on a number of elements. First of all we should ask ourselves “which signals do we want to measure?” and “why do we want to measure in the first place?”. In a common error analyses we take all worst-case error values into account. In this case where the measured data is heavily processed errors caused in the measurement of signals we are not interested in should not be prominent in the total error. The second reason is the fact that noise measurements are often used in analysis between different bands or different time periods. Most errors are stable and can be ignored in such relative measurements. A method could be to take the elements of the system that introduce the largest error and consider this the total error.

The following items need to be taken into account:

– Calibration uncertainty of measurement antenna
– Calibration uncertainty of receiver/analyser
– Mismatch between antenna and low noise amplifier
– Mismatch between LNA and analyser
– Gain accuracy of LNA (function of mismatch)
– Attenuation accuracy of external attenuator
– Accuracy of the noise source to determine the correction factors.
– Short-term stability of measurement receiver
– Linearity of measurement receiver.

9.1 Calibration uncertainty of measurement antenna

Impedance

Impedance can be checked with a network analyser, the accuracy depends on the mechanical stability of the antenna and the environmental stability such as ground properties of the site. The last factor is almost impossible to include in the total error calculation. Simulations have shown that influences on the impedance can be neglected in most cases. Typical values for the return loss are between 20 dB and 30 dB.

Gain

For the gain we should consider the gain integrated over the area of the antenna exposed to the actual noise to be measured. For small antennas we can perform a normal calibration in an anechoic chamber or on an open area test side (OATS). For large antennas this type of calibration is difficult to perform. A possible way is as follows: we should take a number of high level known sources that can be received with the relevant part of the aperture of the antenna. This way we can perform a substitution measurement with a smaller (easier to calibrate) antenna. Normal accuracy values for antenna calibrations are between 0.7 and 2 dB. This is not accurate enough, we can assume a higher accuracy if the antenna is of a simple construction like a dipole and different parts of the antenna like baluns can be measured separately.

In this case there should be no objects around the antenna affecting the properties of the antenna.

9.2 Mismatch between receiver antenna and LNA

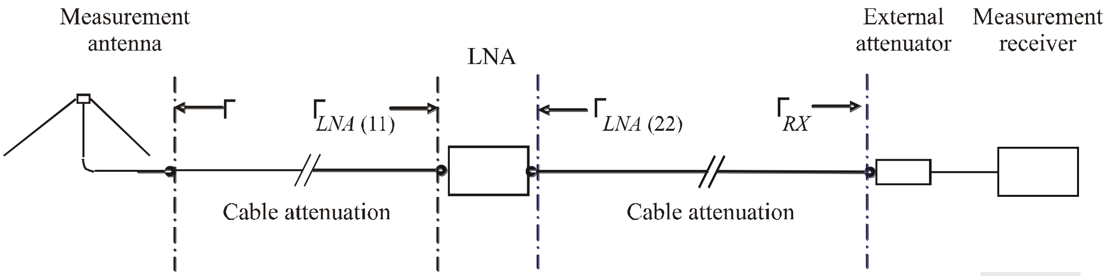
The receiver will be used with an external attenuator of at least 3 dB, the lower the attenuation the better. The typical input return loss of a receiver is $\Gamma_{RX} > 13$ dB with the internal attenuator switched off.

The output return loss of the antenna is $\Gamma_{ANT} > 20$ dB.

The input and output return loss of a typical LNA is $\Gamma_{LNA} > 7$ dB.

A schematic presentation of mismatch errors is given in Fig. 21.

FIGURE 21



Rap 2055-21

The mismatch loss of the receiver to the LNA is $A_{MIS} = 10\ \log\left(1 - \left|\Gamma_{RX}\right|^2\right)$.

The mismatch loss of the LNA to the receiver is $A_{MIS} = 10 \log\left\{1 - \left|\Gamma_{LNA(22)}\right|^2\right\}$.

Mismatch uncertainty is $U_{MIS} = \dfrac{1}{\left|1 - \Gamma_{RX}\Gamma_{LNA(22)}\right|^2}$.

In absolute terms $\left|U_{MIS}\right|_{max} = \dfrac{1}{\left(1 - \rho_{RX}\rho_{LNA(22)}\right)^2}$.

In logarithmic form $U_{MIS} = 20\ \log_{10}(1 \pm \rho_{RX}\rho_{LNA(22)})$ (dB).

The same exercise can be performed for the antenna and LNA input resulting in equation (8):

$$\boldsymbol{U_{MIS}} = 20\ \log_{10}(1 \pm \rho_{\boldsymbol{LNA}(11)}\rho_{\boldsymbol{ANT}}) \qquad \text{dB} \qquad (8)$$

The attenuation of the cabling is measured and has its own calibration uncertainty depending on the calibration equipment used. A way to simplify error analysis is to assume the whole setup: antenna, LNA, external attenuator and cables as a single system. By applying a calibration signal to the input of the LNA the effects of mismatch losses and errors between input LNA and input receiver will be compensated for. This has to be repeated for every measuring frequency (band). This way a single calibration and calibration uncertainty is determined.

9.3 Gain accuracy of LNA

The gain of the LNA can easily be determined with a receiver and a generator. Assuming the short-term stability of both instruments is ideal, the accuracy of the resulting measurement equals the readout accuracy of the receiver which is typically between 0.1 and 0.01 dB. The long-term gain stability of the amplifier and the dependency of the gain on the in and output mismatch introduces the dominant error that has to be determined experimentally.

9.4 Accuracy of external attenuator

The attenuation of the external attenuator can easily be determined with a receiver and a generator.

Assuming the short-term stability of both instruments is ideal, the accuracy of the resulting measurement equals the readout accuracy of the receiver which is typical between 0.1 and 0.01 dB.

9.5 Calibration uncertainty of receiver/analyser

The calibration uncertainty is a standard value given by the manufacturer as $u(P_{M\text{-}CAL})$ typical values are between 0.4 dB and 1.5 dB (normal distributed, 95% uncertainty).

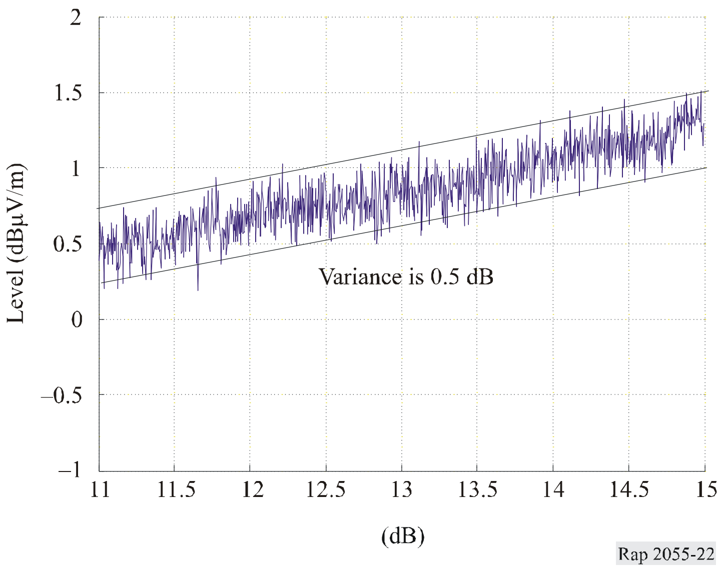
This is a total uncertainty for the whole frequency range and all filter attenuator combinations. The measurement error for this type of measurement can be improved by excluding elements from the receiver error analyses that are not relevant for the measurement. The built in attenuator for example is not used instead an external attenuator is used. Most manufacturers provide information to calculate the new total measurement error/uncertainty.

9.6 Accuracy of the noise source to determine the correction factors

In parts of the calibration of the measurement setup a noise source is used to determine the magnitude of correction factors. Its important that the output power of the noise source is stable. Figure 22 shows a correction factor curve established with an unstable noise source.

FIGURE 22

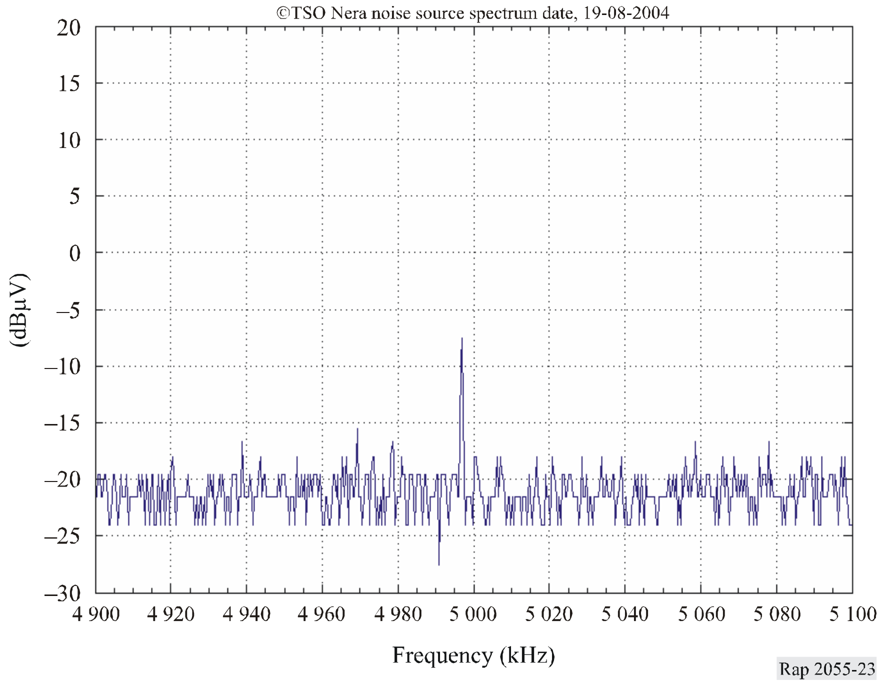
Unstable noise source, peak variance = 0.5 dB, drift > 1 dB



The noise source should have Gaussian noise properties and the output should be pure noise. Figure 23 shows the spectrum of a noise source containing carriers at certain frequencies around 5 MHz.

FIGURE 23

Spectrum of noise source with carrier



The last important item is the output impedance of the noise source, a directional coupler with reference load or a network analyser suitable for hot S22 measurements can be used to check this impedance.

9.7 Total measurement uncertainty

For the determination of the total measurement uncertainty we need to determine the calibration uncertainty of all elements affecting the measurement accuracy.

The following items need to be determined:

– Uncertainty and distribution

– Sensitivity coefficient

– Standard uncertainty of the source

– Derivation factor.

Using this information we have to calculate the combined standard uncertainty and the expanded standard uncertainty (%).

Bibliography

ITU-R Recommendations

Recommendation ITU-R SM.332 – Selectivity of receivers.

Recommenation ITU-R P.372 – Radio noise.

Recommendation ITU-R P.527 – Electrical characteristics of the surface of the Earth.

Recommendation ITU-R P.845 – HF field-strength measurement.

Annex 1

K-factor calculations

For many antennas the so-called *K*-factor is given. The *K*-factor is a constant to convert the voltage at the terminals of an antenna (dBµV) to electrical field strength (in dBµV/m). This *K*-factor is useful if we want to use such an antenna for field-strength-measurements. The unit of *K*-factor is dB(1/m).

In most cases the gain of an antenna is given in dB_i or dB_x where x represents the reference antenna. So we have to convert from gain to *K*-factor.

K-factors as used in standardized electromagnetic compatibility (EMC) measurements are a different story. EMC measurement antennas are used on a prescribed measurement platform and are also calibrated under these circumstances. The *K*-factor is not only given in relation to the measurement distance but is also a worst case figure. For antenna-measurements and field-strength measurements these EMC *K*-factors are of no use.

Gain expresses the ratio $radiationdensity_{testantenna}/radiationdensity_{referenceantenna}$ (dB).

This gain can be determined using the pointing vector S which describes the E as well as the H field being a measure for power density.

The pointing vector can be described as follows: $S(\theta,\varphi) = [E_\theta^2(\theta,\varphi) + E_\varphi^2(\theta,\varphi)]/Z_0$ (W m^{-2}).

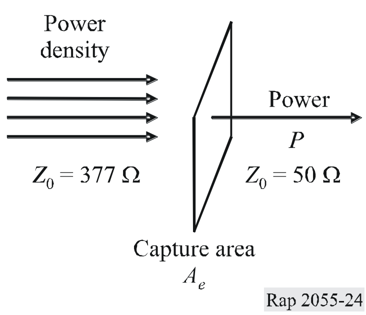
When speaking of power density in a point this $S = E^2/Z_0$ (W m^{-2}).

The impedance of free space is $Z_0 = \varepsilon_r.\varepsilon_0.\mu_r.\mu_0$ and so for vacuum $\varepsilon_0.\mu_0 = 376.7\ \Omega$. Normally we round this to $Z_0 = 377\ \Omega$ also the number 120 π is sometimes used.

The *K*-factor is only about the electrical field (dB). For a conversion we have to transform gain in an absolute number divided by Z_0 the root of this number is the gain. However it is not that simple; the next description can bring some clearance.

Imagine the antenna as a transducer that can convert a part of the power density in a 3-dimensional space in power at its terminals. The antenna has its own internal impedance Z_0. Figure 24 clarifies this and shows that free space also has an impedance Z_0.

FIGURE 24



As mentioned before, power density is expressed using the pointing vector S. The total power received by the antenna depends on its capture area A_e.

Valid is	$A_S \cdot S = P \Leftrightarrow 1/A_e = S/P$
Further	$S = E^2/377\,\Omega$
And	$P = U^2/50\,\Omega$

$$\Rightarrow 1/A_e = (E^2/U^2)\cdot(50\,\Omega/377\,\Omega)$$

$$\Leftrightarrow (E^2/U^2) = (1/A_e)\cdot(377\,\Omega/50\,\Omega)$$

$$\boxed{\begin{array}{l}\Rightarrow K = E/U = \sqrt{(1/A_e)\cdot(377\,\Omega/50\,\Omega)} \\ A_e = (G\cdot\lambda^2)/4\pi \Leftrightarrow 1/A_e = 4\pi/(G\cdot\lambda^2)\end{array}}$$

$$\Rightarrow K = \sqrt{4\pi/(g\cdot\lambda^2)\cdot(377\,\Omega/50\,\Omega)}$$

$$\Leftrightarrow K = \sqrt{4\pi\cdot(377\,\Omega/50\,\Omega)}\cdot(1/\lambda)\cdot(1/\sqrt{G})$$

$$\Leftrightarrow \qquad \boxed{K = \frac{9.73}{\lambda.\sqrt{G}}}$$

The inverse of this formula can be used to determine a formula to calculate *G* back to *K*.

$$\Leftrightarrow \qquad \boxed{G = \left(\frac{9.73}{K.\lambda}\right)^2}$$

This is all valid for a 50 Ω antenna, for other input impedances we can derive a set of similar formulas. Pay attention to the fact that both *K*-factor and *G* are presented in linear form and the *K*-factor is a voltage ratio and gain a power ratio.

The next formula is the same as the previous two formulas but converted to dBs.

$$\Leftrightarrow \qquad \boxed{K = 20 \log f - G - 29.78 \text{ dB}}$$

where:

f; frequency (MHz)

G: gain (dBi).

____