REPORT ITU-R P.2089

The analysis of radio noise data

(Question ITU-R 214/3)

(2006)

Scope

Impulsive noise is an important aspect of man-made noise in particular. This Report describes a method of analysing noise measurements so as to characterize both the impulsive and the Gaussian parts of the noise distribution.

1 Sources of radio noise

Radio noise external to the radio receiving system derives from the following causes:

– radiation from lightning discharges (atmospheric noise due to lightning);

– aggregated unintended radiation from electrical machinery, electrical and electronic equipments, power transmission lines, or from internal combustion engine ignition (man-made noise);

– emissions from atmospheric gases and hydrometeors;

– the ground or other obstructions within the antenna beam;

– radiation from celestial radio sources.

NOTE 1 – Radio noise comprises the background noise level in the absence of other signals, whether intentionally or unintentionally radiated, so that noise or signals due to unwanted co-channel transmissions or due to spurious emissions from individual transmitting or receiving systems are not considered. In addition, noise due to local or identifiable specific sources is not included.

Of these sources atmospheric noise due to lightning and man-made noise may include impulsive contributions, whereas the other sources are likely to have entirely Gaussian characteristics.

2 Terms for the specification of noise intensity and their interrelationship

External radio noise comprises two main components: White Gaussian noise (WGN) and impulsive noise (IN).

Impulsive disturbances to a receiver system may be considered in two classes:

Impulsive noise – Where the disturbance is broadband compared to the IF filter bandwidth of the receiver being considered. Impulsive noise is typically made up of an aggregate of very short impulses that are very wideband and are frequently man-made in origin. The class includes impulses from automotive ignition circuits, thermostats, lighting, etc.

Other impulsive disturbances – Where the disturbance has a bandwidth which is spectrally comparable to, or less than, the IF filter bandwidth of the receiver being considered. Such a disturbance is likely to be structured, possibly generated by telecommunication systems, and is probably not of interest to the receiver being considered. Such disturbances are not taken into account as a component of radio noise.

2.1 Noise representations

A noise voltage is a function of time that can be described statistically with the use of random variables. The time-varying noise voltage $v(t)$ is represented as a passband signal modulated on a carrier frequency f_c thus:

$$v(t) = \mathrm{Re}\left\{\hat{v}(t)e^{j2\pi f_c t}\right\} \quad (1)$$

where $\hat{v}(t)$ is the noise voltage complex baseband signal centred about 0 Hz that can be represented in Cartesian or polar form as:

$$\hat{v}(t) = x(t) + jy(t) = \sqrt{x(t)^2 + y(t)^2}\, e^{j\arctan\left(y(t) / x(t) \right)} \quad (2)$$

where $x(t)$ and $y(t)$ are the baseband signal real and imaginary components respectively.

The instantaneous noise power is defined as:

$$w = \left|\hat{v}(t)\right|^2 \quad (3)$$

The mean noise power is defined as:

$$w_0 = E\{w\} \quad (4)$$

where $E\{\ \}$ denotes the expected value of its argument.

The noise power is normalized by the average noise power due to black body radiation and thermal noise that is present in all radio systems. This average noise power is defined by the formula:

$$k\, T_0\, b$$

where:

k = 1.38×10^{-23}, Boltzmann's constant, given in Joules per Kelvin

T_0 = 290 K, absolute temperature

b: receiver noise equivalent bandwidth.

Furthermore, the standard convention is used that variables in upper case are the decibel equivalents of those in lower case, e.g. $W = \log_{10}(w)$. In this format W is known as a *figure* and w is known as a *factor*.

2.2 White Gaussian noise statistics

A random statistical process can be characterized in terms of a probability density function (PDF). In the case of WGN, by definition, the voltage is modelled by a Gaussian distribution with zero mean and a uniform power spectral density (PSD). In terms of polar coordinates, the WGN amplitude is Rayleigh distributed and the phase is uniformly distributed. If a long enough measurement is made, then an amplitude histogram will approximate to the PDF.

Assuming a mean power level of w_{0g} and a random noise variable, w_{RV}, the power PDF for WGN is:

$$p_g(w_{RV}) = \frac{1}{w_{0g}} e^{\frac{-w_{RV}}{w_{0g}}} \quad (5)$$

For any distribution, the cumulative distribution function (CDF) is defined as:

$$P(w_{RV} \leq w) = \int_0^w p(w_{RV})\,dw_{RV} \tag{6}$$

where w is the noise power independent variable. In radio engineering, the amplitude probability distribution (APD) function is used rather than the CDF, as it indicates the probability that the power exceeds a given level. The APD function is related to the PDF by:

$$A(w) = P(w_{RV} > w) = \int_w^\infty p(w_{RV})\,dw_{RV} \tag{7}$$

If the noise is WGN distributed according to equation (5), then the APD function is:

$$A_g(w) = e^{\frac{-w}{w_{0g}}} \tag{8}$$

w_{0g}, normalized with respect to $k\ T_0\ b$, is also described as the external noise factor, f_a, or in logarithmic terms as the noise figure, F_a, where:

$$F_a = 10 \log f_a$$

2.3 WGN on the amplitude probability graph (APD) graph

An APD conventionally has the form where the ordinate represents the amplitude level exceeded, scaled linearly in decibels, and the abscissa represents the percentage of time for which the level is exceeded. The abscissa is linear in terms of the function 1 – log(ln(1/$A_g(w)$)). Unity distance on the abscissa is defined as the distance between two points where the value of the function differs by one.

The instantaneous noise power equals the mean noise power (i.e. $w = w_{0g}$) when:

$$A_g(w) = e^{-1} \approx 0.368 \tag{9}$$

Thus a value for w_{0g} can be obtained by reading the power level at the 37% point on the APD graph. A Rayleigh distribution has a gradient of −10: a change of level of 10 dB for a unit distance change in probability.

Further information on the Rayleigh distribution is given in Recommendation ITU-R P.1057.

2.4 Impulsive noise statistics

Impulsive noise is modelled as a series of impulses that are Poisson distributed in time which have a Weibull power distribution. This power distribution is convenient as it plots as a straight line on the APD graph. A simple line fit to this region therefore allows one to produce statistical parameters to quantify the amount of impulsive noise present.

Assuming a random noise variable, w_{RV}, the Weibull power PDF is:

$$p_w(w_{RV}) = a.b.w_{RV}{}^{b-1}.e^{-aw_{RV}{}^{b}} \tag{10}$$

where a and b are the parameters of the distribution.

Using the definition in equation (7), the corresponding APD function for an independent variable, w, is:

$$A_w(w) = e^{-aw^b} \tag{11}$$

Equation (11) may be recast in terms of parameters w_{0w} and α, which may be evaluated directly from the APD graph:

$$A_w(w) = e^{-\left(\frac{w}{w_{0w}}\right)^{1/\alpha}} \tag{12}$$

where the intercept, a, and the slope, b, can be found from:

$$a = \frac{1}{w_{0w}^{1/\alpha}} \qquad b = \frac{1}{\alpha} \tag{13}$$

As with the WGN distribution, the instantaneous and the power w_{0w} are equal when:

$$A_w(w) = e^{-1} \approx 0.368 \tag{14}$$

Thus at a cumulative probability of (approximately) 37%:

$$10\log(w) = 10\log(w_{0w}) \tag{15}$$

The parameters w_{0w} and -10α are the 37% power and the gradient respectively of the impulsive part of the APD graph.

In practice the values of w_{0w} and α can be readily obtained by fitting a line to the steepest part of the APD graph, but are not in themselves particularly helpful. As the amount of IN increases, w_{0w} tends to decrease and α increases. The meaning of w_{0w}, in particular, is counter-intuitive and it is also a small number that is sensitive to errors in estimating the line gradient.

It is therefore more useful to estimate the mean and standard deviation of the IN noise power. These parameters are more intuitive than either a and b, or w_{0w} and α. They are also less sensitive to estimation errors.

The mean and standard deviation of impulsive noise, given by the Weibull distribution is:

$$m_w = w_{0w}\Gamma(1+\alpha) \tag{16}$$

$$s_w = w_{0w}\sqrt{\Gamma(1+2\alpha) - \Gamma^2(1+\alpha)} \tag{17}$$

where $\Gamma(\ )$ denotes the gamma function defined as:

$$\Gamma(a) = \int_0^\infty e^{-t} t^{a-1} dt \tag{18}$$

These parameters can be usefully represented in decibel form as:

$$M_w = 10.\log_{10}(m_w) \tag{19}$$

$$S_w = 10.\log_{10}(s_w) \tag{20}$$

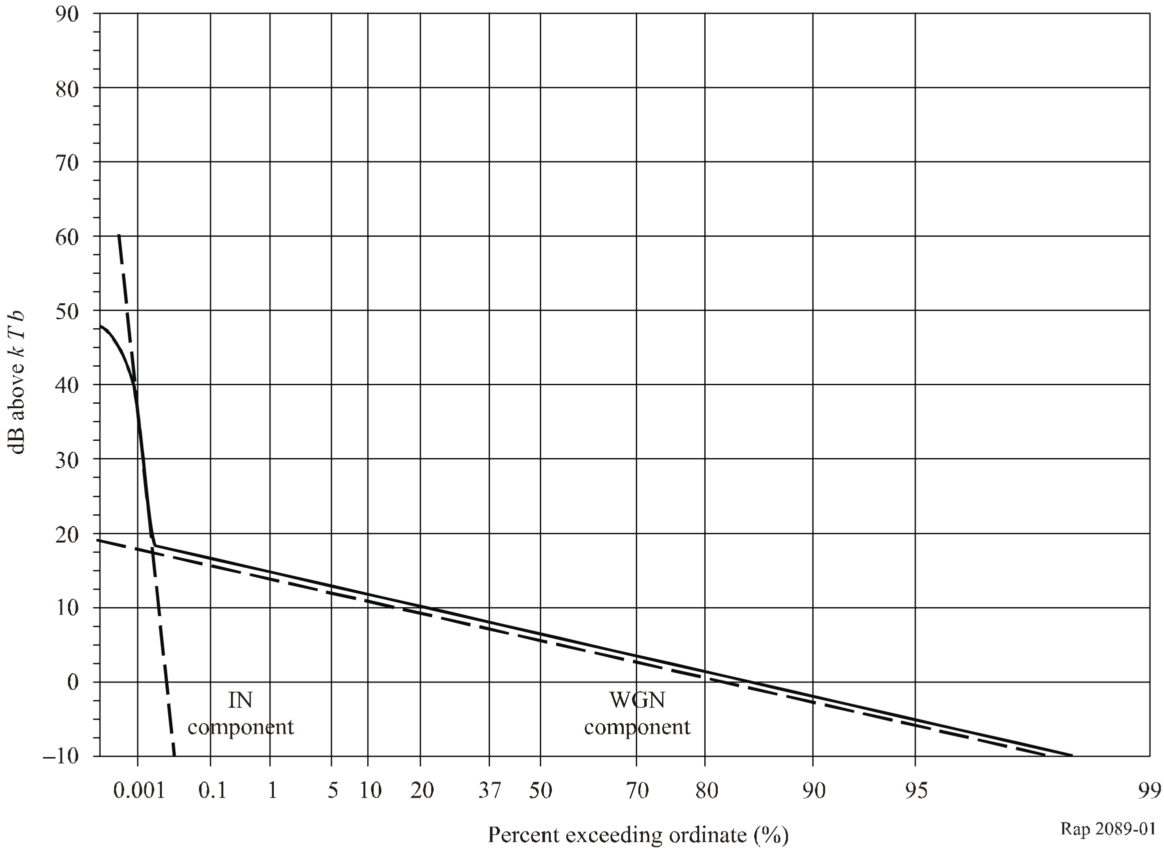
Both parameters are obtained from the APD graph in units of dB above $k\ T_0\ b$. These may be rescaled to units of dB(μV/MHz) so that they can be scaled linearly with bandwidth.

2.5 Noise measurement parameter extraction

The noise parameters may be estimated from the APD graphs. Figure 1 indicates the salient features of the APD graph.

FIGURE 1

Example APD graph showing salient features



The following features are shown in Fig. 1:

– The WGN component, the level of which is estimated using the dashed line indicated.

– The impulsive noise component, which is approximated by the dashed line indicated.

2.5.1 WGN parameter extraction

The noise environment may be characterized by three parameters, f_a (or w_{0g}), w_{0w} and α. The first of these may be approximated by reading the 37% power on the APD graph, making any necessary adjustment for receiving system noise. This actually gives w_{0g} (or W_{0g} because the APD graph is scaled in dB) instead of f_a. However, this approximation may be poor when measurements are made in the presence of signals or other disturbances which are non-Gaussian, in which case, an algorithm which reaches the true Gaussian component should be used.

In the presence of Nakagami-Rice distributed noise (i.e. where there is a contribution due to continuous signals) the w_{0g} extraction from the APD graph is best performed by fitting a straight line of gradient −10 to the Gaussian part of the APD graph (indicated in Fig. 1). In practice this is best performed by making a joint assessment in both the frequency and time domains to ensure that the effects of any narrow-band signals are eliminated.

2.5.2 IN parameter extraction

Two parameters are used to characterize the IN component, w_{0w}, α. These parameters may be evaluated by fitting a straight line to the impulsive part of the APD graph.

The parameter α is immediately available from the gradient of impulsive noise component of the APD, and w_{0w} is evaluated by solving the equation $w = w_{0w}\left(\ln\left(\frac{1}{A_w(w)}\right)\right)^{\alpha}$ at the point of maximum gradient. The plateau section of the APD graph, at small exceedance percentages, is a poor indicator of the impulsive noise level. The values for w_{0w} and α may be converted to the mean and standard deviation using equations (16) and (17).

2.5.3 Influence of receiver bandwidth

It has been found at VHF and UHF that using bandwidths of 1 MHz and greater means that the probability of impulses overlapping in time is extremely small. Bandwidths used in the measurement of man-made noise of 1 MHz and larger significantly assist in eliminating the effects of coherent signals (providing they are of low amplitude). Narrower bandwidths cause the impulses to spread significantly in relation to the average impulse rates observed and the IN line on the APD graph will tend to flatten making it difficult to convert to a different bandwidth. Thus it is suggested that all future measurements in this frequency range be made with a bandwidth of at least 1 MHz and preferably 2 MHz.

3 An approximate alternative procedure for determining the APD in the presence of impulsive noise.

The data contained in Recommendation ITU-R P.372 for radio noise due to lightning were obtained at a time when the capability for data acquisition and processing was limited. In this case the parameter used to describe departure of the APD from a Rayleigh distribution is V_d. This parameter is the ratio in decibels of the r.m.s. to the average of the noise envelope voltage. Values for monthly median and standard deviation of this parameter appropriate for noise due to lightning are given in part c of each of the Figs. 15-38 of that Recommendation. The Recommendation also gives curves for converting V_d to other bandwidths and for the APD for various values of V_{dm}. Examples of the use of this information are given in ex-CCIR Report 322-3.