The Method of Measuring the Energy Pass-Band of a Communication Receiver

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Abstract- The paper presents the method to measure the energy pass-band Δf of a communication receiver on the basis of the spectrum density characteristic of its own noises on the receiver output. Moreover, it gives a numeric estimator of this band Δf and introduces the dependences for combined standard uncertainty in measuring the energy pass-band of this receiver.

I. Introduction

While measuring characteristics and parameters of linear sets or electronic devices, there arises a necessity to measure the values of their energy pass-band. This band is also called: noise band. It characterises the transmissions of white noise energy by the electronic set or device. This band is defined as [1]:

$$\Delta f = \frac{\int_0^\infty |H(f)|^2 df}{|H(f)|^2_{\max}} \tag{1}$$

where $H(f)$ is a frequency characteristic of the tested set or device.

The accuracy of measuring the energy pass-band has a decisive influence on an error in measuring any characteristic, a functional parameter of a set or a device. For instance in a communication receiver the value of its useful sensitivity is proportional to the value of the energy pass-band [2].

II. The method to measure the energy pass-band of a communication receiver

The results obtained by the authors show explicitly that there is a possibility to measure the energy pass-band Δf of a communication receiver on the basis of the spectrum density measurement of the power of its own noises observed on the low frequency output of a receiver.
In this case, the fully equivalent dependence defining the energy pass-band of a receiver is the following dependence:

$$\Delta f = \frac{\int_0^\infty G_n(f) df}{G_n(f)_{\max}} \tag{2}$$

where $G_n(f)$ is spectrum density of the power of its own noises observed on the output of the receiver and $G_n(f)_{\max}$ is its maximal value.

Determining the band Δf according to the dependence (2) there is no need to give on the input of the receiver a signal from the signal generator or the standard noise generator [1, 2]. It is necessary, however, to join to an antenna input of the receiver the resistance equal to its input resistance and set the amplification in high frequency stages of a receiver to the maximum value. This is fully justified, because in a communication receiver, which constitutes a cascade-connected linear two-ports, the intensity of the noises on the receiver output depends on their level on the input stages. It is worth mentioning the fact that it is commonly accepted to treat a communication receiver as a linear set, in which the ratio of the signal mean power to the mean power of the noises on the output is directly proportional to the level of the input signal. It results from these considerations that it is possible to

assume that a receiver, as a linear set, is steered by white noise and fulfils all the requirements necessary for measuring the energy pass-band with the use of the standard noise generator [1, 2].
Next, in the proposed method of measurement, for a given kind of receiver modulation the spectrum density of the noise power is measured on its low frequency output (Figure 1).
The observation of noises on the receiver output is carried out in the measurement system, which makes use of digital processing and an analysis of the signal [2]. The digital measurement data is processed in the virtual instrument (Figure 1) operating in the LabVIEW software environment, in

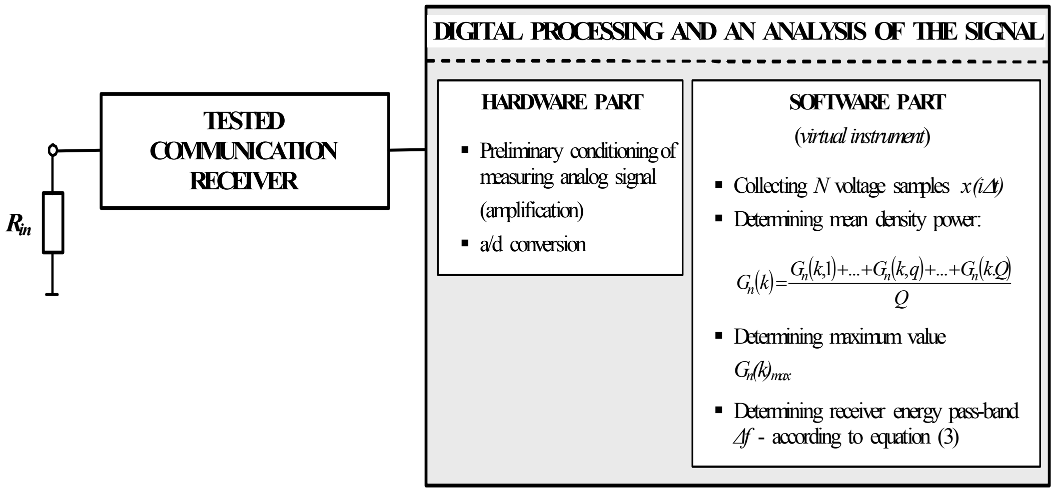


Figure 1. The measurement system for digital measuring of the receiver energy pass-band

which the energy pass-band Δf of the receiver is measured according to the dependence:

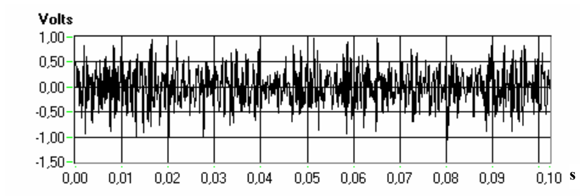
$$\Delta f = \frac{\sum_{k=o}^{\frac{K}{2}} G_n(k) \cdot \frac{1}{K\Delta t}}{G_n(k)_{\max}} \tag{3}$$

where Δt is a sampling period, $K = \frac{N}{Q}$ is a number of samples in the set, N is total number of samples of the analysed signal and Q is the number of averagings of the power spectrum densities.

III. Mesurement results

The presented, selected results of experimental examinations of the energy pass-band of a selected communication receiver, RA1776 made by RACAL, were obtained for the frequencies in marine bands, for the modulation J3E (receiver bandwidth at -3 dB equals 2,7 kHz).
Figure 2a presents the graphs of time waveforms of the noises on the output of a low frequency receiver in the marine band 8 MHz (at the frequency of receiver tuning 8243 kHz), when the resistance characteristic for its recommended input impedance (50 Ω) was joined to its input. On the basis of the data obtained from this waveform the power spectral density was measured with the use of software (Figure 2b).
It results from Figure 2 that in order to measure the power spectral density and to calculate the values of the energy pass-bands for different kinds of modulation, it is sufficient only to register the data of its internal noises, and then to determine the desired parameters with software.
The determined, averaged values of the energy pass-band for the receiver RA.1776 for the frequencies from the radio-telephony bands used in marine radio communication within the range 0,1 ...30 MHz, are presented in Table 1.
Analogous measurements carried out for other radio communication receivers confirmed the obtained results and the rightfulness of the use of the presented method to measure the energy pass-band Δf .

a)



b)

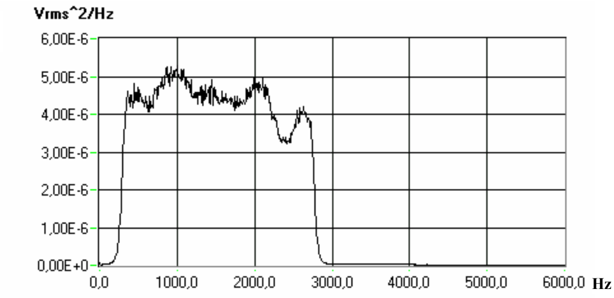


Figure 2. Instantaneous voltage waveform (a) and the power spectral density (b) with the resistance R_{in} on its input

IV. Uncertainty in measuring the energy pass-band

In order to assess uncertainty $u_c(\Delta f)$ in measuring the energy pass-band it was assumed that input variables of the measurement equation (3), which are successive, determined with the help of the program, discrete values of the spectral power density of the noise signal on the receiver output $G_n(k)$,

Table 1. Measured values of energy pass-band and their uncertainties

The frequency of receiver operatation *[kHz]*	The values of energy pass-band and their uncertainties			
	Δf [Hz]	*u(Δf) [Hz]*	*U95%(Δf) [Hz]*	*u(Δf)/Δf [%]*
125	3745,68	18,04	36,08	0,48
2645	3814,50	15,17	30,34	0,40
4104	3871,46	15,74	31,48	0,41
6212	3852,30	14,54	29,08	0,38
8343	3814,46	14,58	29,16	0,38
12290	3838,29	17,89	35,78	0,47
16444	3797,92	16,74	33,48	0,44
18801	3782,86	15,73	31,46	0,42
22078	3809,32	15,08	30,16	0,40
25085	3766,04	20,36	40,72	0,54

are not correlated. Thus, the combined uncertainty of measuring the energy pass-band $u_c(\Delta f)$ is expressed by the following dependence:

$$u_c^2(\Delta f) = \sum_{k=0}^{\frac{K}{2}} \left(\frac{1}{K\Delta t G_n(k)_{\max}}\right)^2 u^2(G_n(k)) + \left(\frac{-\Delta f}{G_n(k)_{\max}}\right)^2 u^2(G_n(k)_{\max}) \qquad (4)$$

were $u(G_n(k))$ is partial uncertainty in measuring spectral power density determined for the frequency f_k and $u(G_n(k)_{max})$ is partial uncertainty determined for the frequency, for which spectrum power density reaches the maximum value.

The spectrum density of the power $G_n(k)$ was calculated with the use of a Fourier's transformation, whereas in the procedure of spectrum estimator smoothing the averaging of sections in time intervals was applied (Figure 1).
The partial uncertainty $u(G_n(k))$ in the measurement of the power spectrum density can be expressed by the following dependences [5]:

$$u(G_n(k)) = 2u_{x(i\Delta t)}\sqrt{\frac{2\Delta t}{Q}G_n(k)} = 2u_{x(i\Delta t)}\sqrt{2\frac{G_n(k)}{B_e N}} \text{ , for } k=0 \qquad (5)$$

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where $B_e = \frac{Q}{N\Delta t}$ determines the resolution of the spectrum analysis and $u_{x(i\Delta t)}$ is uncertainty connected with single sample registration.

The uncertainty $u_c(\Delta f)$ in calculating the energy pass-band Δf is affected by errors connected with the inaccuracy in registering input samples $x(i\Delta t)$ of the measurement signal, including the quantisation error resulting form a/d processing, a/d converter resolution, as well as the parameters of the spectral analysis (sampling frequency, DFT resolution, the number of the processed samples) (Table 2) [4, 5].

Table. 2. The combined uncertainty in measuring the energy pass band (Δf = 4150,7 Hz, f_p = 20 kHz, B_e = 9,8 Hz, $u_{x(i\Delta t)}$ = 17,33 mV)

Number of averagings Q	$u_c(\Delta f)$ [Hz]	$u_c(\Delta f)/\Delta f$ [%]
50	68,62	1,65
100	48,52	1,17
500	21,70	0,52
1000	15,34	0,37

Standard uncertainty $u(\Delta f)$ can be also assessed on the basis of the series of measurement results (their dispersion) as the experimental standard deviation of the arithmetic mean of the measurement results (the method of A-type[3]):

$$u(\Delta f) = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(\Delta f_i - \bar{\Delta f})^2} \qquad (7)$$

where $\Delta f_{i\,n}$ is a single measurement result , n is a number of measurements and $\bar{\Delta f}$ the arithmetic mean of the measurement results:

$$\bar{\Delta f} = \frac{1}{n}\sum_{i=1}^{n}\Delta f_i \text{ .} \qquad (8)$$

Expanded measuring uncertainty $U(\Delta f)$ is determined in the following way:

$$U(\Delta f) = k \cdot u(\Delta f) \qquad (9)$$

where k is coverage factor depending on the accepted level of confidence and distribution of measurement results.

For a long series of observations (n>30) it is accepted that the measurement results have a normal distribution; then the coverage factor k for the level of confidence equals 95% is 2.
The calculated relative standard uncertainties for the measurements of the pass-band Δf, measured at 100 averaged values of the spectrum power density are about 0,5 % (Table 1).

V. Conclusions

The presented method allows measuring the energy pass-band Δf of a communication receiver without the use of standard generators.
This method, after some modification, can be applied to measure the energy pass-band of other devices or sets. After some slight modification of the digital algorithm of signal processing it can be also applied to measure e.g. the 3 dB or 6dB pass-band.
In this method, the accuracy of measuring Δf depends exclusively on uncertainty of the measurement of spectrum density of the noise power observed on the receiver output. It results from the carried out calculations, in which experimental data were made use of, that the main source of uncertainty in measuring the energy pass-band are the properties of the hardware of the measurement equipment used (equations 5, 6). In the considerations the constituent errors resulting from the fact that the receiver was treated as a linear set, were not taken into account as they are negligibly small.

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