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*ТЕХНИЧЕСКИЕ НАУКИ /
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ИНФОРМАТИКА, ВЫЧИСЛИТЕЛЬНАЯ ТЕХНИКА И УПРАВЛЕНИЕ / INFORMATICS, COMPUTER ENGINEERING AND MANAGEMENT

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Определение частотных зависимостей децилей отношения сигнал-помеха

Determination of frequency dependencies of deciles of the signal-to-noise ratio

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Аннотация. *Уровень сигнала и помех в декаметровом диапазоне радиоволн подвержен значительным случайным изменениям, что оказывает влияние на надежность радиосвязи. Надежность радиосвязи в декаметровом диапазоне определяется отношением среднего уровня сигнала к уровню шума на входе приемника к его допустимому значению, которое, в свою очередь, зависит от выбранной рабочей частоты. Также важным показателем является стандартное отклонение (среднеквадратическое отклонение) соотношения сигнал-помеха на входе приемника. Последнее принято считать постоянной величиной и составляет 14 дБ. Тем не менее, согласно экспериментальным данным, стандартное отклонение (среднеквадратическое отклонение) отношения мощности сигнала к мощности шума на входе приемника в декаметровом диапазоне может варьироваться в зависимости от частоты, что может сказаться на точности расчетов надежности связи.*

Ключевые слова: коротковолновая радиолиния, виды радиопомех, среднеквадратическое отклонение, нижняя дециля, верхняя дециля

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Abstract. *The level of signal and interference in the decameter range of radio waves is subject to significant random changes, which affects the reliability of radio communications. The reliability of radio communication in the decameter range is determined by the ratio of the average signal level to the noise level at the receiver input to its permissible value, which, in turn, depends on the selected operating frequency. Also an important indicator is the standard deviation (standard deviation) of the signal-to-noise ratio at the receiver input. The latter is considered to be a constant value and is 14 dB. Nevertheless, according to experimental data, the standard deviation (RMS deviation) of the ratio of signal power to noise power at the receiver input in the decameter range may vary depending on frequency, which may affect the accuracy of communication reliability calculations.*

Keywords: short-wave radio line, types of radio interference, standard deviation, lower decile, upper decile

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Introduction. It is known [1–5] that the key factor for ensuring the reliability of radio communications in the decameter range is the probability that the reliability of communications will meet or exceed the permissible level.

Materials and research methods. As a rule [1, 2], the reliability of radio communications $D_{св}$ □ $\overline{Z}$ is determined by the average value of the signal-to-interference ratio $\overline{Z}$ □ $\overline{E_с}/\overline{E_п}$, i.e. the ratio of the average values of the electromagnetic field strength of the signal $\overline{E_с}$ and radio interference $\overline{E_п}$ in the receiving device. The reliability of radio communications $D_{св}$ is calculated as:

$$D_{св} = F\left(\left(\overline{Z} - Z_{доп}\right)/\sigma_z\right), \text{дБ}, \quad (1)$$

where $\overline{Z}$ is the average value of the signal-to-interference ratio (dB), $Z_{доп}$ is the permissible signal-to-interference ratio (dB), σ_z is the standard deviation of the signal-to-interference ratio (dB).

It must be emphasized that, as noted in the source [3], the standard deviation of the signal-to-noise ratio at the input of a shortwave radio link receiver can vary significantly: from $\sigma_z = 6...11$ дБ day to $\sigma_z = 10...16$ дБ night. Taking such a wide range of values into account can have a significant impact on the accuracy of shortwave communications reliability calculations. For this reason, average values obtained from statistical data are traditionally used to calculate the reliability of decameter radio communications. For example, in the method [4] it is proposed to use the same value $\sigma_z = 14$ дБ for all operating frequencies.

The standard deviation (RMS) of the average signal-to-noise ratio σ_z at the receiver input is determined by the deviation of the upper $D_u\overline{Z}$ or lower $D_l\overline{Z}$ decile of the average signal-to-noise ratio: $\sigma_z = D_u\overline{Z}/1,28$, $\sigma_z = D_l\overline{Z}/1,28$. Since the deviation of the upper $D_u\overline{Z}$ and lower $D_l\overline{Z}$ deciles depends on the frequency f, therefore the standard deviation of the average signal-to-noise ratio also depends on the frequency $\sigma_z(f) = D_u\overline{Z}(f)/1,28$, $\sigma_z(f) = D_l\overline{Z}(f)/1,28$.

The purpose of the report is to establish the dependence of the values of the deciles of the signal-to-interference ratio, depending on the choice of operating frequency.

Research results and their discussion. Study of the dependence of signal-to-interference ratio deciles in the shortwave range on frequency. The main indicator of the quality of decameter (DCM) radio communication [1-4] is reliability, or the probability P of providing communication with reliability no worse than acceptable (i.e. $P_{ош} \le P_{ош\,доп}$). In accordance with the recommendations [6], the calculation of communication reliability $D_{св}$ is carried out for two cases:

1) if the average signal-to-noise ratio is greater than the permissible value $(\overline{Z} > Z_{доп})$, then $D_{св}$ the value of the lower decile of the average signal-to-noise ratio is determined $D_l\overline{Z}$ as

$$D_{св} = 130 - 80\left(1 + \frac{\overline{Z} - Z_{доп}}{D_l\overline{Z}}\right) (\%), \quad (2)$$

2) if $(\overline{Z} < Z_{\text{доп}})$, then $D_{\text{св}}$ is determined by the value of the upper decile of the average signal-to-noise ratio $D_u\overline{Z}$ as

$$D_{\text{св}} = 80\left(1+\frac{Z_{\text{доп}}-\overline{Z}}{D_u\overline{Z}}\right)^{-1} - 30 \ (\%), \qquad (3)$$

In accordance with the recommendations [6], the deviation of the upper $D_u\overline{Z}$ decile of the average signal-to-interference ratio is determined by the formula:

$$D_u\overline{Z} = \left(\left(D_uP_{\text{c}\,d}\right)^2 + \left(D_uP_{\text{c}\,h}\right)^2 + \left(D_lF_{apg}\right)^2\right)^{\frac{1}{2}} = \left(\left(D_uP_{\text{c}\,d}\right)^2 + \left(D_uP_{\text{c}\,h}\right)^2 + \right.$$
$$\left. + \left(10\log\left(\frac{10^{\frac{F_{am\,a}}{10}} + 10^{\frac{F_{am\,p}}{10}} + 10^{\frac{F_{am\,g}}{10}}}{10^{\frac{F_{am\,a}-D_{l\,a}}{10}} + 10^{\frac{F_{am\,p}-D_{l\,p}}{10}} + 10^{\frac{F_{am\,g}-D_{l\,g}}{10}}}\right)\right)^2\right)^{\frac{1}{2}} \ \text{(dB)}, \qquad (4)$$

where $D_uP_{c\,d}$ is the deviation of the top decile of the signal from day to day (dB), $D_uP_{c\,h}$ – deviation of the upper decile of the signal during the hour (dB), D_lF_{apg} – deviation of the lower decile of the total power (combination) of atmospheric (a), industrial (p) and galactic (g) interference (dB).

Decile of the average signal-to-noise ratio is determined similarly [6]: $D_l\overline{Z}$

$$D_l\overline{Z} = \left(\left(D_lP_{\text{c}\,d}\right)^2 + \left(D_lP_{\text{c}\,h}\right)^2 + \left(D_uF_{apg}\right)^2\right)^{\frac{1}{2}} = \left(\left(D_lP_{\text{c}\,d}\right)^2 + \left(D_lP_{\text{c}\,h}\right)^2 + \right.$$
$$\left. + \left(10\log\left(\frac{10^{\frac{F_{am\,a}+D_{u\,a}}{10}} + 10^{\frac{F_{am\,p}+D_{u\,p}}{10}} + 10^{\frac{F_{am\,g}+D_{u\,g}}{10}}}{10^{\frac{F_{am\,a}}{10}} + 10^{\frac{F_{am\,p}}{10}} + 10^{\frac{F_{am\,g}}{10}}}\right)\right)^2\right)^{\frac{1}{2}} \ \text{(dB)}, \qquad (5)$$

where $D_lP_{c\,d}$ is the deviation of the lower decile of the signal from day to day (dB), $D_lP_{c\,h}$ – deviation of the lower decile of the signal within an hour (dB), D_uF_{apg} – deviation of the upper decile of the total power (combination) of atmospheric (a*)*, industrial (p*)* and galactic (g*)* interference (dB).

A number of parameters included in (4, 5) depend on the operating frequency f as follows.

It is known [6] that for long-term signal fading (day from day), the deviation of the upper $D_uP_{c\,d}$ and lower $D_lP_{c\,d}$ deciles depend on the ratio of the operating frequency f to the main MUF of the path. Frequency dependencies $D_uP_{\text{c}\,d}(f)$ are $D_lP_{\text{c}\,d}(f)$ given in Table 2 of the recommendation [6].

In accordance with the recommendation [7], short-term deviations (within an hour) of signal deciles from the season of the year, time of day and frequency do not depend and are: upper $- D_uP_{\text{c}\,h} = 5$ dB, lower $- D_lP_{\text{c}\,h} = 8$ dB.

The determination of the frequency dependencies of the median values of the power of atmospheric $F_{am\,a}(f)$ and industrial interference $F_{am\,p}(f)$ and galactic noise included in (4, 5) $F_{am\,g}(f)$ are described in detail in the method [8], which takes into account the data of the IRI - 2016 abstract model [9].

The frequency dependences of the deviations of the upper $D_{u\,a}(f)$ and lower $D_{l\,a}(f)$ deciles of atmospheric interference are determined using data on the variability and nature of atmospheric interference depending on the frequency f and time of day and year, presented in Figures 13c-36c of the recommendation [10].

According to [10], deviations of the upper $D_{u\,p}$ and lower $D_{l\,p}$ deciles of industrial interference and galactic noise $D_{u\,g}$ ($D_{l\,g}$) do not depend on the season of the year, time of day and frequency f and are set at the same level: $D_{u\,p}=D_{l\,p}=D_{u\,g}=D_{l\,g}=2$ dB.

Taking into account the frequency dependencies $D_uP_{c\,d}(f)$, $D_lP_{c\,d}(f)$, $F_{am\,a}(f)$, $F_{am\,p}(f)$, $F_{am\,g}(f)$, $D_{u\,a}(f)$ and $D_{l\,a}(f)$ formulas (4) and (5), to determine the deviation of the upper $D_u\overline{Z}$ or lower $D_l\overline{Z}$ decile of the average signal-to-interference ratio, it takes the following form:

$$D_u\overline{Z}(f)=\left(\left(D_uP_{c\,d}(f)\right)^2+\left(D_uP_{c\,h}\right)^2+\left(D_lF_{apg}(f)\right)^2\right)^{\frac{1}{2}}=\left(\left(D_uP_{c\,d}(f)\right)^2+\right.$$

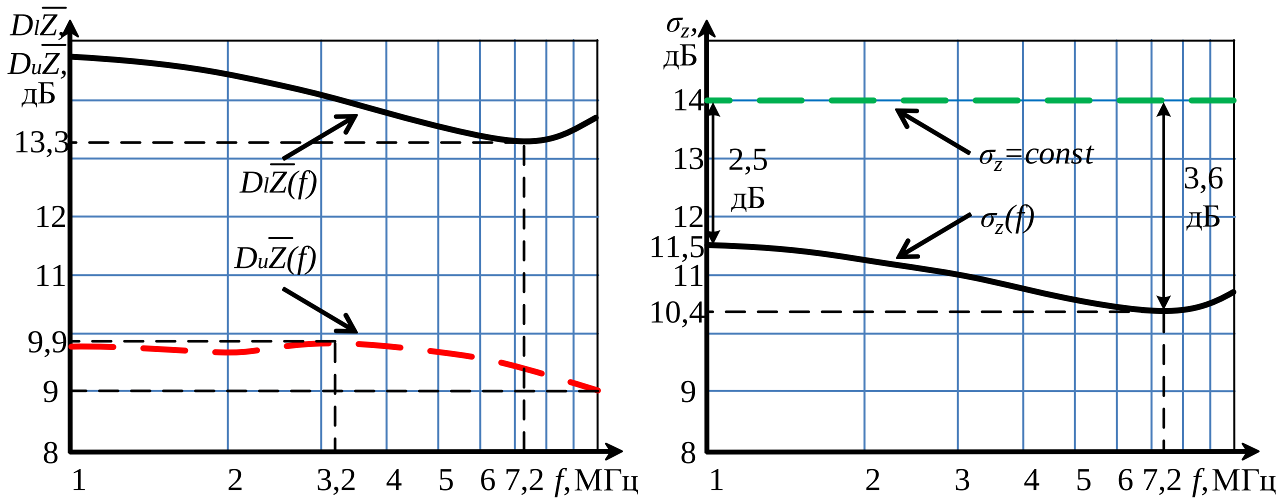
$$\left.+\left(D_uP_{c\,h}\right)^2+\left(10\log\left(\frac{10^{\frac{F_{am\,a}(f)}{10}}+10^{\frac{F_{am\,p}(f)}{10}}+10^{\frac{F_{am\,g}(f)}{10}}}{10^{\frac{F_{am\,a}(f)-D_{l\,a}(f)}{10}}+10^{\frac{F_{am\,p}(f)-D_{l\,p}}{10}}+10^{\frac{F_{am\,g}(f)-D_{l\,g}}{10}}}\right)\right)^2\right)^{\frac{1}{2}}\ \text{(dB)}, \qquad (6)$$

$$D_l\overline{Z}=\left(\left(D_lP_{c\,d}(f)\right)^2+\left(D_lP_{c\,h}\right)^2+\left(D_uF_{apg}(f)\right)^2\right)^{\frac{1}{2}}=\left(\left(D_lP_{c\,d}(f)\right)^2+\right.$$

$$\left.+\left(D_lP_{c\,h}\right)^2+\left(10\log\left(\frac{10^{\frac{F_{am\,a}(f)+D_{u\,a}(f)}{10}}+10^{\frac{F_{am\,p}(f)+D_{u\,p}}{10}}+10^{\frac{F_{am\,g}(f)+D_{u\,g}}{10}}}{10^{\frac{F_{am\,a}(f)}{10}}+10^{\frac{F_{am\,p}(f)}{10}}+10^{\frac{F_{am\,g}(f)}{10}}}\right)\right)^2\right)^{\frac{1}{2}}\ \text{(dB)}. \qquad (7)$$

Thus, in the obtained expressions (6, 7), in addition to constant parameters, $\left(D_uP_{c\,h}=5\text{ дБ}, D_lP_{c\,h}=8\text{ дБ}, D_{u\,p}=D_{l\,p}=D_{u\,g}=D_{l\,g}=2\text{ дБ}\right)$ a number of frequency dependencies are included, which are determined: $D_uP_{c\,d}(f)$, $D_lP_{c\,d}(f)$ – according to Table 2 of the recommendation [6]; $F_{am\,a}(f)$, $F_{am\,p}(f)$, $F_{am\,g}(f)$, $D_{u\,a}(f)$ and $D_{l\,a}(f)$ according to the method [8], $D_{u\,a}(f)$ and $D_{l\,a}(f)$ - according to the recommendation [10].

In accordance with expressions (6, 7) and the initial data used in the method [8, 11], the graph (Figure 1a) shows the frequency dependences of the deviation of the lower $D_l\overline{Z}(f)$ decile (solid line) and the upper $D_u\overline{Z}(f)$ decile (dashed line) of the average signal-to-noise ratio in the receiver frequency band $b=200$ Hz, for the summer season at 00 hours 00 minutes.



A) b)

Figure 1 – Frequency characteristics: a) deviations of the upper $D_u\overline{Z}(f)$ and lower $D_l\overline{Z}(f)$ deciles of the average signal-to-noise ratio; b) the standard deviation of the signal-to-noise ratio σ_z

Analysis of the presented graphs (Figure 1a) shows that the deviations of the lower and upper deciles of the average signal-to-interference ratio depend significantly on the operating frequency. The largest deviation value of the lower decile is $D_l\overline{Z}=14,7$ dB at frequency $f=1$ MHz, top decile $D_u\overline{Z}=9,9$ dB at $f=3,2$ MHz frequency. The smallest deviation value of the lower decile is $D_l\overline{Z}=13,3$ dB at a frequency $f=7,2$ of MHz, the upper decile $D_u\overline{Z}=9$ is dB at a frequency of $f=10$ MHz. The maximum difference between the deviation values of the lower decile of the average signal-to-interference ratio depending on frequency reaches $\Delta D_l\overline{Z}=14,7-13,3=1,4$ dB, between upper decile deviation values $-\Delta D_u\overline{Z}=9,9-9=0,9$ dB.

The graph (Figure 1b) shows the frequency dependence of the standard deviation of $\sigma_z(f)$ the average signal-to-noise ratio and the standard deviation $\sigma_z=const=14$ dB according to [4].

Analysis of the presented graph (Figure 1b) shows that the standard deviation of the average signal-to-interference ratio significantly depends on the operating frequency. The largest value of the standard deviation is $\sigma_z=11,5$ dB at $f=1$ MHz frequency, least $-\sigma_z=10,4$ dB at frequency $f=7,2$ MHz. The maximum difference between the deviation values of the standard deviation of the signal-to-interference ratio depending on frequency reaches $\Delta\sigma_z=11,5-10,4=1,1$ dB. The resulting frequency dependences of the standard deviation $\sigma_z(f)$ differ significantly from the standard deviation $\sigma_z=const=14$ dB in accordance with [4]. The smallest discrepancy is observed at frequency $f=1$ MHz and is $\Delta\sigma_{z\,\min}=14-11,5=2,5$ dB, highest – $\Delta\sigma_{z\,\max}=14-10,4=3,6$ at frequency $f=7,2$ MHz, which can significantly affect the reliability of communications in the DCM range.

According to the graph (Figure 1b), at a frequency $f=7,2$ of MHz the standard deviation of the average signal-to-interference ratio at the receiver input is $\sigma_z=D_u\overline{Z}/1,28=13,3/1,28\approx10,4$ dB. This value corresponds to experimental data [3], where in the summer season at night the value of the standard deviation at the input of the DCM radio link receiver can vary from $\sigma_z=10...16$ dB.

It should be noted that when calculating the reliability of communication $D_{св}$ in a DCM radio link, the standard deviation σ_z is determined taking into account the deviation of the lower decile of $D_l\overline{Z}$ the average signal-to-interference ratio. If communication reliability $D_{св}$ is less than 50 %, MSD σ_z is determined by the deviation of the top decile $D_u\overline{Z}$ of the average signal-to-noise ratio.

Conclusion. Based on the results of the study, assessing the values of the deciles of the signal-to-interference ratio, depending on the choice of operating frequency, allows us to draw the following conclusions:

1. The upper and lower deciles take different values depending on the operating frequency in the decameter range. The maximum difference between the deviation values of the lower decile of the average signal-to-noise ratio reaches $\Delta D_l\overline{Z}=1,4$ dB, between upper decile deviation values $-\Delta D_u\overline{Z}=0,9$ dB.

2. The standard deviation of the signal-to-noise ratio also depends on the choice of operating frequency and differs from the statistical value in $\sigma_z=const=14$ dB. The largest

difference in the values of the frequency dependence of the standard deviation $\sigma_z(f)$ on $\sigma_z = const = 14$ dB is $\Delta\sigma_z = 3,6$ dB.

In accordance with the established frequency dependencies of the lower $D_l\overline{Z}(f)$ and upper deciles $D_u\overline{Z}(f)$ and, therefore, standard deviation $\sigma_z(f)$, communication reliability $D_{св}$ can take on different values.

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