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STUDY OF THE RECIPROCAL FUNCTION OF INDETERMINACY OF A WIDEBAND--ETC(U).
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FOREIGN TECHNOLOGY DIVISION

STUDY OF THE RECIPROCAL FUNCTION OF INDETERMINACY OF A WIDEBAND SIGNAL WITH A COMPLEX LAW OF ANGULAR MODULATION

by

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А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ë in Russian, transliterate as yë or ë. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	Α	α	Nu	Ν	ν
Beta	Β	β	Xi	Ξ	ξ
Gamma	Γ	γ	Omicron	Ο	ο
Delta	Δ	δ	Pi	Π	π
Epsilon	Ε	ε ϵ	Rho	Ρ	ρ ϱ
Zeta	Ζ	ζ	Sigma	Σ	σ ς
Eta	Η	η	Tau	Τ	τ
Theta	Θ	θ ϑ	Upsilon	Τ	υ
Iota	Ι	ι	Phi	Φ	φ ϕ
Kappa	Κ	ϰ κ ϰ	Chi	Χ	χ
Lambda	Λ	λ	Psi	Ψ	ψ
Mu	Μ	μ	Omega	Ω	ω

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}

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rot	curl
lg	log

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STUDY OF THE RECIPROCAL FUNCTION OF INDETERMINACY OF A WIDEBAND SIGNAL WITH A COMPLEX LAW OF ANGULAR MODULATION

G. V. Svinchevskaya

A study is made of the function of indeterminacy of a signal with a complex law of angular modulation and the reciprocal function of indeterminacy of the pair, signal - filter, which with respect to its properties approaches the properties of the function of indeterminacy of a Gaussian LChM-signal [Tr. note: ЛЧМ- linear frequency-modulated].

The function of indeterminacy is a universal characteristic of complex wideband signals which makes it possible to select one or another signal in various radar situations [1, 2, 3]. Among the wideband signals, an LChM-signal with a Gaussian envelope is of undoubted interest from the point of view of properties of the function of indeterminacy [4, 5]. Practical realization of such a signal, however, is quite difficult because of the limited possibilities of modern radar station transmitters. This is explained by the fact that the majority of powerful pulse superhigh frequency generators operate in the key mode in which amplitude modulation is impossible.

In this work a study is made of the function of indeterminacy and the reciprocal function of indeterminacy of a signal with a complex law of angular modulation and a rectangular envelope. The reciprocal function of indeterminacy of such a signal approximates, with respect to its properties, the function of indeterminacy of a Gaussian LChM-signal, and the realization of this signal is not difficult.

The law of angular modulation of a sounding signal is described in the following manner:

(1) $$f(t)=f_1(t)+f_2(t),$$

where

(2) $f_1(t)=f_0+kt,$ and $f_2(t)=\Delta f_m \cos\omega_m t.$

In this case K is the rate of frequency change during a pulse T, equal to Δf/T; Δf is the frequency deviation; $\Delta f_m=\beta f_m$; β is the index of modulation; f_m is the frequency of modulation.

In complex form the sounding signal has the following form:

(3) $$S(t)=e^{j\Theta(t)}=e^{j[\Theta_1(t)+\Theta_2(t)]}\quad |t|\leqslant \frac{T}{2},$$

where $\Theta(t)$ is the phase of the signal determined by the law of change of the instantaneous frequency of the signal (1).

On the strength of the familiar relationship from the theory of Bessel functions [6]

$$e^{j\beta\sin\omega_m t}=\sum_{k=-\infty}^{+\infty} J_k(\beta)\cdot e^{jk\omega_m t},$$

(3) may be rewritten in the following manner:

(4) $$S(t)=e^{j\Theta_1(t)}\left\{J_0(\beta)+\sum_{k=1}^{\infty} J_k(\beta)e^{jk\omega_m t}+(-1)^k\sum_{k=1}^{\infty} J_k(\beta)\,e^{-jn\omega_m t}\right\}$$

with $|t|\leqslant \frac{T}{2}$.

The function of indeterminacy of such a signal is calculated according to the formula [3]

(5) $$\chi(\tau, \Omega) = \frac{1}{2E} \left| \int_{-\infty}^{+\infty} A(t) \cdot A^*(t-\tau) \cdot e^{-i\Omega t}\, dt \right|,$$

where E is the energy of the signal, equal to T/2, and A(t) is the complex envelope of the sounding signal equal tc

(6) $$A(t) = e^{i\left(\frac{\mu t^2}{2} + \beta \sin \omega_m t\right)}.$$

where $\mu = 2\pi k$.

Taking into account (6) the functicn of indeterminacy (5) for $\tau \geqslant 0$ has the following form:

(7) $$\chi(\tau, \Omega) = \frac{1}{T} \left| e^{-i\frac{\mu\tau^2}{2}} \int_{-\frac{T}{2}+\tau}^{T/2} e^{i(\mu\tau+\Omega)t}\, e^{i2\beta \cos \omega_m \left(t-\frac{\tau}{2}\right) \sin \omega_m \left(t-\frac{\tau}{2}\right)}\, dt \right|.$$

Analogously to (7) the expression is written for $\tau \leqslant 0$. In this case the integrand does not change and the limits of integration become equal to T/2 and T/2 + τ.

Transforming (7), expanding the last exponential factor in the integrand into a series with respect to Bessel functions [6]

$$e^{j2\beta\sin\frac{\omega_m\tau}{2}\cos\omega_m\left(t-\frac{\tau}{2}\right)}=\sum_{k=-\infty}^{+\infty} j^k J_k\left(2\beta\sin\frac{\omega_m\tau}{2}\right)\exp\left[jk\omega_m\left(t-\frac{\tau}{2}\right)\right]. \quad (8)$$

Substituting (8) into (7) changing the order of summation and integration and combining the results for $\tau\geqslant 0$ and $\tau\leqslant 0$ we obtain

$$\chi(\tau,\ \Omega)=\left|\sum_{k=-\infty}^{+\infty} j^k J_k\left(2\beta\cdot\sin\frac{\omega_m\tau}{2}\right)\chi_{ЛЧМ}(\tau,\ \Omega+k\omega_m)\right|. \quad (9)$$

From the last expression it is evident that the presence of a supplementary sinusoidal component in the composition of the instantaneous frequency of the sounding signal leads to the fact that the function of indeterminacy of a signal with a complex law of angular modulation is the sum of functions of indeterminacy of a signal with linear frequency modulation, shifted along axis Ω by frequencies, which are multiples of the modulation frequency ω_m, the envelopes of which change in accordance with the Bessel functions.

The distribution of areas of high correlation of the function $\chi(\tau, \Omega)$ is shown in Fig. 1. Analogously, from (4) it is evident that the sounding signal is the total of LChM-pulses with a rectangular envelope, the amplitude values of which are proportional to the Bessel functions. In this case we shall call the component of the signal the central component

(10) $$S_{\text{ц}}(t) = J_0(\beta) \cdot e^{j\Theta_1(t)} \quad |t| \leqslant \frac{T}{2}.$$

The basic idea of obtaining a reciprocal function of indeterminacy, approaching, with respect to its properties, a function of indeterminacy of a Gaussian LChM-signal, lies in giving the envelope of the central component a form close to Gaussian and in using a filter in the receiver which is matched with this component. A change in the form of the envelope of the central component may be achieved due to a change in the index of modulation during a pulse.

As shown by the studies, the form of an envelope close to Gaussian may be obtained during the change of the index of modulation $\beta = c|t|$ (where c = 5.26/T). The law of change of the envelope of the central component which corresponds to it is shown in Fig. 2a as a function of β and during pulse T.

The law of change of the envelope of the central component can be approximated by the following analytical function:

(11) $$J_0[\beta(t)] = e^{-\alpha t^2} \cos \frac{\pi t}{T} \quad -\frac{T}{2} \leqslant t \leqslant \frac{T}{2},$$

where $\alpha = 3/T^2$.

In Fig. 2b the dotted line shows the curve of the approximating function. The root-mean-square error of approximation in this case does not exceed 3 o/o. The law of change of the envelope of the central component we shall call quasi-Gaussian.

Taking (11) into account the complex envelope of the central component of the sounding signal is written in the following manner:

(12) $$A_{u}(t) = e^{-\frac{3t^2}{T^2}} \cos \frac{\pi t}{T} e^{j\frac{\mu t^2}{2}} \quad -\frac{T}{2} \leqslant t \leqslant \frac{T}{2}.$$

For determination of the characteristic of the filter we calculate the spectrum of the complex envelope of the central component using the method of a stationary phase [2]

(13) $$S_{u}(\omega) = \int_{-T/2}^{T/2} A_{u}(t) \cdot e^{-j\omega t}\, dt = \begin{cases} \sqrt{\frac{2\pi}{\mu}}\, e^{-\frac{3\omega^2}{\Delta\omega^2}} \cos \frac{\pi\omega}{\Delta\omega}\, e^{j\left(\frac{\omega^2}{2\mu} \pm \frac{\pi}{4}\right)} \\ \text{with } -0{,}5\,\Delta\omega < \omega < 0{,}5\,\Delta\omega \\ 0 \text{ with } |\omega| > 0{,}5\,\Delta\omega. \end{cases}$$

In accordance with (13) the characteristic of the filter matched with the central component is expressed in the following manner:

(14) $$S_\Phi(\omega) = S_u^*(\omega).$$

The reciprocal function of indeterminacy of the pair, signal - filter, determined by (4) and (14) may be represented in the form

(15) $$\chi_{вз}(\tau, \Omega) = \frac{1}{4\pi\sqrt{EE_1}}\left|\int_{-\infty}^{+\infty} S(\omega-\Omega)\cdot S_u^*(\omega)\cdot e^{j\omega\tau}\,d\omega\right|,$$

where $S(\omega)$ is the spectrum of the complex envelope of the sounding signal and E_1 is the energy of its central component equal to

(16) $$E_1 = \frac{1}{\pi}\int_0^{0,5\Delta\omega} |S_u(\omega)|^2\cdot d\omega = \frac{1,19\sqrt{\pi}\cdot T}{2\sqrt{6}}.$$

The spectrum of the sounding signal is determined using a Fourier transform from (4)

$$S(\omega)=\int_{-T/2}^{T/2} S(t)\cdot e^{-j\omega t}\,dt=J_0(\beta)\int_{-T/2}^{T/2}\exp\left\{j\left[(\omega_0-\omega)\,t+\frac{\mu t^2}{2}\right]\right\}dt+$$
$$+\sum_{1}^{\infty}J_k(\beta)\int_{-T/2}^{T/2}\exp\left\{j\left[(\omega_0-\omega+k\omega_m)\,t+\frac{\mu t^2}{2}\right]\right\}dt+ \tag{17}$$
$$+(-1)^k\sum_{1}^{\infty}J_k(\beta)\int_{-T/2}^{T/2}\exp\left\{j\left[(\omega_0-\omega-k\omega_m)\,t+\frac{\mu t^2}{2}\right]\right\}dt.$$

Consequently the spectrum of the scunding signal consists of the sum of an infinite number of spectral ccmponents, the modulus cf which is proportional to the Bessel functions. Consequently each ccmponent of the signal (4) has a spectrum typical for LChM-signals and the central frequencies of the spectral components are equal tc $\omega_0 \pm k\omega_m$. Depending on the selection of the value ω_m the components may overlap or separate. Under the condition $0{,}5\,\Delta\omega \ll \omega_m$ where $\Delta\omega$ is the band of frequencies occupied by each spectral component the overlap is quite small and the spectrum of the sounding signal may be represented in the form of the curve in Fig. 3.

With a change in the index of modulation during a pulse, taking into account (17), the reciprocal function of indeterminacy is written in the following manner

$$\chi_{B3}(\tau,\ \Omega)=\frac{1}{4\pi\sqrt{EE_1}}\left|\left\{\int\limits_{-\infty}^{+\infty}J_0[\beta\ (t)]e^{i\left[\frac{\mu t^2}{2}-t(\omega+\Omega)\right]}dt+\right.\right.$$

(18)
$$+\int\limits_{-\infty}^{+\infty}\sum_{1}^{\infty}J_k[\beta\ (t)]e^{i\left[\frac{\mu t^2}{2}-t(\omega+\Omega-k\omega_m)\right]}dt+\int\limits_{-\infty}^{+\infty}(-1)^k\sum_{1}^{\infty}J_k[\beta\ (t)]\times$$

$$\times e^{i\left[\frac{\mu t^2}{2}-t(\omega+\Omega+k\omega_m)\right]}dt\Bigg\}\sqrt{\frac{2\pi}{\mu}}\,e^{-\frac{3\omega^2}{\Delta\omega^2}}\left(\cos\frac{\pi\omega}{\Delta\omega}\right)e^{-i\frac{\omega^2}{2\mu}}\times$$

$$\times e^{j\omega\tau}d\omega\Bigg|=\chi_{B311}(\tau,\ \Omega)+\chi_{B312}(\tau,\ \Omega)+\chi_{B321}(\tau,\ \Omega).$$

From (18) it is evident that, as does the function of indeterminacy (9), the reciprocal function of indeterminacy consists of the totality of the basic component $\chi_{B311}(\tau,\Omega)$ and the lateral components shifted on axis Ω to frequencies which are multiples of the modulation frequency ω_m.

Taking (13) into account the basic component $\chi_{B311}(\tau,\Omega)$ is written as

(19)
$$\chi_{B31}(\tau,\ \Omega)=\frac{1}{2\mu\sqrt{EE_1}}\left|\int\limits_{-\infty}^{+\infty}e^{-\frac{6\omega^2}{\Delta\omega^2}}e^{-\frac{3\Omega^2}{\Delta\omega^2}}e^{\frac{6\omega\Omega}{\Delta\omega^2}}\cos\frac{\pi\omega}{\Delta\omega}\cos\frac{\pi(\omega-\Omega)}{\Delta\omega}\times\right.$$

$$\left.\times e^{-i\frac{\Omega^2}{2\mu}}e^{i\frac{\omega\Omega}{\mu}}e^{j\omega\tau}d\omega\right|=\frac{1}{4\mu\sqrt{EE_1}}\left|e^{-\frac{3\Omega^2}{\Delta\omega^2}}\left(\cos\frac{\pi\Omega}{\Delta\omega}J_1+0{,}5J_2\right)\right|.$$

where

$$J_1=\int_{-\infty}^{+\infty} e^{-\frac{6\omega^2}{\Delta\omega^2}} e^{\frac{6\omega\Omega}{\Delta\omega^2}} e^{j\frac{\omega\Omega}{\mu}} e^{j\omega\tau}\,d\omega;$$

$$J_2=\int_{-\infty}^{+\infty} e^{-\frac{6\omega^2}{\Delta\omega^2}} e^{\frac{6\omega\Omega}{\Delta\omega^2}} e^{j\frac{\omega\Omega}{\mu}}\left[e^{j\frac{\pi}{\Delta\omega}(2\omega-\Omega)}+e^{j\frac{\pi}{\Delta\omega}(\Omega-2\omega)}\right]\exp(j\omega\tau)\,d\omega.$$

During calculation of components J_1 and J_2 we use transforms which reduce to the calculation of the integral of probabilities [7], obtaining the final expression for J_1 and J_2:

(20)
$$J_1=\sqrt{\frac{\pi}{6}}\,\Delta\omega\exp\left\{\frac{\Delta\omega^2}{24}\left[\frac{6\Omega}{\Delta\omega^2}+j\left(\tau+\frac{\Omega}{\mu}\right)\right]^2\right\}.$$

(21)
$$J_2=\sqrt{\frac{\pi}{6}}\,\Delta\omega\exp\left\{\frac{\Delta\omega^2}{24}\left[\frac{6\Omega}{\Delta\omega^2}+j\left(\tau+\frac{\Omega}{\mu}+\frac{2\pi}{\Delta\omega}\right)\right]^2\right\}e^{-j\frac{\pi\Omega}{\Delta\omega}}+$$
$$+\sqrt{\frac{\pi}{6}}\,\Delta\omega\exp\left\{\frac{\Delta\omega^2}{24}\left[\frac{6\Omega}{\Delta\omega^2}+j\left(\tau+\frac{\Omega}{\mu}-\frac{2\pi}{\Delta\omega}\right)\right]^2\right\}e^{j\frac{\pi\Omega}{\Delta\omega}}.$$

Substituting the obtained values (20) and (21) into (19) and making simple transformations we obtain

$$\chi_{\text{вэп}}(\tau,\Omega)=0{,}43\,e^{-\frac{\pi^2\Delta f^2(\tau+\Omega/\mu)^2}{6}}\left[\cos\frac{\pi\Omega}{\Delta\omega}+e^{-\frac{\pi^2}{6}}\cdot\operatorname{ch}\frac{\pi\Delta\omega}{6}\left(\tau+\frac{\Omega}{\mu}\right)\right].$$

The cutting of $\chi_{\text{вэп}}(\tau,\Omega)$ by planes $\tau = 0$ and $\Omega = 0$ may be represented as:

$$\chi_{\text{вэп}}(\tau,0)=0{,}43\cdot e^{-\frac{\pi^2\Delta f^2\tau^2}{6}}\left(1+e^{-\frac{\pi^2}{6}}\operatorname{ch}\frac{\pi\Delta\omega\tau}{6}\right);$$

$$\chi_{\text{нзп}}(\Omega,\ 0)=0{,}43\cdot e^{-\frac{\Omega^2T^2}{24}}\left(\cos\frac{\pi\Omega}{\Delta\omega}+e^{-\frac{\pi^2}{6}}\operatorname{ch}\frac{\pi\Delta\omega T}{6}\right).$$

The length of the compressed pulse at the level 3 dB is equal to 1.51/Δf; respectively the width $\chi(\Omega,0)$ along the axis of Doppler frequencies comprises 1.51/T.

The cutting of the surface $\chi_{\text{нзп}}(\tau,\Omega)$ by a plane parallel to plane (τ,Ω) and at a level 0.5 from its maximum value is described by the equation

$$0{,}43\, e^{-\frac{\pi^2\Delta f^2\left(\tau+\frac{\Omega}{\mu}\right)^2}{6}}\left\{\cos\frac{\pi\Omega}{\Delta\omega}+e^{-\frac{\pi^2}{6}}\operatorname{ch}\frac{\pi\Delta\omega}{6}\left(\tau+\frac{\Omega}{\mu}\right)\right\}=0{,}5.$$

After taking the logarithm and following simple transformations this expression may be reduced to the classical equation of a curve of the second order which is an ellipse with the equation of the major axis $\nu = k\tau$ with $\nu = \Omega/2\pi$.

Comparison of the cross sections plotted taking the last equation into account shows that the drop $\chi_{\text{нзп}}(\tau,\Omega)$ along the axis of Doppler frequencies takes place more slowly than in the case of a Gaussian LChM-signal.

Evaluation of the energy losses during the use of the signal with the complex law of angular modulation takes place in the following manner:

(22)
$$\Delta\rho = \frac{(S/N)_{\Phi}}{(S/N)_{max}},$$

where $\left(\frac{S}{N}\right)_{\Phi}$ is the ratio of the peak power of the signal at the output of the quasi-Gaussian filter to the mean square of noise; $(S/N)_{max} = \frac{2E}{N_0}$ is the signal/noise ratio during matched processing of the signal (4); E is the energy of the signal; N_0 is the spectral density of white noise.

Substituting values $(S/N)_{\Phi}$ and $(S/N)_{max}$ in (22) we obtain

$$\Delta\rho = \frac{\left[\frac{1}{\pi}\int\limits_0^{0,5\Delta\omega} |S_{\Phi}(\omega)|\cdot|S(\omega)/d\omega\right]^2}{\left[\frac{N_0}{\pi}\int\limits_0^{0,5\Delta\omega} |S_{\Phi}(\omega)|^2\cdot d\omega\right]} : \frac{2E}{N_0} = \frac{E_1}{2E} = 3{,}6\ \text{dB}.$$

In the last expression $S(\omega)$ is the spectrum of the complex envelope of the sounding signal; $S_{\Phi}(\omega)$ is the ceefficient of transmission of a quasi-Gaussian filter. Calculation of losses is made taking into account the fact that cnly the component spectrum (13) is present at the output of the filter.

According to data cited in [1], analogous losses in the case of a Gaussian LChM signal comprise 3.5 dB.

Let us compare the obtained results with ancther variation of the pair, signal - filter, which can prcvide the same properties as the reciprocal function of indeterminacy as the pair examined above.

The signal in this case is represented by an LChM-signal with a rectangular envelope which is subjected to weight processing by a filter, whose modulus of the transmissicn coefficient is equal to the square of the modulus of the transmissicn coefficient of a quasi-Gaussian filter (16) - a quasi-Gaussian square filter.

The calculation of the reciprocal function of indeterminacy according to equation (15) in this case leads tc the following expression:

$$\chi_{\text{вз}}(\tau, \Omega) = 0{,}314 \cdot e^{-\frac{\Delta\omega^2\left(\tau+\frac{\Omega}{\mu}\right)^2}{24}}\left[1+e^{-\frac{\pi^2}{6}}\,\mathrm{ch}\,\frac{\pi\Delta\omega}{6}\left(\tau+\frac{\Omega}{\mu}\right)\right].$$

Calculations show that in this case losses in the signal/noise ratio are approximately 5 dB.

Table 1 shows comparative data for three signals which makes it possible to judge the effectiveness of the suggested pair, signal - filter.

In this table the relative efficiency of the signal in decibels indicates the sum of the relative energy of the signals and of the losses of mismatching. The latter arise: 1) during amplitude modulation of the sounding signal due to inefficient use of the power of the transmitter; 2) during non-optimal processing: a) of a signal with a complex law of angular modulation ~~with~~ by a quasi-Gaussian filter, b) of an LChM-signal with a rectangular envelope by a quasi-Gaussian square filter.

Comparison with other known means of weight processing of an LChM-signal [8] and also with signals with nonlinear frequency modulation [9] shows that although a signal with a complex law of angular modulation is inferior to them with respect to energy losses, it is superior with respect to properties of the reciprocal correlation function and has a low level of lateral lobes and weak criticality toward Doppler frequency shifts.

CONCLUSIONS

1. The study of the reciprocal function of indeterminacy of a signal with a complex law of angular modulation showed that its properties approximate the properties of the function of indeterminacy of a Gaussian LChM-signal.

2. In contrast to a Gaussian LChM-signal we can practically realize a signal with a complex law of angular modulation and a rectangular envelope.

3. With almost identical energy losses in the signal/noise ratio with a Gaussian LChM-signal, a signal with a complex law of angular modulation clearly wins out in comparison with weight quasi-Gaussian square processing of a rectangular LChM-signal although it is inferior to such a weight function as Hemming's function [8].

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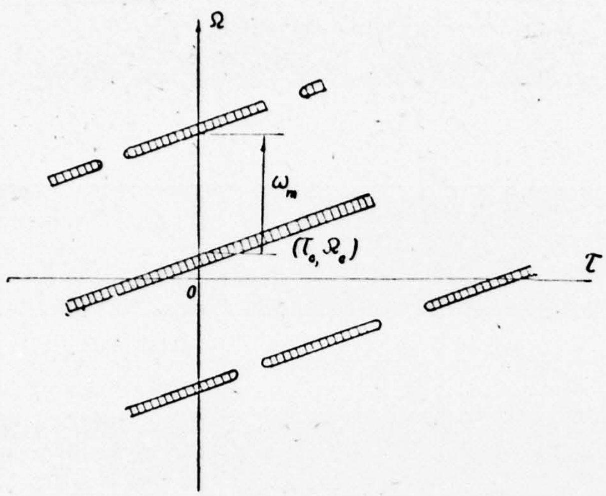

Fig. 1. Location of the range of high correlation of the function of indeterminacy of a signal with a complex law of frequency modulation.

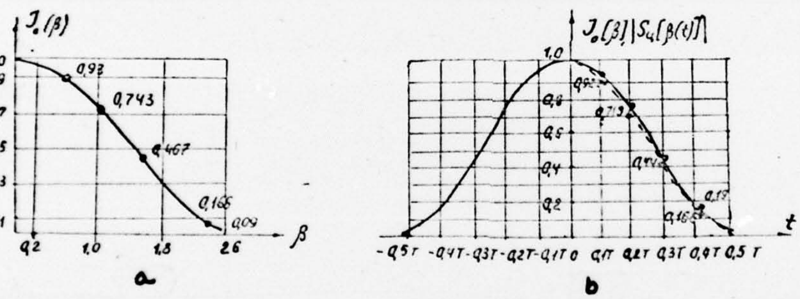

Fig. 2. Change of the envelope of a central component of a sounding signal: a - dependences on β; b - during a pulse.

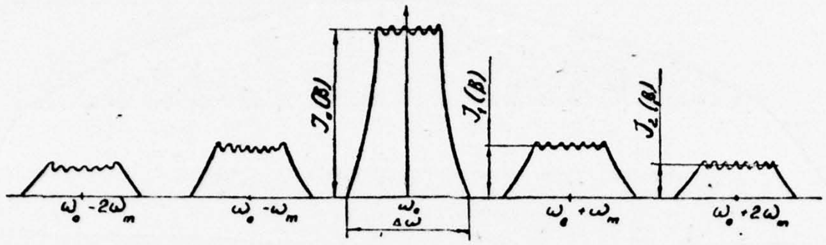

Fig. 3. Spectrum of a signal with a complex law of frequency modulation with β = const and $\omega\Delta/2 \ll \omega_m$.

Table 1.

(1) Название сигнала	(2) Относительная энергия, дб	(3) Потери рассогласования, дб	(4) Относительная эффективность, дб	(5) Длительность основного лепестка
(6) ЛЧМ-сигнал с гауссовой огибающей	—3,53	0	—3,53	$\frac{1,5}{\Delta f}$
(7) ЛЧМ-сигнал с прямоугольной огибающей и квазигауссовым квадрат-фильтром	—5	0	—5	$\frac{1,51}{\Delta f}$
(8) Сигнал со сложным законом угловой модуляции	0	—3,6	—3,6	$\frac{1,51}{\Delta f}$

((KEY: 1) Name of signal; 2) Belative energy, dB; 3) Losses of mismatching, dB; 4) Belative efficiency, dB; 5) Duration of the basic lobe; 6) LChM-signal with a Gaussian envelope; 7) LChM-signal with a rectangular envelope and quasi-Gaussian square filter; 8) Signal with complex law of angular modulation.))

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