DOI: https://doi.org/10.15407/rpra29.03.173
UDC 621.396:621.372

O.V. Sytnik, S.O. Masalov

O.Ya. Usikov Institute for Radiophysics and Electronics NAS of Ukraine
12, Acad. Proskury St., Kharkiv, 61085, Ukraine
E-mail: ssvp127@gmail.com

ANALYSIS OF RESCUE RADAR NOISE IMMUNITY UNDER BROADBAND INTERFERENCE

Subject and Purpose. *The subject of the research is the statistical characteristics of the signal, noise, and interference and their distribution functions. The emphasis is on exploring the properties of these elements and assessing their impact on algorithms designed to detect and identify the manifestations of human breathing and heartbeat during rescue operations. The work seeks comprehensive descriptions of broadband structural noise to develop optimum digital signal processing algorithms and ensure quicker and more reliable detection and identification of information signals during rescue missions.*

Method and Methodology. *The analysis is grounded on the mathematical modeling method. The distribution function of correlation function peaks for a pseudo-noise signal is synthesized considering the first moments. The estimates derived from this distribution are used to assess the influence of broadband structural noise on the performance of algorithms for detecting and identifying radar signals.*

Results. *In the most important band, where signal spectral components bear information on human breathing and heartbeat, estimates of the first four moments of a random process have been made to contribute to an appropriate model of fluctuating broadband structural noise. Analytical expressions of the function of structural interference distribution have been derived. A specific case focused on the interference represented by a phase-shift keyed signal with randomly alternating ones and zeros has been examined. Estimates of probabilities of false alarms and target misses have been calculated across various signal-to-noise ratios. Furthermore, a procedure to determine an optimal signal-detection threshold has been proposed.*

Conclusions*. Analytical expressions of the distribution density of broadband structural interference have been derived. Quantitative estimates have been calculated to assess the impact this interference exerts on algorithms designed for detecting and recognizing radar information signals for rescuers. An adaptive procedure adjusting a target detection threshold as interference varies during the radar operation has been proposed.*

Keywords**:** *Pseudo-Noise Modulation, Noise, Algorithm, Pulse Modulation, Mersenne code, Broadband Structural Interference, Rescue Radar, Opaque Obstacle.*

Introduction

Radars for rescuers are specialized devices for finding survivors trapped beneath the rubble surface. The design of these radars must meet stringent technical requirements [1, 2] because they are intended for human subject detection through optically opaque barriers 0.1 to 10...15 m thick [3, 4]. Optically opaque obstacles such as brick wall fragments or concrete slabs severely attenuate the radar signal (by 30 to 90 dB [1—12]) during its propagation to the target and back. The only sign indicating a living body is Doppler phase shifts produced in the reflected radar signals by human breathing and heartbeat processes [5, 6]. These phase fluctuations have ultra-low frequ-

Citation: Sytnik, O.V., Masalov, S.O., 2024. Analysis of rescue radar noise immunity under broadband interference. *Radio Phys. Radio Astron.*, **29**(3), pp. 173—179. https://doi.org/10.15407/rpra29.03.173

encies 0.1 to 1.2 Hz [7, 8], making it practically impossible to use radars with pulse modulation [9—11] for the probing signal.

At the same time, the employment of broadband pseudo-noise continuous modulation in through-wall radar measurements can effectively address the detection problem. For the modulating function, Mersenne-code-based sequences [10—14] can be effectively used. Errors occurring in the code structure during the signal reception and caused by broadband structural interference can compromise the signal correlation function, which eventually degrades detection capabilities of the radar. Wideband structural interference can be generated by broadband communication systems or industrial noise, structural interference is similar to the desired signal and affects the information-bearing characteristics of the signal. Beyond that, it is known that the spectral distribution of the noise in the infra-low-frequency band cannot be approximated by a Gaussian law, adding complexity to the construction of optimal algorithms for detecting and identifying targets. Besides, the noise induced by wideband structural interference in this frequency band has high amplitudes in its spectral components. When combined with a nonlinear element, they generate a fluctuation process with novel properties that were missed in the synthesis of the decision-making rules. The development of optimal stochastic methods for detecting and identifying targets requires more understanding of the noise and interference properties. Otherwise, decision-making rules and algorithms may render results in error.

Typically, the analysis of the impact of broadband structural interference on the rescue radar performance is often confined to the effect of the noise interference with a certain root-mean-square $1/\sqrt{B}$, where B is the signal base [15]. It is assumed that maximum spikes of the correlation function do not exceed $3/\sqrt{B}$. This approach, however, is not precise enough to properly assess the noise immunity of radar signal processing algorithms. This is still more evident when dealing with structural interference during Mersenne code reception, because both structural interference and Mersenne code look like chaotic jumps of the signal phase. Hence, for comprehensive analysis of the radar noise immunity, both the distribution of signal correlation function peaks and the probability density of structural interference itself must be taken into account.

Considering all that, the main focus of the article is on the analysis of the statistical characteristics of the signal, noise, and interference, including their distribution functions. The goal is to synthesize a rescue radar structure with a high performance within the frequency band of signals containing information on human respiration and heartbeat.

1. Estimation of distribution probability density for signal and noise correlation function peaks

Let a periodic correlation function of a pseudo-noise phase-keyed signal have an arbitrary peak of amplitude R. The derivation of the decision-making rules for the algorithms of detecting and identifying radar signals for rescuers requires, first of all, to estimate the probability density $W(R)$ of the random variable R. Given a set of sample data, the probability density function is conveniently constructed by the method of moments [16]. In it, the theoretical moments of the distribution function are compared with the corresponding moments derived from the statistically reliable sample. If it is known that the odd moments are identically zero, which is normally true for phase-keyed Mersenne-coded signals, then the probability density function is uniquely determined by the set of even moments. In practice, only a finite number of moments can be gained. These are, first of all, the dispersion $\sigma^2 = 1/B$ of a random variable (where B is the signal base) and its fourth moment called the kurtosis coefficient, γ. With them, an estimate of the probability density function $W(R)$ can be constructed close to the real one. To take into account the broadband nature of the signal and noise when expressing the probability density function of the random variable R, the normalization relative to the signal base B is advisable. The normalized random variable, r, will be related to R as

$$r = R\sqrt{B} = R/\sigma. \tag{1}$$

With this normalization and for the moments $M_1[r] = M_3[r] = 0$, $M_2[r] = 1$, the probability density $W(r)$ can be approximated by the truncated Edgeworth series [17, 18]

$$W(r) = \left(\sqrt{2\pi}\right)^{-1} \times$$
$$\times \exp\left\{-r^2/2\right\}\left[1 + \frac{\gamma}{4!}H_4(r)\right], \quad \gamma << 1, \tag{2}$$

where $H_4(r)$ is the Chebyshev-Hermite polynomial [17].

In practice, however, the kurtosis coefficient γ can be much greater than unity. In this situation, the approximation of probability density function (2) with normalization (1) will differ significantly from the actual distribution. In this case, the Pearson method [19] suits better and approximates the probability density function closer, as it enables estimating high-order moments based on the known first four moments of the random variable r. Then the probability density function of the random variable r can be found by solving the following differential equation [19]

$$\frac{dW(r)}{dr} = \\ = \frac{rW(r)}{\left[-2(\gamma+3)/(5\gamma+6)\right]+\left[-\gamma/(5\gamma+6)\right]r^2}. \quad (3)$$

For any $|r| < \infty$, the probability density as a solution of equation (3) takes the appearance

$$W(r) = C\left(\left[-2(\gamma+3)/(5\gamma+6)\right]+ \\ +\left[-\gamma/(5\gamma+6)\right]r^2\right)^{-L}, \quad (4)$$

where $L = (5\gamma+6)/2\gamma$. The constant C comes from the condition $\int\limits_{-\infty}^{\infty} W(r)dr = 1$ and takes the form

$$C = [-2(\gamma+3)/(5\gamma+6)]\times \\ \times\sqrt{\frac{[-\gamma/(5\gamma+6)]}{[-2(\gamma+3)/(5\gamma+6)]\pi}}\frac{G((5\gamma+6)/2\gamma)}{G\left(\sqrt{(5\gamma+6)/2\gamma}\right)},$$

where $G(\cdot)$ is the gamma function.

In practice, the random variable r is constrained within $-\sqrt{B} \le r \le \sqrt{B}$, suggesting that the kurtosis coefficient γ is always constrained.

2. Analysis of broadband interference effect on rescue radar operation

Figure 1 shows a generalized detection circuit consisting of a matched filter, detector, and a threshold device connected in series.

The main characteristics of the detector are the probability of false alarm, P_{FA} and the probability of correct detection, P_{CD} (or the probability of target miss, $P_{MT} = 1 - P_{CD}$). When the matched filter input is fed by the signal plus broadband structural interference, one should determine a threshold value depending on a given probability of false alarm. At any time t_0, the voltage at the detector output is

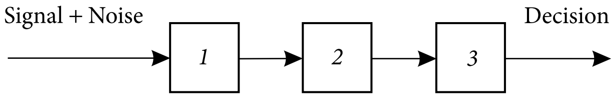

Fig. 1. The detection circuit: *1* — matched filter, *2* — detector, and *3* — threshold device

$$U_n = k\sqrt{P_n}\left|R(t_0)\right|, \quad (5)$$

where P_n is the noise power and k is the normalization factor.

In general terms, the probability of false alarm is

$$P_{FA} = P(U > H) = W_U(r)dr, \quad (6)$$

where H is the threshold. Combining relations (4) and (6) yields the probability density function

$$W_U(r) = 2\left(k\sqrt{P_n}\sigma\right)^{-1} W\left(\frac{r}{k\sqrt{P_n}\sigma}\right). \quad (7)$$

Substituting (7) into (6) gives the probability of false alarm

$$P_{FA} = 1 - 2\int\limits_0^{r_0} W(r)dr, \quad (8)$$

where $r_0 = H\sqrt{B}/\left(k\sqrt{P_n}\right)$.

Integrating probability density (4) and expressing the result through the elementary functions for integer values of L, one obtains the characteristic function in the explicit form

$$\Theta(r) = \frac{r}{2L-1}\times \\ \times\sum_{k=1}^{L-1}\frac{(2L-1)(2L-3)\cdots(2L-2k+1)}{2^k(L-1)(L-2)\cdots(L-k)\left(1+r^2\right)^{n-k}} + \\ + \frac{(2L-3)!!}{2^{L-1}(L-1)!}\mathrm{arctg}(r). \quad (9)$$

Using characteristic function (9), one gets probability of false alarm (8) in the analytical form

$$P_{FA} = 1 - \frac{2}{\sqrt{\pi}}\frac{G(L)}{G(L-1/2)}\Theta\left(r_0\sqrt{\frac{\gamma}{2(\gamma+3)}}\right). \quad (10)$$

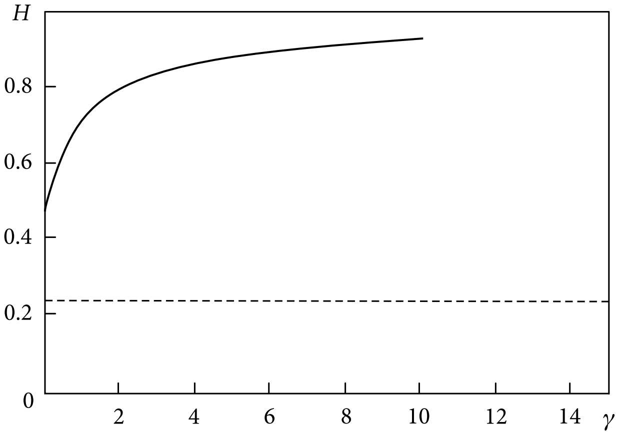

Fig. 2. Target determination threshold H versus kurtosis coefficient γ of the distribution of the correlation function peaks at $P_{FA} = 10^{-5}$ and $P_n = \text{const}$

In Fig. 2, the threshold $H = \sigma r_0$ is plotted versus the kurtosis coefficient γ. The dashed line marks the interference level $3/\sqrt{B}$. It is seen that the threshold voltage calculated using the kurtosis coefficient γ of the random variable r distribution exceeds the interference level by at least 3 dB.

The probability of correct detection can be calculated by the formula [19]

$$P_{CD} = \frac{2}{\sqrt{\pi}} \frac{G(L)}{G(L-0.5)} \times$$
$$\times \Theta\left[\sigma^{-1} \sqrt{\frac{\gamma}{2(\gamma+3)}} \left(\sqrt{\frac{P_s}{P_n}} + H \right) \right]. \qquad (11)$$

3. Features of rescue radar structure

The radar structure with probing signal modulation by pseudo-random periodic Mersenne code is featured by the necessity to form coherent modulating functions which neither the receiving nor the transmitting blocks of the radar can do without. Figure 3 presents a structural diagram of a coherent radar with a quadrature receiver.

The structural diagram of the coherent radar with a quadrature receiver in Fig. 3 uses the following numeral labeling: *1* — master oscillator, *2* — amplitude modulator, *3* and *4* — dividers with division factors 20 and 10, respectively, *5* — transmitting antenna, *6* — power amplifier, *7* and *12* — balanced modulators, *8* and *9* — narrow-band filters, *10* — Mersenne code generator, *11* — time-delay control circuit, *13* — amplifier, *14* — receiving antenna, *15* — low-noise amplifier, *16* — balanced mixer, *17* — band-pass filter, *18* and *19* — quadrature channels, *20* and *20′* — balanced mixers, *21*, *21′*, and *25* — band-pass filters, *22* and *22′* — narrow-band low-frequency amplifiers, *23* — square-law detector, *24* — adder, *26* — solver (thresholder), and *27* — phase rotator.

The heart of the circuit is standard high-stability master oscillator *1* whose relative frequency instability of the signal is no worse than $10^{-5}\ldots10^{-6}$ at the carrier frequency 2 GHz. The output signal of oscillator *1* is simultaneously acquired by amplitude modulator *2* and frequency dividers *3* and *4* with division factors 20 and 10, respectively. One more input of amplitude modulator *2* acquires 100 MHz oscillations from divider *3*. Narrow-band filters *8* and *9* connected to the output of modulator *2* separate oscillations of the upper (filter *8*) and lower (filter *9*) side frequencies of the amplitude-modulated oscillation. The frequency spacing between coherent oscillations at the outputs of filters *8* and *9* is 200 MHz. The upper side frequency signal from the output of filter *8* is used in the transmitter, while the lower side frequency signal from filter 9 is used as a heterodyne's signal of the receiver.

The probing signal is formed at balanced modulator *7*. After being amplified by power amplifier *6* to about — 10 dB/Wt, the probing signal is radiated through transmitting antenna *5* into space. The other input of balanced modulator *7* receives the modulating function of Mersenne code signal generated by generator *10*. The clock frequency of the Mersenne code generator is derived from the frequency of master oscillator *1* by the frequency division at divider *3*. Generator *10* outputs the delayed signal in a digital form — the modulating signal producing a subcarrier oscillation at about 1.3 kHz frequency.

In this case, the period of the subcarrier oscillation exactly equals the two periods of the pseudo-random sequence signal. This is necessary to organize the primary amplification of the information signal from the outputs of balanced mixers *20* and *20′*. By multiplying the original sequence and the sequence delayed by one elementary pulse, the heterodyne signal modulating function is obtained. Block *11* monitors the time delay of the heterodyne signal. The delay determines the target distance. The heterodyne signal of the receiver is formed at the output of balanced modulator *12* whose inputs acquire oscillations coherent to the transmitter signal and coming

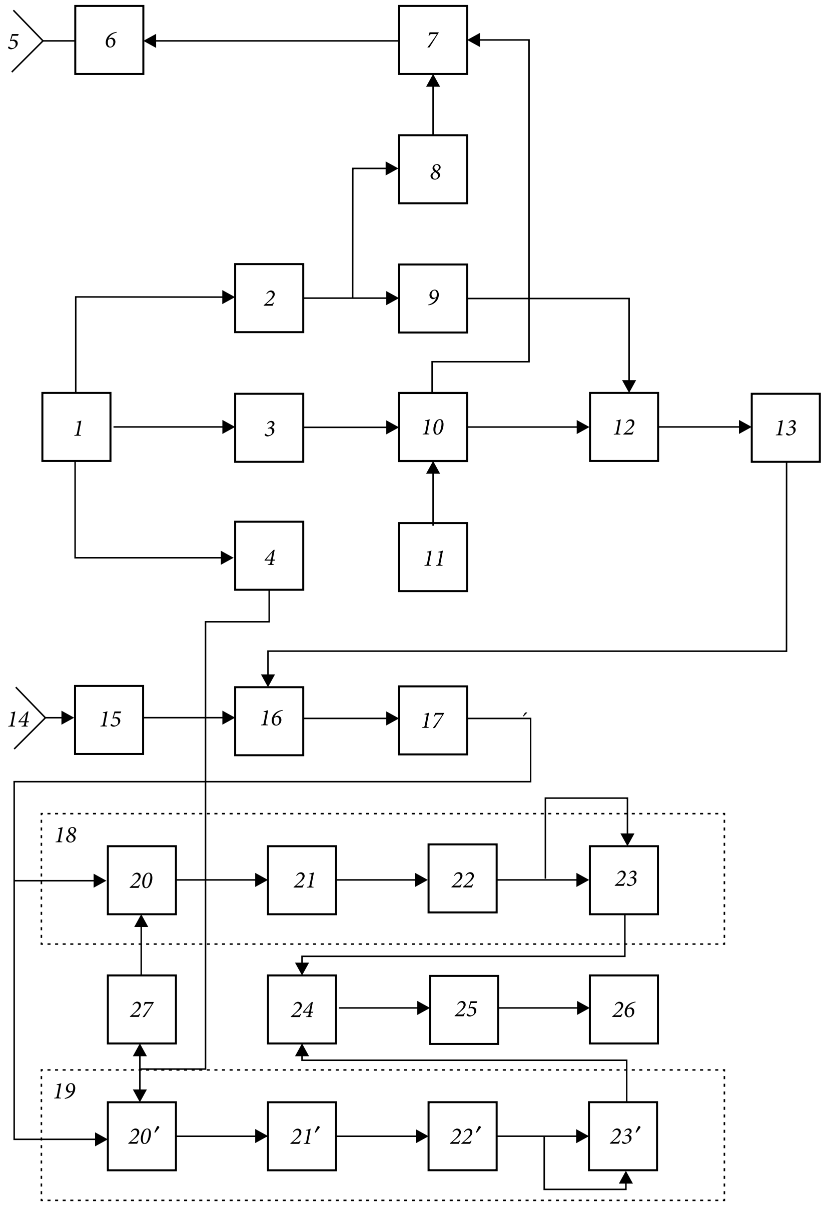

Fig. 3. Structural diagram of a coherent radar with a quadrature receiver

from filter *9,* as well as the delayed, Mersenne-code modulated signal at the subcarrier from the output of generator *10*.

Before being sent to balanced mixer 16 used as a correlator, the heterodyne signal is amplified and filtered at amplifier *13*. The other input of mixer *16* acquires the target reflected oscillations captured by antenna *14* and amplified by low-noise amplifier *15* whose noise factor is less than 2 dB and the gain is no worse than 10...15 dB. At the output of mixer *16*, there is band-pass filter *17* which outputs the information signal at the intermediate, 200 MHz frequency to two identical quadrature channels *18* and *19*. Balanced mixers *20* and *20′* of each channel transfer the information signal to the subcarrier frequency 1.3 kHz. Simultaneously, the corresponding quadrature component of the signal is suppressed due to the phase shift of the heterodyne signal at phase rotator *27*. Before being combined at adder *24*, these signals are filtered using band-pass filters *21* and *21′*, amplified at narrow-band low-frequency amplifiers *22* and *22′*, and squared at blocks *23* and *23′*. After the information signal has been extracted at band-pass filter *25*, an inference about target presence or absence is made at solver (thresholder) *26*, where the signal is checked against the threshold.

The rescue radar scheme considered right above showed a satisfactory performance and a fairly high sensitivity to weak return echoes from a human subject behind an obstacle. Interfering reflections from stationary local objects were effectively suppressed. However, even though the structural scheme is rather simple, the technical implementation of particular blocks presents certain difficulties. Hardware requirements are becoming increasingly stringent to provide highest quality signals during modulation, emission, complex path propagation, reflection, reception, and various processing. The main problem of the radar in Fig. 1 is a parasitic leakage of the transmitter signal to the receiver input. In the Mersenne-code signal spectrum, it is difficult to suppress the parasitic carrier at the modulator output by more than 40...50 dB. The narrow-band rejection inevitably compromises the pseudo-random signal spectrum. Therefore, a variety of methods should be used for suppressing parasitic signals and interferences at the carrier frequency. These methods are, as a rule, complicated and unreliable.

Conclusion

The rescue radar noise immunity estimates achieved as analytical relationships of corresponding error probability characteristics when detecting Mersenne code keying signals under broadband interference can be effectively implemented in the synthesis of an optimal — by a maximum likelihood criterion — receiver. The optimization of the detection procedure can be conducted based on the continuous adaptive estimation of the kurtosis coefficient. The kurtosis coefficient monitors and adjusts the detection threshold versus a given probability of false alarm and interference level.

When the radar is under broadband structural interference, the signal processing algorithm adapts based on current estimates of the kurtosis coefficient during the observation, thus adjusting the detection threshold and providing decision-making feedback. For an array of signals satisfying the intersymbol interference condition, an optimal detection can be achieved using a linear correlator, eliminating the need to separate and in-phase combine signals of quadrature channels.

A distinctive feature of broadband structural noise is that it is similar to a desired signal, becoming a combination of Mersenne and similar codes over the observation interval. Therefore, decisions about the presence or absence of a target mark should be based on sufficient statistics to properly select a detection threshold. A time-varying threshold enables using a linear correlation receiver under any interference combinations, ensuring a probability of correct detection nearly at its highest.

The concepts outlined in the paper have been implemented into the rescue radar described in [7] to improve it. According to full-scale experiments, the proposed system effectively suppresses unwanted reflections from stationary objects in the neighborhood and shows approximately −90 dB sensitivity in detecting a living person behind a 0.3 m thick obstacle of concrete slabs. The primary issue with the continuous probing signal radar given in Fig. 1 was that the transmitter signal happened to be inadvertently passed to the receiver input. In our last variant, the problem has been overcome by incorporating coherent Doppler selection.

REFERENCES

1. Sytnik, O.V., 2021. Problems and Solutions of Alive Human Detection Behind the Opaque Obstacles. *Telecommunications and Radio Engineering*, **80**(9), pp. 1—13.
2. Chen, K.M., Huang, Y., Zhang, J., and Norman, A., 2000. Microwave life-detection systems for searching human subjects under earthquake rubble or behind barrier. *IEEE Trans. Biomed. Eng.*, **47**(1), pp. 105—114.
3. Sytnik, O.V., 2007. Identification of Slow-Moving Targets Outside Optically Opaque Obstacles. *Telecommunications and Radio Engineering*, **66**(18), pp. 1677—1683.
4. Sytnik, O.V., 2015. Adaptive Radar Techniques for Human Breathing Detection. *J. Mechatron.*, **3**(4), pp. 1—6.
5. Sytnik, O.V., Kartashov, V.M., 2019. Methods and Algorithms for Technical Vision in Radar Introscopy. *Optoelectronics in Machine Vision-Based Theories and Applications — Advances in Computational Intelligence and Robotics*, pp. 373—391. DOI: 10.4018/978-1-5225-5751-7.ch013
6. Nguyen, T.V., Liqiong, T., Veysel, D., Syed, F.H., Nguyen, D.M., & Subhas, M., 2019. Review-Microwave Radar Sensing Systems for Search and Rescue Purposes. *Sensors*, **19**(13), pp. 28—79.
7. Sytnik, O.V., 2018. *Methods and Algorithms of Signal Processing for Rescuer's Radar*. Riga, Latvia, Palmarium Academic Publ.

8. Bugaev, A.S., Chapursky, V.V., Ivashov, S.I., Razevig, V.V., Sheyko, A.P. & Vasilyev, I.A., 2004. Through wall sensing of human breathing and heart beating by monochromatic radar. In: *Proc. of the Tenth Int. Conf. on Ground Penetrating Radar, GPR 2004*. Vol. 1, pp. 291—294. Delft, The Netherlands, 21—24 June 2004, Delft University of Technology.
9. Aristov, V., Gaigals, G., Supols, G., Lobanovs, Ed., Riekstins, V., and Zujs, V., 2021.Ultra-Wideband Pulse Radar with Discrete Stroboscopic Receiver for Detection of Small Targets Behind Dielectric Obstacles, *Transp. Telecommun.*, **22**(2), pp. 196—206.
10. Chernov, V.M., Pershina, M.V., 1997. "Error-free" calculation of the convolution using generalized Mersenne and Fermat transforms over algebraic fields. In: Sommer, G., Daniilidis, K., Pauli, J. (eds). *Computer Analysis of Images and Patterns*. CAIP 1997. Lecture Notes in Computer Science, vol. 1296. Springer, Berlin, Heidelberg. DOI: 10.1007/3-540-63460-6_171
11. Taylor, J.D. ed., 2012. *Ultrawideband Radar. Applications and Design*. Boca Raton, London, New York: CRC Press.
12. Sytnik, O.V., 2014. Quasi-Optimal Receiver with Non-Coherent Discriminators for Rescuer Radar. *J. Commun. Eng. Networks,* **2**(2), pp. 55—62.
13. Saikawa, T., Tanaka, K., Tanaka, K., 2020. Formal Verification and Code-Generation of Mersenne-Twister Algorithm. In: *Proc. of the Int. Symp. on Information Theory and Its Applications (ISITA)*, Kapolei, HI, USA, 2020.
14. Zhang, J., Du, Y., & Yan, He, 2020. Code Design for Moving Target-Detecting Radar in Nonhomogeneous Signal-Dependent Clutter. *Math. Probl. Eng.*, **2020**, id 7609547, 13 p.
15. Levanon, N., & Mozeson, E., 2004. *Radar Signal*. Hoboken, NJ: John Willey & Sons, Inc.
16. Van Trees, H.L., 2001. *Detection, Estimation, and Modulation Theory: Detection, Estimation, and Linear Modulation Theory*. John Wiley & Sons. DOI:10.1002/0471221082
17. Allan, D.W., Shoaf, J.H. & Halford, D., 1974. *Statistics of Time and Frequency Data Analysis*. NBS Monograph140, Washinghton D.C., pp. 151—204.
18. Hall, P. 1992. *The Bootstrap and Edgeworth Expansion*. Springer Series in Statistics, Springer & Verlag.
19. Garren, S.T., 1998. Maximum likelihood estimation of the correlation coefficient in a bivariate normal model, with missing data. *Stat. Probab. Lett.*, **38**(3), pp. 281—288.

Received 19.12.2023

О.В. Ситнік, С.О. Масалов

Інститут радіофізики та електроніки ім. О.Я. Усикова НАН України
вул. Акад. Проскури, 12, Харків, 61085, Україна

АНАЛІЗ ЗАХИЩЕНОСТІ РАДАРА ДЛЯ РЯТУВАЛЬНИКІВ
ЗА НАЯВНОСТІ ШИРОКОСМУГОВИХ ЗАВАД

Предмет і мета роботи. Предметом дослідження є статистичні характеристики сигналу, шуму та завад, а також функції їх розподілу. Основну увагу зосереджено на дослідженні властивостей цих факторів та оцінці їх впливу на алгоритми, призначені для виявлення та ідентифікації проявів процесів дихання та серцебиття людини під час рятувальних операцій. Метою цієї роботи є створення комплексного опису широкосмугових структурованих завад для розроблення оптимальних алгоритмів цифрової обробки сигналів, які забезпечуватимуть швидке і надійне виявлення та ідентифікацію інформаційних сигналів під час аварійно-рятувальних робіт.

Методи та методологія. Робота базується на методі математичного моделювання. Синтез функції розподілу піків кореляційної функції псевдошумового сигналу передбачає врахування перших моментів. На основі цього розподілу були отримані оцінки впливу структурованих широкосмугових завад на функціональність алгоритмів виявлення та ідентифікації радіолокаційних сигналів.

Результати. У діапазоні, де зосереджені спектральні компоненти інформаційного сигналу, створювані диханням і серцебиттям людини, на основі оцінок перших чотирьох моментів випадкового процесу побудовано відповідну модель флуктуаційної широкосмугової структурованої завади. Отримано аналітичні вирази для функції розподілу структурованої завади. Досліджено конкретний випадок, коли структурована завада була представлена сигналом з фазовою маніпуляцією з випадковим чергуванням нулів і одиниць. Оцінки ймовірностей помилкових тривог і пропуску цілі обчислювалися для різних співвідношень сигнал/шум. Додатково запропоновано метод визначення оптимального порогу виявлення сигналу.

Висновки. Отримано аналітичні вирази для густини розподілу широкосмугових структурованих завад. Обчислено кількісні оцінки впливу структурованої завади на алгоритми виявлення та розпізнавання радіолокаційних інформаційних сигналів радара для рятувальників. Запропоновано адаптивну процедуру зміни порогу виявлення цілі при зміні завадової обстановки під час роботи радара.

Ключові слова: *псевдошумова модуляція, шум, алгоритм, імпульсна модуляція, код Мерсенна, широкосмугові структуровані завади, радар для рятувальників, непрозорі перешкоди.*