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The phenomenon of incoherent signal interference

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Abstract— **in this work the methodology, tools and results of modeling the evolution of a binary mixture of signals are described, and therefore the phenomenon of incoherent signals interference was found. This phenomenon is appeared in the fact that the linear summation of the components of a binary mixture of signals and the signal waveform of the mixture changes, depending on the relation of the amplitudes of summable components.**

Keywords— **identification tester, measuring of signal form, interference, coherency, random signals summation**

I. INTRODUCTION

The concept of interference in physics has two levels of interpretation. To wide extent, the interference oscillations is considered as a change in the nature of sound, heat, light and electrical phenomena, explained by the vibrational motion [1]. In radio engineering, this corresponds to the definition of interference, as anything that changes or damages the information transferred by a signal from the transmitter through a communication channel to the receiver (e.g. solar interference in satellite communication). In the narrow sense, interference is a superposition of waves, with which they are mutually reinforcing in some points of space and weakening - in others. Herewith the result of interference depends on the phase difference of superimposed waves.

The theory of such interference (i.e. interference in the narrow sense) is based on the vector summation of two oscillations [2]. In particular, the two simultaneously propagating sinusoidal spherical waves S_1 and S_2, generated by point sources B_1 and B_2, will cause the vibration in the point M, which, according to the principle of superposition, is described by formula $S = S_1 + S_2$. According to the formula of a spherical wave:

$$S_1 = \frac{A_1}{r_1}\sin \Phi_1 = \frac{A_1}{r_1}\sin(\omega_1 t - k_1 r_1 + \alpha_1),$$

$$S_2 = \frac{A_2}{r_2}\sin \Phi_2 = \frac{A_2}{r_2}\sin(\omega_2 t - k_2 r_2 + \alpha_2),$$

where: Φ_1 and Φ_2 – the phases of propagating waves; k_1 and k_2 – the wave numbers; ω_1 and ω_2 – cyclical frequency of each wave; α_1 and α_2 – the initial phases; r_1 and r_2 – the distances from the point M to point sources B_1 and B_2. In the resultant wave:

$$S = S_1 + S_2 = \frac{A}{r}\sin \Phi$$

the amplitude and the phase are determined by formulas:

$$\frac{A}{r} = \sqrt{\left(\frac{A_1}{r_1}\right)^2 + \left(\frac{A_2}{r_2}\right)^2 + 2\frac{A_1}{r_1}\frac{A_2}{r_2}\cos(\Phi_2 - \Phi_1)},$$

$$\Phi = arctg\,\frac{\frac{A_1}{r_1}\sin \Phi_1 + \frac{A_2}{r_2}\sin \Phi_2}{\frac{A_1}{r_1}\cos \Phi_1 + \frac{A_2}{r_2}\cos \Phi_2}.$$

The theory states that only *coherent* waves may interfere. In the theory of signals [3] the concept of coherence has several definitions. Firstly, coherence is considered as an agreed behavior of several vibrational or wave processes in the time. Secondly, the vibrations are called coherent, if the difference of their phases remain constant or changing regularly. Thirdly, the coherent signals are considered with the same frequency ($\omega_1 = \omega_2$), and fluctuations which occur along the same direction. This result of the interference will be determined by the phase difference:

$$\Delta\Phi = \Phi_2 - \Phi_1 = \alpha_2 - \alpha_1 + k(r_1 - r_2).$$

Fourthly, the coherence is interpreted as a measure of the spectral width of the signal. In this case, the smaller the spectral width of the signal is, the degree of coherence is higher.

The results of interference, called the interference figure, depending on the wavelength and the distance between the point sources are shown in fig. 1 [4].

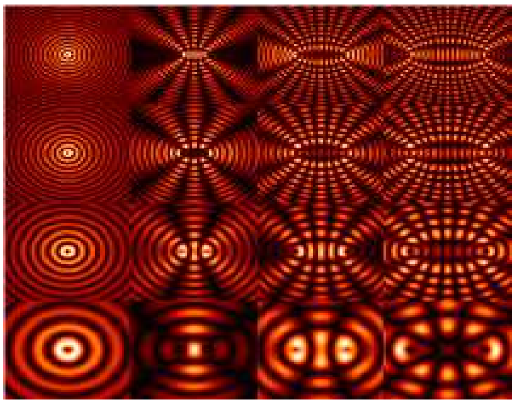

Fig. 1. The results of interference, depending on the wavelength and the distance between the point sources

For a fully coherent sources, the interference figure is an endless alternation of light and dark areas (bands), which correspond to the sum and difference of the amplitudes of the interacting oscillations. An example of nearly coherent light sources are lasers with very narrow spectral line of radiation.

With regard to the radio-technical sources, absolutely coherent can be only those that generate a strictly periodic sinusoidal signals. Such signals have minimal spectral width, because the spectrum consists of a single harmonic. To partially coherent refer generators of non-sinusoidal periodic signals, for example, of triangular shape. The spectrum of this signal contains several harmonics, distributed in a certain way. Partially coherent signals are also such signals, which correspond to the mixture of periodic sinusoidal component and random noise, whose intensity is much smaller than the intensity of useful component. The generators of random signals, having a continuous spectrum in a certain range of frequencies are considered to be absolutely incoherent. Thus the spectral power density of a random signal may have a different form of distribution. In particular, the random signal which has a uniform spectral density, is called "white noise". Random signal which has an arbitrary, irregular spectral density, is called "colored noise".

Accepting the terms of coherence it turns out that the phenomenon of interference (like a picture of alternation light and dark bands) of incoherent sources must be absent. But there is an exception. If two signals are forming from the same incoherent source and there is a phase shift between the signals, the interference can still be observed. In particular, the sun emits incoherent light waves, that is equivalent to the random noise with nearly uniform density. However, we can see the interference color pictures on the surface of thin films on the water from sunlight.

The theory of signal links the concept of interference with the concept of correlation, considering any laws of variation of the components for the amplitude of the resulting signal which is proportional to the product of the amplitudes of the sources and the cosine of the phase shift in equation (1). For two independent random signals, the correlation coefficient is 0, which corresponds to the orthogonality properties ($\cos\Delta\Phi = \cos \pi / 2 = 0$) and, thus, the square of the amplitude of the resulting signal is equal to the sum of the squares of the amplitudes of the components. For coherent sources the amplitude of the resulting wave is equal to the sum of the amplitudes of the components (amplification effect) in cases where the phase shift is 0 degrees. When the phase shift is 180 degrees, the amplitude of the resulting wave is equal to the difference between the amplitudes of the components (the effect of attenuation). This conclusion is fully corresponds to the established understanding in physics of the phenomenon of interference.

The analytical description (1) of the interference phenomenon is supposed that the shape of the resulting fluctuations S = S1 + S2 does not change at any ratio of amplitudes and phases of terms.

However, the authors carried out special studies which showed that the interference is more complex, that appears *in changes of shape of the resulting signal depending on the ratio of the amplitudes of the interacting oscillations* [5,6]. However, this phenomenon is absent in coherent sources, but occurs for *incoherent* sources.

In this work the methodology, tools and results of modeling the evolution of a binary mixture of signals are described, and therefore the phenomenon of incoherent signals interference was found.

II. Methods and Tools of Researches

Methods of research is explained by the structural scheme (Fig. 2), containing the generators of 1 and 2 signals, combiner, power meters, signal generators output, indexing divider, calculating the power ratio of signals and identification scale which is used to measure the distribution form of the mixture signal at the combiner output.

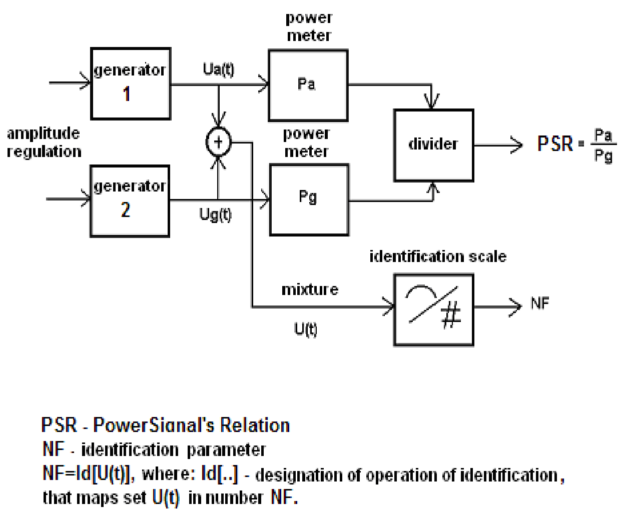

Fig. 2. Block diagram of the method for conducting experiments

The essence of research is to study the evolution of binary additive mixtures of signals U (t) = A_1Ua (t) + A_2Ug (t). The evolution in this case, is [7] a mixture of transition from one boundary state to another with the change of components amplitudes ratio (A_2/A_1) from 0 to indefinitely large value (ideally to ∞). In particular, if the ratio (A_2/A_1) = 0, then the output signal of the combiner U (t) = A_1Ua (t) is the same as the form of the output signal of the 1-th generator. If the ratio (A_2/A_1) = ∞, then the output signal of the combiner U (t) = A_2Ug (t) coincides in form with the output signal of the 2-nd generator. In this regard, the question arises: how will the shape of the signal U (t) be changed within the range $0 < (A_2/A_1) < \infty$?

To answer this question, an experiment should be made as to adjust the amplitude of the signal generator, measure the ratio (A_2/A_1), for example, in the form of power signal's relation (PSR), and also to measure the waveform of the mixture.

The tool, called NF-tester for the identification of the type [8] was used to measure the waveform of the mixture. The structure code (program LabVIEW-7.1) of the NF-tester is shown in Fig. 3.

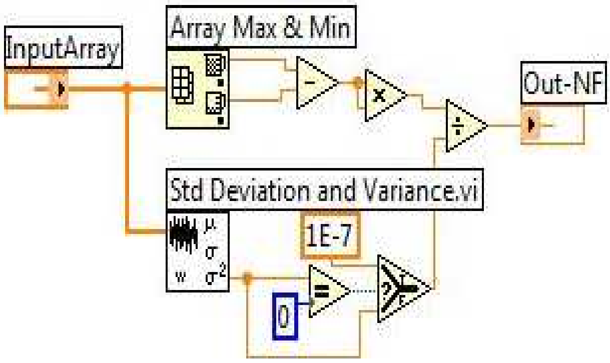

Fig. 3. Structure code of the NF-tester

Mathematical model of the tester is based on computation of the signal amplitude ratio to its standard deviation (SD):

$$NF = \left[\frac{\max\{x_i\} - \min\{x_i\}}{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - X)^2}} \right]^2 = K_f N,$$

and interprets the treatment values (X) of the signal as the transformation the amount of information of size N at the input of the recognition system to the amount of information of size NF at the output. Identifying parameter NF, called a *virtual volume*, displays the form of distributions of random signals numerically, as it's shown in Table. 1.

TABLE 1.
NF-TESTER IDENTIFICATION SCALE

IdP=NF, N-Amount of signal	**Kind of distribution of a random signal**						
	2mod ***1***	***Asin*** ***2***	***Even*** ***3***	***Simp*** ***4***	***Gaus*** ***5***	***Lapl*** ***6***	***Kosh*** ***7***
Mean (NF), N=10000, L=100	4	8	12	24	60	150	10630
Error (p=0,95),%	0,003	1,5	1,7	3,3	17	41	50
Analogues among periodic signals	Squ	Sin	Tri, Saw	-	-	-	-

This table is called the identification scale (IS) [8], because the linguistic structures appears to be ordered in it, in the form of names of distributions (2mod – two-modal, asin - arcsine, even - even, simp - triangular, gaus - normal, lapl - Bilateral exponential, kosh - Koshy) of random signals.

The objects of the research were random signals with the distributions pointed above, and also periodic signals of rectangular (squ), sine (sin), triangular (tri) and sawtooth (saw) forms. If the components $Ua(t)$, $Ug(t)$ of the mixture have the same name, then a mixture $U(t)$ is called auto-sum, in other cases - cross-sum. In particular, the examples of auto-and cross-sum can be the mixtures that were obtained by summation of random signals and shown in Fig. 4.

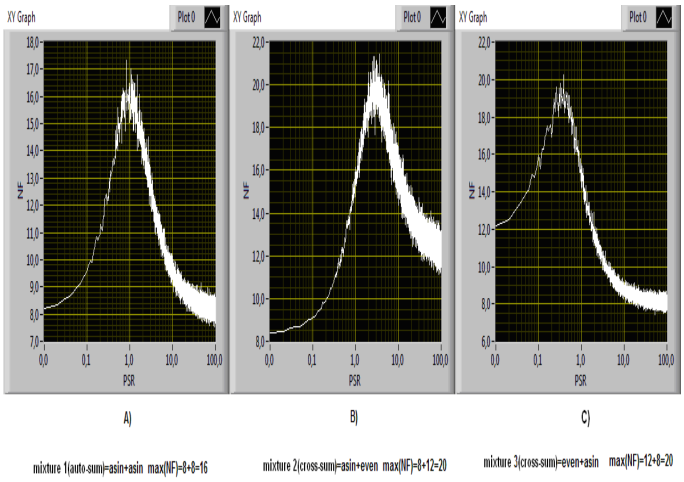

Fig. 4. The example of the mixture waveform depending on the ratio of powers of random components to auto-sum (A) and cross-sum (B,C)

As it's seen from the graphs, the dependence NF (PSR) have a clearly defined extremum (in this example, maximum), that is equal to the sum of the identification numbers of interacting components, and it indicates the change in the waveform of the mixture. Exactly this effect the authors propose to call «the phenomenon of incoherent interference». The position of the maximum for the auto-sum coincides with the condition of equality of components power (fig. A). For the cross-sum the position of maximum is shifted from the condition PSR = 1 in the large (Graph B) or less (Graph C) side, depending on which of the components is subjected to regulation. In other words, in this type of summation of components of the mixture the commutative law is not observed. It indicates the nonlinear nature of their interaction.

III. THE RESULTS OF RESEARCH

The results of evolution research of the auto-sums of random signals, which distribution names are given in Table. 1, are shown in Fig. 5.

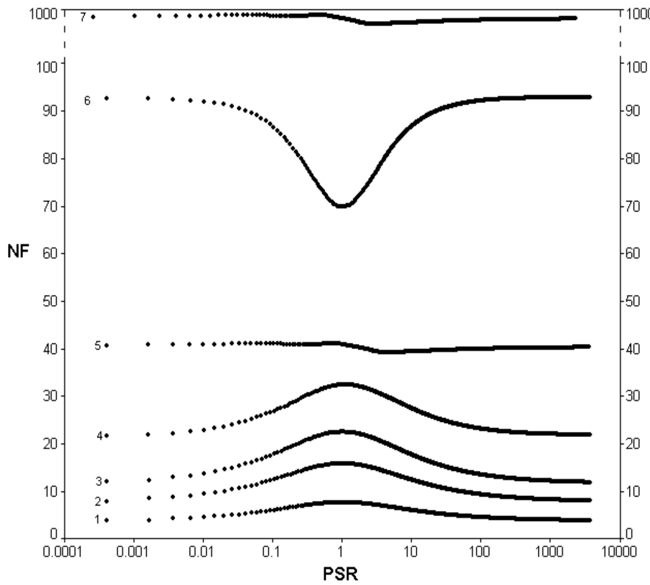

Fig. 5. Evolutionary identification characteristics of auto-sums of random signals (1-2mod, 2-asin, 3-even, 4-simp, 5-gaus, 6-lapl, 7-kosh)

The reducing of random fluctuations in the graphs is achieved by averaging of a large number (L = 100) of the individual implementations of dependencies such as Fig. 4, A. The volume of random realizations was N = 1000. The numbers (from 1 to 7) of dependencies correspond to serial numbers of the names of allocation from the table. 1. For example, the number 5 refers to the dependence which was obtained by summation of two random signals with a normal (gaus) distribution. The values of power ratio (Power Signal's Relation) of summable components are situated on abscissa axis, and the value of identification number (NF) is on the ordinate axis. The form of evolutionary identification characteristics (EIC) allows to make an objective classification of random signals into three groups as follows.

The first group is formed from the signals, whose auto-sum has a maximum. These signals (1-2mod, 2-asin, 3-even, 4-simp) belong to the class of signals with limited distributions. The second group is formed from the signals (6-lapl), whose EIC has a minimum. These signals have unlimited distributions. In the biggest degree, the effect of the interaction of components of the mixture for these groups of signals, occurs when their capacities are equal. Third group of signals are the signals with so called stable [9] distributions (5-gaus, 7-kosh), whose EIC does not depend on the power terms ratio. Therefore, these characteristics have the form of straight lines, parallel to abscissa axis. It should be noted another peculiarity, which appears in regular, deterministic nature of the EIC family. Consequently, these characteristics, first, can be modeled by the generators of periodic signals and, second, it's possible to create the analytical descriptions that will theoretically allow to estimate the effects of the interaction of random signals, for example, to predict.

To test these assumptions, the authors proposed and studied the deterministic model of the phenomenon of incoherent interference, which is built on 2 generators of periodic signals. The structure of the programmed code of the model is shown in Fig. 6.

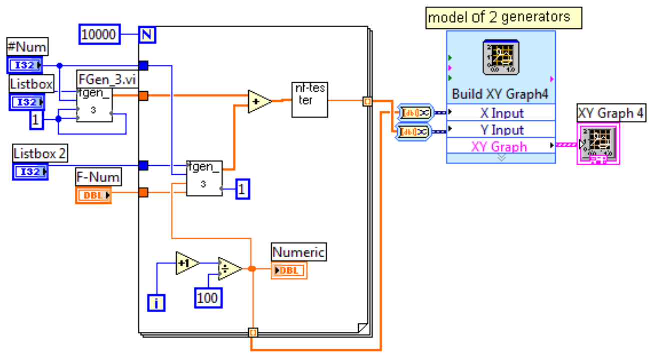

Fig. 6. The deterministic model of obtaining EIC of random signals mixture

The structure contains two functional generator of type FGen_3.vi, combiner, NF-tester, the visualization block of EIC, the elements of shaping, amplitude and frequency signal generators. The cycle of type For-Next is intended for automatically building EIC, and as the driving parameter is the amplitude of the signal generator located inside the loop. The amplitude of the second signal generator varies from 0,01 to 100, simulating, thus, the changing of intensity ratio of summable components, because the amplitude of the first signal generator is fixed at a constant level, for example, which is equal to 1. NF-tester measures the shape of the output signal of the combiner, as a function of the ratio of intensities.

In order to get a particular dependency (Fig. 7) with the help of this model, it is necessary to tune the frequencies of the first F1 and F2 of the second generators according to the data from table. 2. The settings of generators for auto-sums of random signals are presented in the diagonal elements of the table. These configuration options allow to generate EIC mixtures for auto-sum with an error of no more than 2%. In the remaining cells the parameters of settings of generators for cross-sums are specified.

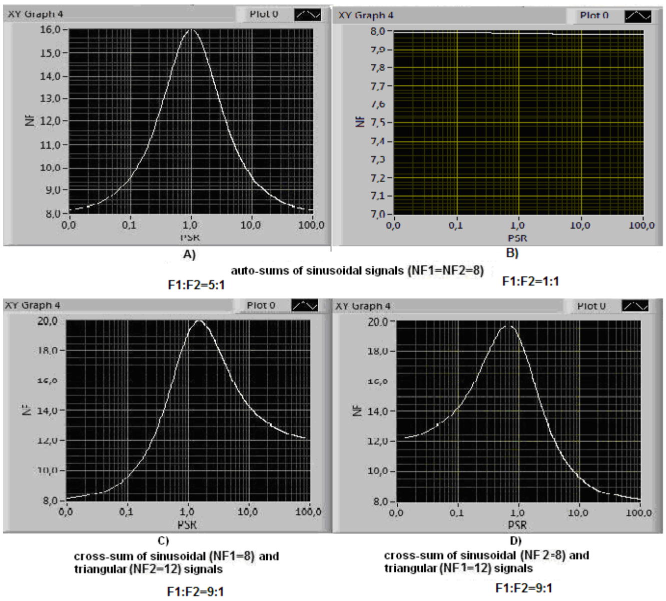

Fig. 7. The graphs EIC of mixtures of periodic signals for the model in Fig. 6

TABLE 2
THE FORM OF PERIODIC SIGNALS OF STANDARD GCCF AND THEIR IDENTIFICATION NUMBERS

Generic parameters F1;F2; Delta,%; Shift	**The form of periodic signals of standard GCCF and their identification numbers (NF-tester)**				
	4	***8***	***12***	***12***	***8***
	Square	***Sine***	***Triangle***	***Sawtooth***	***Cos***
Square	10	9	9	28	9
	1	1	1	1	1
	0,08	0,3	0,55	1,7	0,32
	1	2	1	1	2
Sine	10	5	9	12,5	7,18
	1	1	1	1	1
	0,05	0,24	1	1,87	0,64
	0,5	1	0,5	0,5	1
Triangle	8	8	5	8,5	8
	1	1	1	1	1
	0,05	0,86	0,66	1,41	1
	1	1,8	1	1	2
Sawtooth	24	12,5	13,5	9,9	21
	1	1	1	1	1
	0,22	0,42	1	1,66	0,62
	1	2	1	1	2,2
Cos	7	7	31	27	5
	1	1	1	1	1
	0,05	0,6	1,4	1	0,25
	0,5	1	0,5	0,5	1

In particular, the data from table 2 show that in the case of addition of 2-sinusoidal signals, the phenomenon of incoherent interference down to the limit is appeared at the difference of generators frequency between each other 5 times (the intersection of the column and the row with the name of SINE). At the same time, there is no interference, if the oscillator frequencies are equal, that, in fact, the results of experiments presented in Fig. 7 confirmed. The figures 7 A and 7, B, respectively, illustrate the results of the interference of two sinusoidal signals when the frequency of the generators differ 5 times (non-coherent signals), and when the frequency of the generators are equal (coherent signals). In the figures 7 C and 7 D are shown the results of incoherent interference (the frequency generators differ 9 times) of sinusoidal and triangular signals while changing the order of summation.

If we compare these results with those that relate to the summation of random signals (Fig. 4 and 5), then the high degree of conformity can be noted.

IV. Conclusions

- The experiments, first, confirm the existence of the phenomenon of incoherent interference with the addition of two signals.
- It is clear that the phenomenon is indifferent to the nature (periodic, random) of summable components.
- There are the optimal conditions of setting the frequency for the periodic generators at which the effect is to maximize. The conditions of setting depend on the shape of summable signals.
- The law of the mixture waveform changing is sensitive to which of the two components is subjected to the regulation.
- The regular nature of the phenomenon of incoherent interference allows to describe it in an analytical form. However, the latter circumstance requires a separate research.

References

[1] Saveliev I.V. *The course of general physics.* In 4 vols. - Moscow: " Publishing KnoRus", 2009. - 1856.

[2] Saveliev I.V. *The course of physics*. In 3 vols. Volume 2. Electricity. Oscillations and waves. Wave optics. Ed. 3rd, a stereotype. - Moskau: "Publishing Lan", 2007. - 480.

[3] Collegiate Dictionary. Electronic version. *http://dic.academic.ru.*

[4] Universal Encyclopedia. Internet resource. *http://ru.wikipedia.org.*

[5] Klikushin Y.N., Koshekov K.T. *Study of the evolution of binary mixtures of signals* // Bulletin of KazNU. - Almaty: " Publishing KazNU", № 1 (44), 2005, 88-93.

[6] Klikushin Y.N., Koshekov K.T. *Models of the evolution of the additive mixture of signal-noise ratio. / / Bulletin of KazNU.* - Almaty: " Publishing KazNU", № 1 (44), 2005, 94-100.

[7] Klikushin Y.N. *Technology identification of scales in the problem of recognition of signals*: Monograph. - Omsk: " Publishing OSTU", 2006 – 96.

[8] Klikushin Y.N. *Classification scheme for probability distributions.* Internet article // Russian Journal of Radio Electronics, Publishing IRE RAS, № 11 (November), 2000: *http://jre.cplire.ru*.

[9] Zolotarev V.M. *One-dimensional stable distributions.* - Moskau: "Nauka", 1983, 365.