

REPORT ITU-R SM.2055

Radio noise measurements

(Question ITU-R 231/1)

(2006)

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 in 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. It 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 Rayleigh distribution has the pdf $P_{RAYLEIGH}(R) = \frac{R}{\sigma^2} e^{-\frac{R^2}{2\sigma^2}}, R \geq 0$. 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

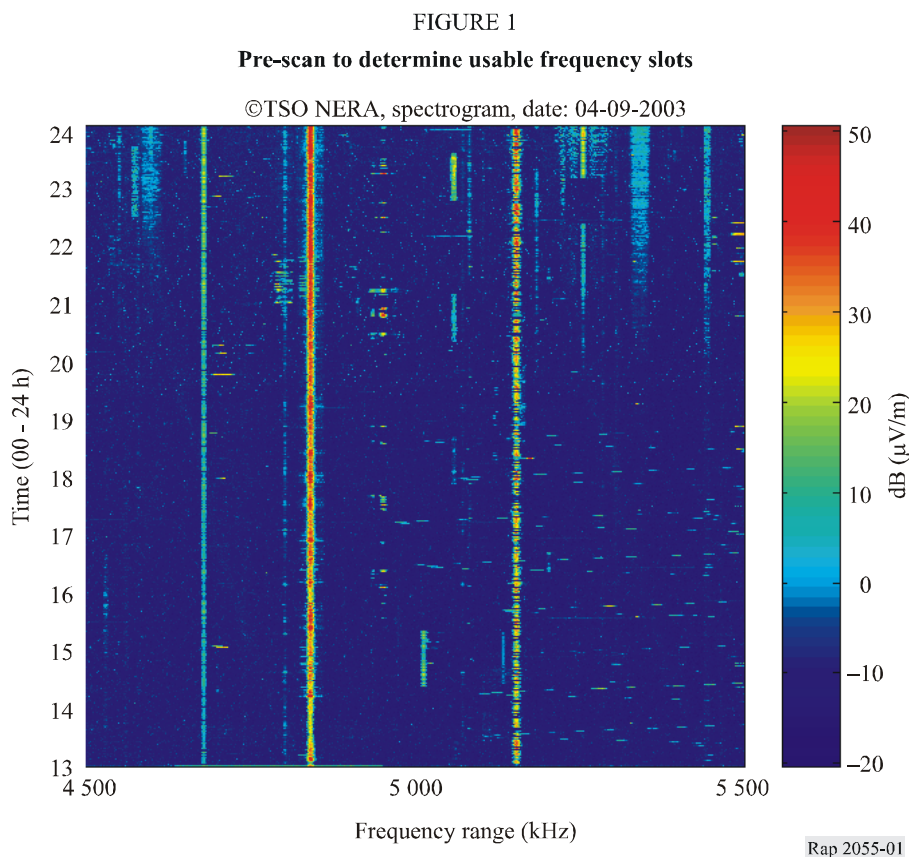
ratio r.m.s./average is $\sqrt{\frac{4}{\pi}}$ or 1.05 dB in power which has to be added to the measured results.

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

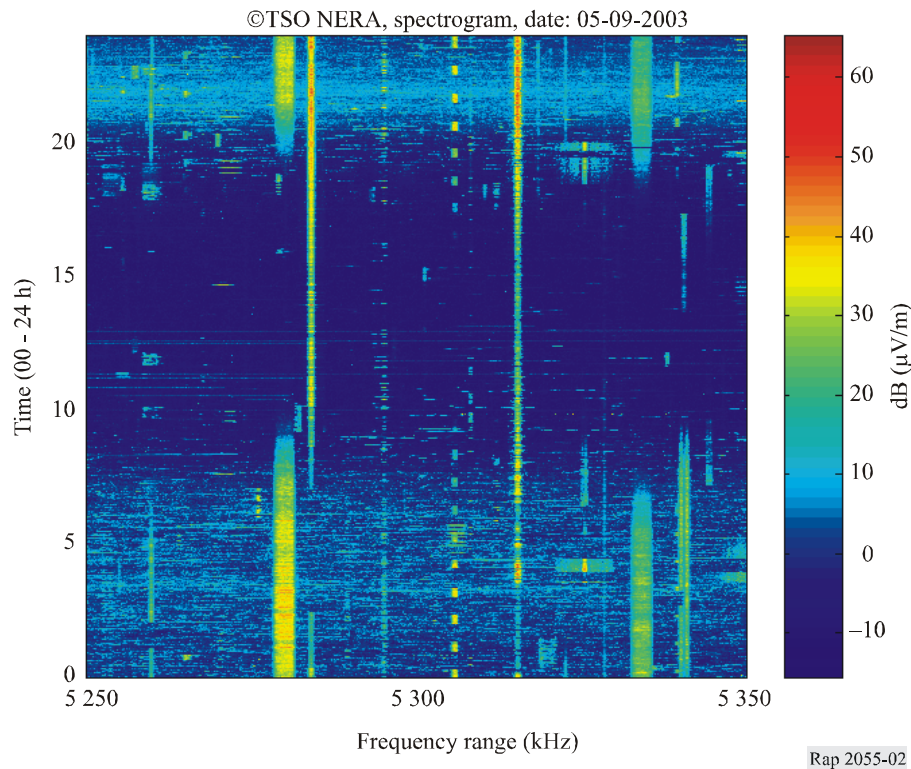
When measuring noise the choice of frequency can be a problem because strong carriers or high average occupation can limit the usable observation time. We first need to investigate (scan) a frequency band which is larger than the frequency band or frequencies to be observed in the final measurement period. 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.



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



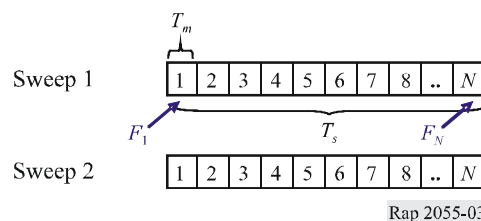
4.3 Collecting the noise containing samples (swept or single frequency measurement)

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.

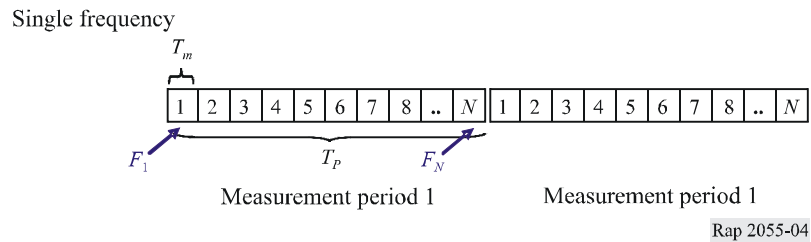
FIGURE 3

Two frequency scans (sweeps) using a spectrum analyser



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



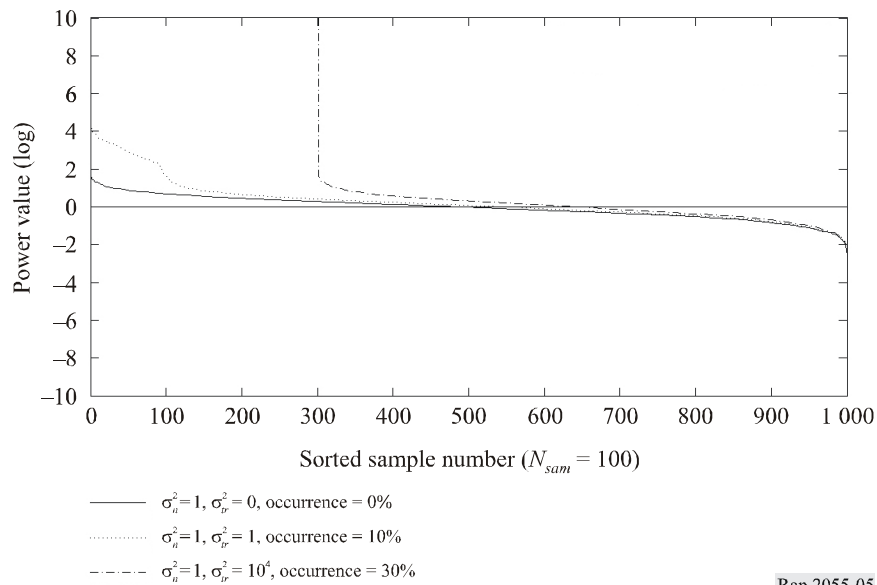
For measuring noise power densities in a small frequency range there is no difference in scanning a small section of frequency band or sampling on only one frequency as long as we take the measurement period of the receiver equal to the sweep time of the analyser. Only when strong constant signals are 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 of 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 calculating 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) then this has to be 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

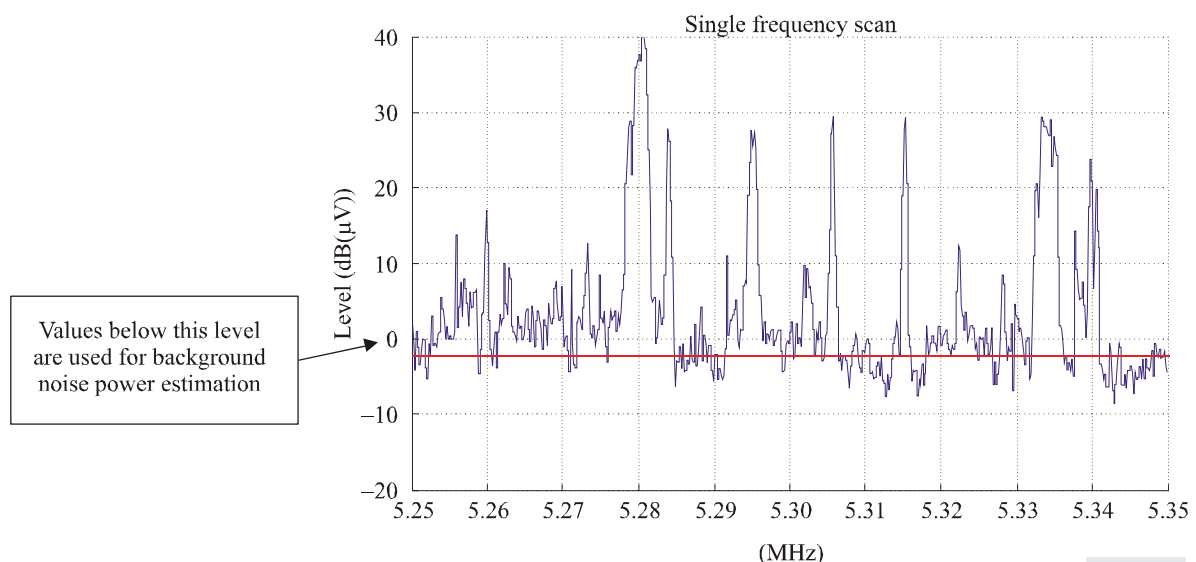
Figure 5 is the result of the simulation of a receiver system showing the (sorted) received power for 1 000 frequency bins and 100 time samples per bin, N_{sam} . The solid curve represents the noise-only situation, with noise power $s_n^2 = 1$. The dotted curve represents a situation in which also a transmitter is present with a bandwidth which fills 10% of the band under consideration, and which has a signal power $s_{tr}^2 = 1$. The dash-dotted curve represents noise plus a transmitter with $s_{tr}^2 = 10^4$, 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 $-2 \text{ dB}\mu\text{V}$, all values above this line are considered non-noise, in other words unwanted signals.

FIGURE 6

Randomly chosen scan

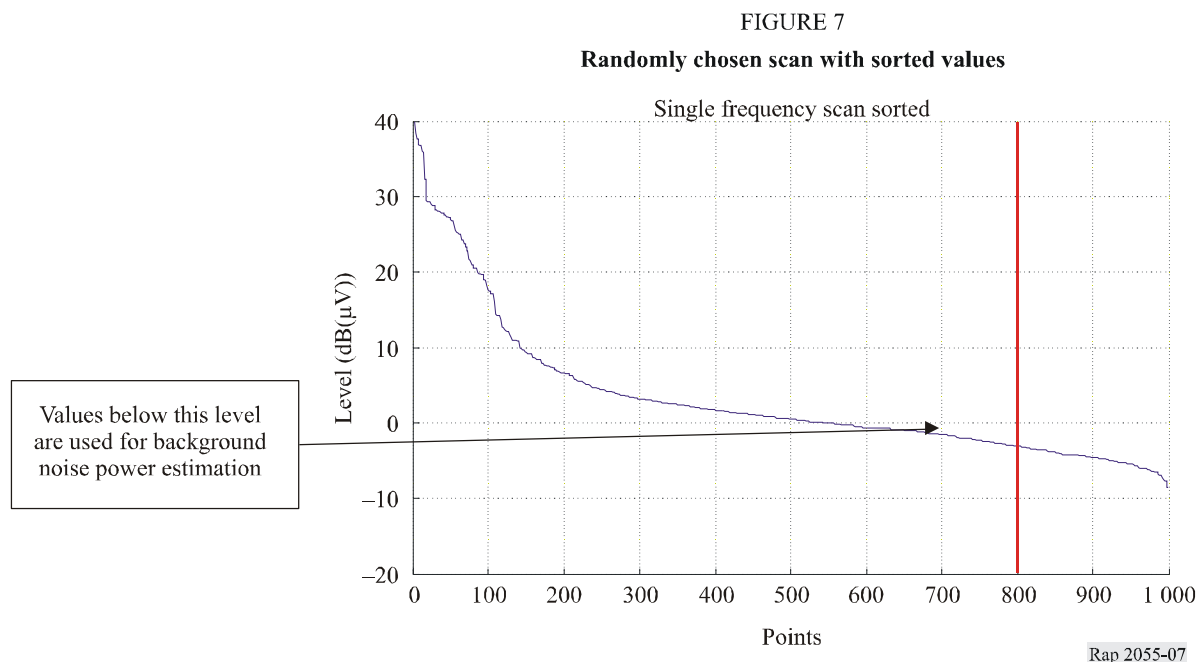


Rap 2055-06



Documents
Document Sharing Hub

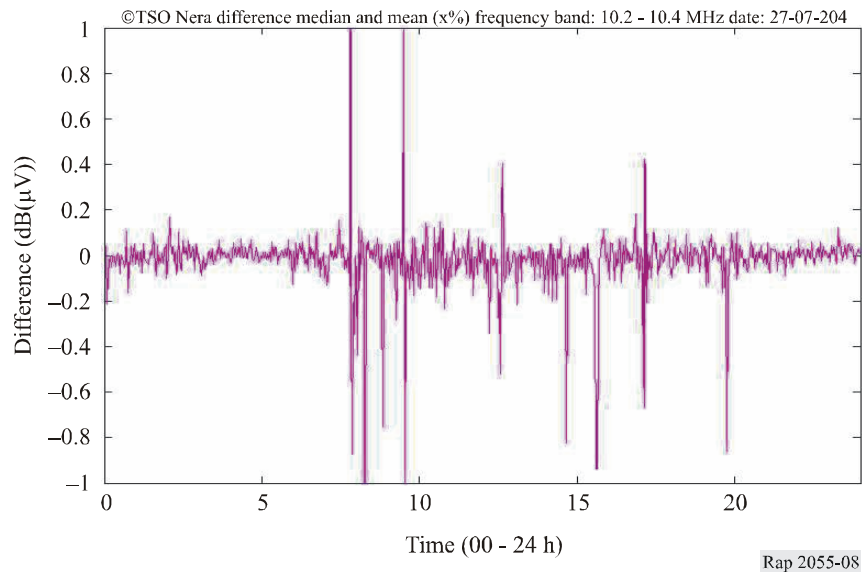
Figure 7 shows the same scan but with all the values sorted. By setting the same level of $-2 \text{ dB}\mu\text{V}$ we can choose the percentage, in this case 20%.



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)

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.

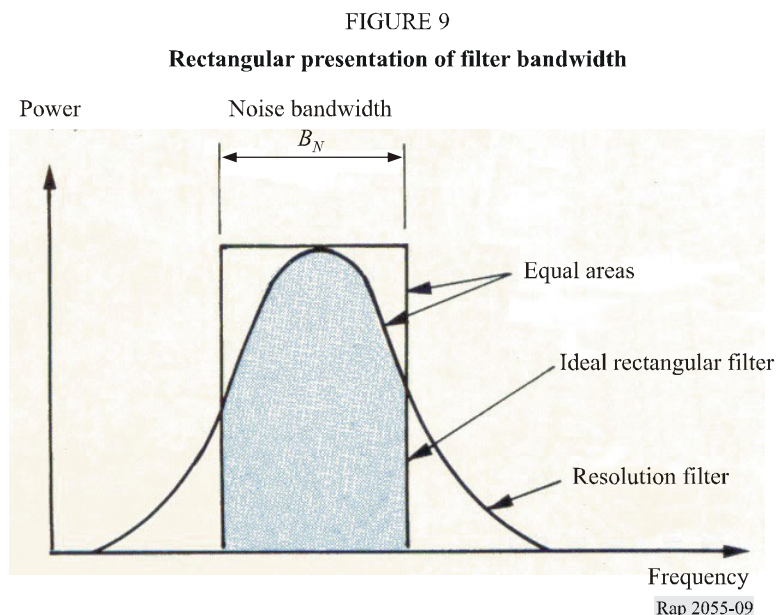
NOTE 2 – To prevent errors caused by the non-linearity of the receiver, the in-band generated power of the noise source needs to be equal to the total received noise power during the measurements.

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.



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

$$10 \log (RBW_2/RBW_1)$$

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:

$$P_0 = K T_0 B \quad (2)$$

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 dB μ V	–7 dB μ V	–7 dB μ V
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:

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

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:

$$V_{AVG} = \frac{1}{N} \cdot \sum_{i=1}^N v_i \quad (4)$$

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 than 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