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Method of radio communication based on non-deterministic radio signals

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***Abstract*— The paper describes a method to make a noise-immune radio communication system with high emission security. The noise-immunity and emission security of information transmitting are provided through the use of non-deterministic radio signals (white Gaussian noise). The block diagrams of the receiver and transmitter to develop the user hardware equipment are presented. The communication range, detection by means of modern passive radar systems and intentional interference effect are considered.**

Keywords—Communication systems, electromagnetic compatibility, electromagnetic interference, Gaussian noise, microwave radiometry, thermal noise.

I. Introduction

State-of-the-art special communication systems necessitate the creation of new radio communication systems. The specific characteristics of these radio communication systems are due to the features of the conditions in which they are operated. Technological advances stimulated the development of new low emission power means of radio communication [1]. The extreme case of this approach is data message transmission via radio signals of the power comparable with the power of the receiver (thermal) noise. Implementation of the extreme case allows the transmission of data messages at very low energies. Practical implementation of this approach requires the development of new radio signal reception, transmission and processing techniques and creation of new coding types. This paper describes a new method to develop a noise-immune radio communication with high electromagnetic compatibility and emission security based on measurement of non-deterministic radio signal (white noise) energy by radiometric methods.

II. Basic Principle

A classical radio communication message block diagram consists of a transmitter, a transmission medium and a radio receiver [2].The proposed approach for creation of the radio communication system based on measurement of the energy of non-deterministic radio signals uses a similar concept.

The issues to be considered when developing a new communication system are as follows:

1. Creation of methods and algorithms for information transmission via nondeterministic radio signals;
2. Modification of the existing coding techniques to process non-deterministic signals;
3. Implementation of the "transmitter-receiver" hardware as a portable personal communication device, that can operate in harsh climatic conditions and provide data rates not less than 32 kbps;
4. Development of methods and algorithms that reduce the effect of interference in the communication channel.

Deterministic radio signal receiving and processing is extremely difficult if signal power is lower than the receiver noise [1].

Denote the detected intrinsic noise at the receiver input as $S_N(t)$ in the time interval of $(0\ldots t_1)$.The detected thermal noise at the receiver input obeys the Gaussian law of the spectral density [3].The mathematical expectation M_N of the $S_N(t)$ signal is equal to:

$$M_N = \frac{1}{t_1} \cdot \int_0^{t_1} S_N(t)dt = 0 \qquad (1)$$

Assume that $S(t)$ is a non-deterministic radio signal with the value of the mathematical expectation of M.

Similarly, to $S_N(t)$, condition (1) is fulfilled for $S(t)$.

If expression

$$\int_0^{t_1} S(t) \cdot S_N(t)\, dt = 0 \qquad (2)$$

is true, the $S_N(t)$ and $S(t)$ signals are uncorrelated. Fulfillment of (2) leads to the expression:

$$D_\Sigma = D + D_N = M((S(t) - M)^2) + \\ + M((S_N(t) - M_N)^2) \qquad (3)$$

where D is $S(t)$ signal dispersion, D_N is $S_N(t)$ signal dispersion and M is mathematical expectation of $S(t)$ calculated similarly to (1).

Expression (3) shows the change possibility of the total noise dispersion (D_Σ) at the receiver input that is equivalent to the increase in the noise power. In this case, the amplitude modulation of the signal $S(t)$ is easy to perform. Thus, the noise power at the receiver input is changed under the $S(t)$ law.

III. Realization Concept

The designing conception of the radio-communication system based on non-deterministic radio signals has much in common with classic radio-communication systems. However, practical implementation of the system needs new and innovation solutions. Microwave radiometers are typically used to measure the noise signal parameters with flat (uniform) spectral density. Therefore, a specialized microwave radiometer should be the base for the radio-communication system receiver.

The amplitude-modulated noise signal can be used to transmit analog information. Data transmission in a digital form is of current importance to improve noise-immunity and efficiency of the radiometric data transmission channel. For non-deterministic radio signals, the radio channel with frequency division multiplexing is one of the techniques to transmit digital data. In this case, every bit of data word is transmitted at a different frequency band.

Fig. 1 shows the block diagram of the radiometric communication system transmitter. The base of the transmitter operating algorithm is the principle of reference noise signal generation similar to that for differential radiometric measurements [3].

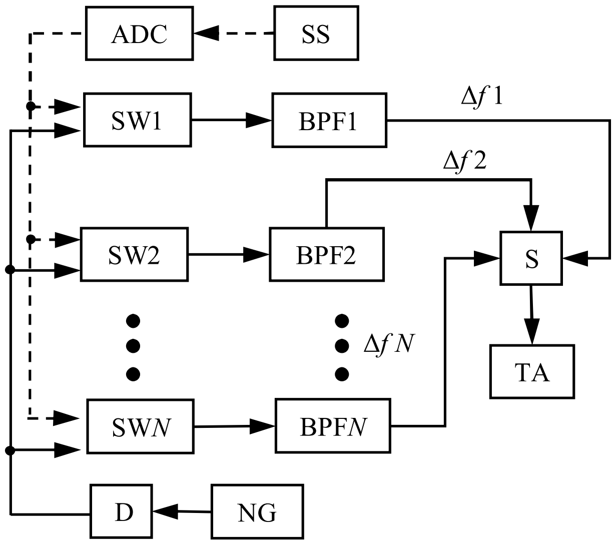

Fig. 1. Block diagram of radiometric communication system transmitter

The transmitter of the radiometric communication system operates as follows. The analog data message is generated in the signal source SS. The analog signal from SS is fed to the input of the ADC, and the outputs of the ADC control the microwave switches SW1, SW2...SS*N*. The microwave switches are absorptive type single pole single throw switches with two operating states – opened and closed. The inputs of the switches are connected to the outputs of the power divider D, and a wide band noise generator NG is connected to its input. The outputs of the switches are connected to the inputs of the band pass filters BPF1, BPF2, ..., BPF*N* with the band width of $\Delta f1$, $\Delta f2$… ΔfN. The outputs of the band pass filters are connected to the microwave adder Ad inputs. The adder outputs are connected to the wide band transmitting antenna TA. Thus, the noise generator signal is fed to the band pass filters through the microwave switches controlled by ADC logic signals. The bit length of the transmitted data word *N* in this radio communication system depends on the quantity of band pass filter and microwave switch pares.

The transmitted data word is generated through amplitude-pulse modulation of the noise generator signal. High state at the ADC input corresponds to the open state mode of the switch that increases the noise power at the corresponding frequency band. When the switch is closed, the noise generator signal is not fed to the BPF as it is absorbed by the switch match load.

Fig. 2 shows an example of the spectral density distribution when transmitting the "+" symbol generated by the six-bit transmitter at the operating frequency band. The digital designation of the "+" symbol in the ASCII table is 43 that corresponds to 101011 sequence in the binary system.

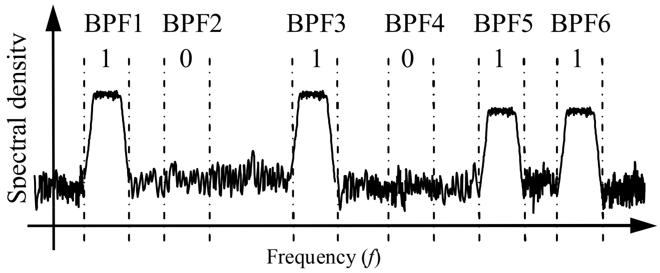

Fig. 2 Spectral density distribution when transmitting the "+" symbol at the operating frequency band

To analyze the data word, the receiver performs operations of frequency selection, gain, and detection of digital signals [4]. The selected operating frequency bands are similar to the transmitter bands.

Fig. 1 shows the block diagram of receiver. The receiver consists of a wide band receiving antenna RA, ferrite circulators C1, C2...C*N*, pass band filters BPF1, BPF2...BPF*N*, microwave radiometers R1, R2, ... R*N*, demodulator DM and indicator Ind. The receiver operates as follows. A data word signal (see the signal type in Fig. 2) is fed to the receiving antenna input. The antenna output is connected to the C1circulator input. The C1 circulator transmits the signal to the output connected to the band pass filter BPF1. The reflected signal from BPF1 input is fed to the C2circulator input in accordance with the BPF1 input return loss. The noise signal with the frequency band $\Delta f1$ is fed to the R1 microwave radiometer input. The other receiver channels operate in a similar way. The third output of last circulator C*N* is connected to the input of matched load. The output signals of the radiometers are fed to the demodulator, which restores the received digital data word in the form suitable for interpretation.

The microwave radiometers are the main part of the receiver. When measuring a high speed change in the antenna noise temperature, the accuracy of classic radiometric methods used to create microwave radiometer is not more than 15…20% due to the receiver gain fluctuation. This limits the maximum bandwidth of the radio communication channel.

The long time stability of microwave radiometers based on classical methods is not high and needs additional techniques such as cryogenic cooling, gain control system and temperature control [6].

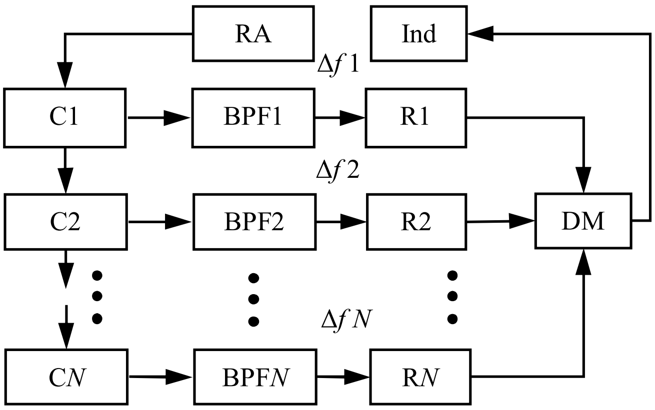

Fig.3 Receiver block diagram

We are designing a new type of microwave radiometers [5, 7]. A microwave radiometer based on the modified radiometric zero-measurement method and multi-receiver concept for designing radiometric systems made up of four receivers is described in [7]. Both system methods allow us to create a radiometric system with the sensitivity exceeding that of an ideal full power radiometer and to improve its dynamic properties. The radiometric systems are highly stable under changing environmental factors, i.e. the temperature control of the receiver is not required.

IV. Features Of Realization

In radiometric measurement, the measured signals are averaged. When designing a microwave radiometer, a contradictory problem to be solved is increase in its sensitivity for the specified system dynamic characteristics. For example, a zero-type radiometer receiver with the frequency bandwidth Δf=100 MHz, with receiver noise temperature T_{RN}=150 K, and a dynamic range of 50...350 K at the specified fluctuation sensitivity ΔT_A=1 K provides the measuring time $t_M\approx$1.1 ms [5]. To transmit one data bit the transmission time two times exceeds the measuring time (about 1.1 ms), that corresponds to the data rate about 0.452 kbps. In this case, the typical characteristics of the radiometer do not satisfy the minimum data rate requirements. To improve the data rate, the sensitivity is to be increased, which is equivalent to the decreased measurement time (improved measurement dynamics).

The fluctuation sensitivity of the modified zero-type radiometers can be efficiently increased using the multi-receiver concept [8]. Four receivers in the radiometer increase the sensitivity twice as much [7]. The graphs shown in Fig. 4 indicate the efficiency of zero-type radiometers with a different number of receivers depending on the required dynamics of measurements. The dashed line denotes the 32 kbps data rate level. The analysis of the data in Fig. 4 (Curve 4) shows that the microwave radiometers with four receivers decrease the measuring time twice as much. This dependence is consistent with research carried out earlier [9].

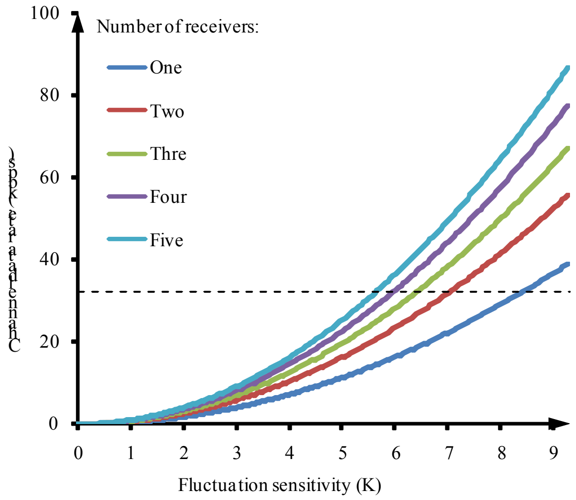

Fig. 4. Channel data rate versus radiometer fluctuation sensitivity

An urgent problem to be solved is detection of radiometric communication systems. An effective way to detect a radio communication channel (active radiation source) is to use a passive radar station [10]. The sensitivity of a modern passive radar station like "Kolchuga" is about –90…–120 dB/W [11], that corresponds to signal power of 10^{-9}–10^{-12} W at the minimum frequency bandwidth of 50 kHz. In case of maximum sensitivity (–120 dB), the radar system can detect the radiometric communication channel if the radiometric transmitter power is more than $1.45{\cdot}10^5$ K (the equivalent of 10^{-12} W).

One of the main features of the developed noise radio communication system is its noise-immunity. As noted in [12], noise interference can be used for radio-electronic jamming of all types of communications electronics. There are two types of radio interference – pulse-modulated interference and additive noise. Consider their influence on the designed radio communication channel.

Fig. 5 illustrates two patterns of the designed radio communication system frequency band, before noise interference (spectrum marked by dotted line) and after additive noise effect. Additive noise and a transmitter signal are of similar nature (including technical realization), consequently, condition (2) is fulfilled. Hence, the spectral densities of noise interference and radio communication signal are summed (Fig. 5(a)).

An effective way to prevent noise adding interference is adaptive change of the dynamic range. In contrast to classical circuit design, the measuring dynamic range in modified zero-type radiometers can be changed without any changes in their structure [13, 14]. The dynamic range is changed by the internal digital control system of the radiometer [15].

The described technique of additive noise interference can be effectively used within the linear dynamic range of the receiver and limited adjustment of internal reference noise source power [5].

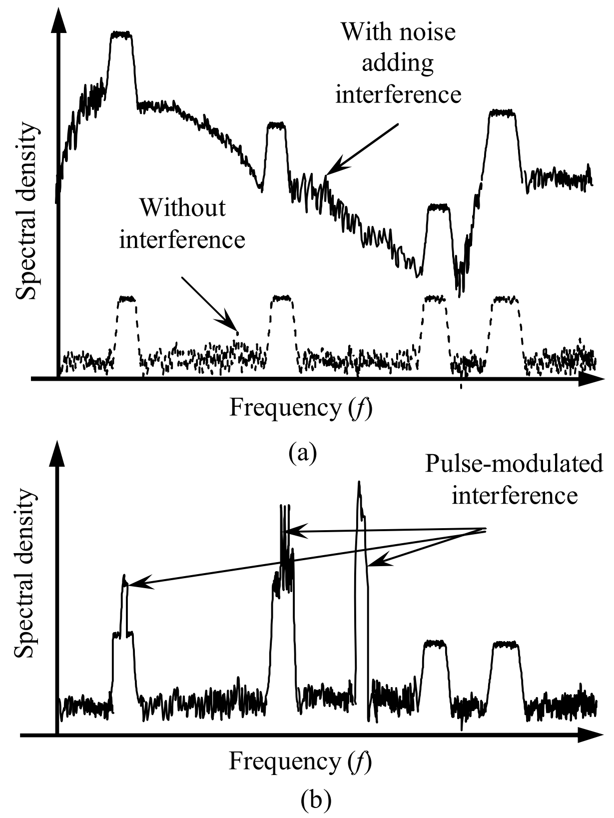

Fig.5. Influence of noise adding interference (a) and pulse-modulated interference on radio communication

The designed noise communication system is less resistant to the impact of pulse-modulated interference. Fig. 6b shows the effect of pulse-modulated interference jamming. The pulse-modulated interference with the energy exceeding the energy of a single digital bit of the pulse-width modulated signal (the equivalent of the energy which corresponds to the minimum fluctuation sensitivity at the operating frequency band [5]) at the input of the receiver distorts the transmitted data bit. This problem can be solved using a special algorithm for adaptive synchronous changing of the transmitter and receiver frequency bands. This paper does not consider realization of it.

Similar problems of interference minimization in radiometric measurement are reported in [16]. The impact of interference can be reduced through direct digitizing of measurement results and digital signal processing. These algorithms are effective used for full-power radiometers. No information on similar signal processing techniques for zero-type radiometers has been found in the open literature.

V. Conclusion

The method to create a radio communication system based on non-deterministic radio signals is proposed. The transmission technique based on frequency division of digital data is described. The efficiency of multi-receiver zero-type radiometer for radio equipment designing is shown.

The paper does not provide detailed information on the radio communication efficiency under the influence of intentional interference and user's radio equipment design. Further research will address the development of the receiver and transmitter simulation models and circuit diagrams. The characteristics of the models will be studied, the experiments on voice message transmission will be carried out and adaptation algorithms for jamming environment will be developed.

References

[1] J.G. Proakis, M. Salehi “Fundamentals of Communication Systems,” in Prentice Hall, 2nd ed. New Jersey 2014, pp. 255 –256.

[2] J. R. Barry, E. A. Lee and D. G. Messerschmitt “Digital Communication” in Kluwer Academic Publishers, Norwell, 2004 pp. 60 – 62.

[3] L. Wang, et al. “Secure transmission with optimal power allocation in untrusted relay networks,” IEEE Wireless Communications Letters vol. 3, Is. 3, pp. 289-292, June 2014.

[4] Q. Li, W. Wang, D. Xu, X. Wang, “A robust anti-jamming navigation receiver with antenna array and GPS/SINS” IEEE Communications Letters vol. 18, Is. 3, pp. 467-470, March 2014.

[5] A.V. Ubaichin, and A.V. Filatov, “Quick event registration by a microwave radiometric method” Proc. CriMiCo, 2014, pp. 1123-1124.

[6] A.V.Filatov, A.V.Ubaichin “The dynamic properties of a digital radiometer system and its operating efficiency,” Measurement Techniques. vol. 12, No. 10, pp. 1–6, October 2012.

[7] A.V. Filatov, A.V. Ubaichin, D.E. Paraev, “A microwave four-channel null L-band radiometer,” Instruments and Experimental Techniques, vol. 55, No. 1. pp. 59-64, January 2012.

[8] A.V. Filatov, A.V. Ubaichin, A.A. Bombizov, “A two-receiver microwave radiometer with high transfer characteristic linearity,” Measurement Techniques, vol. 55, No. 11, pp. 1281–1286, November 2013.

[9] A.V. Filatov, N.A. Karataeva, A.G. Loshchilov, “A microwave radiometer for measuring signals with a low effective noise temperature,” Instruments and Experimental Techniques, vol. 49, Is. 6, pp. 817-823, December 2006.

[10] D. Goeckel, et al. “Covert communications when the warden does not know the background noise power,” IEEE Communications Letters, vol. 20, Is. 2, pp. 236-239, February 2016.

[11] K. Zikidis, A. Skondras, C. Tokas Low “Observable Principles, Stealth Aircraft and Anti-Stealth Technologies,” Journal of Computations & Modelling, vol.4, No.1, pp. 129-165, January 2014.

[12] L. David “Introduction to Electronic Warfare Modeling and Simulation,” in Adamy SciTech Publishing, Raleigh, 2006 pp. 42 –49.

[13] D. B. Kunkee, “Design and Evaluation of the First Special Sensor Microwave Imager,” Sounder. IEEE Trans. Geoscience Remote Sens. No. 4, pp. 863–883, January 2008.

[14] N. Sun and F. Weng, “Evaluation of Special Sensor Microwave Imager/Sounder (SSMIS) Environmental Data Records,” IEEE Trans. on Geoscience and Remote Sensing. vol. 46, Is. 4, pp. 1006-1016, April 2008.

[15] Multi-receiver zero radiometer, by A.V. Filatov, A.V. Ubaichin. (2013, Sept. 23). Patient RU 2541426C1 [Online]. Available: www.findpatent.ru/patent/254/2541426.html

[16] A.B. Tanner, “Calibration of a Synthetic Aperture Radiometer,” IEEE Trans. on Geoscience and Remote Sensing, vol. 31, Is. 1, pp. 257-267, January 1993.