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THE DISTORTION OF RADIO SIGNALS SPECTRA BY PARAMETRIC SYSTEM "BASIC ANTENNA – FUSELAGE OF HELICOPTER"

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Abstrakt. *Established that, directivity diagram of the system of "basic antenna – fuselage of helicopter" becomes a function of the time due to the presence of the metal main screw, which during rotation, periodically changes geometry of aircraft body. In this case the radio signal, which is received or radiated by helicopter antenna system undergoes undesirable parametric transformations. The mathematical model of parametric transformational system is proposed which is the base for investigation of spectral composition of distorted signals with amplitude and angle modulation. The recieved results are analyzed and summarized.*

Keywords: video impulses, helicopter screw, directivity diagram, effective length of the antenna, parametric signal transduction, spectrum, radio signal.

Introduction. Length of the main vanes of helicopter rotor, metal or plastic with metal rods (stringers) is comparable with geometrical dimensions of the fuselage of the aircraft. Therefore, position in the space of screw blade, which can be considered as constructive element of the aircraft body, affects the shape of the normalized directivity diagram of the system, that consists of a base antenna and the metallic fuselage on which it is installed, and in which high-frequency electric currents are generated – the source of the electromagnetic field. Thus, each screw blade becomes a separate element of the complex in its spatial configuration of antenna system (AS). Directivity diagram of the antenna system of onboard radio communications and navigation devices of working decameter, meter and decimeter ranges, has frustum character through arising reradiating of electromagnetic field of the basic antenna by metal fuselage of the aircraft [1; 2]. But the helicopter fuselage with ist main screw can be seen as another vibrator complicated asymmetric antenna, in which the primary vibrator is a basic antenna [3]. When during the rotation of the main helicopter screw minima and maxima of truncated normalized directivity diagram of complicated antenna system are changed over time (fig. 1) and periodically repeated in the direction of any space, for example, azimuth angle, which is measured from the longitudinal axis of the aircraft (fig. 2).

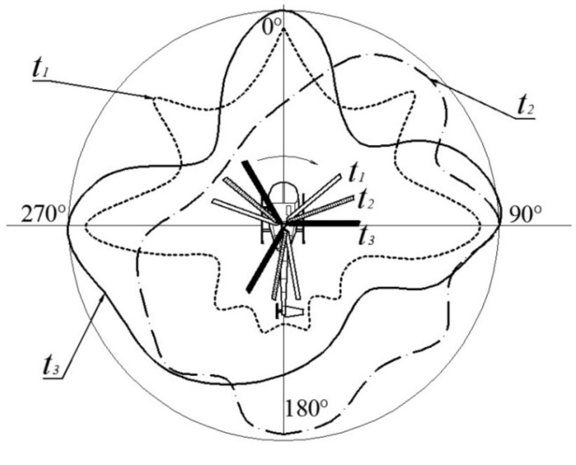

Fig. 1. Curvature of antenna directivity diagram during helicopter screw rotation

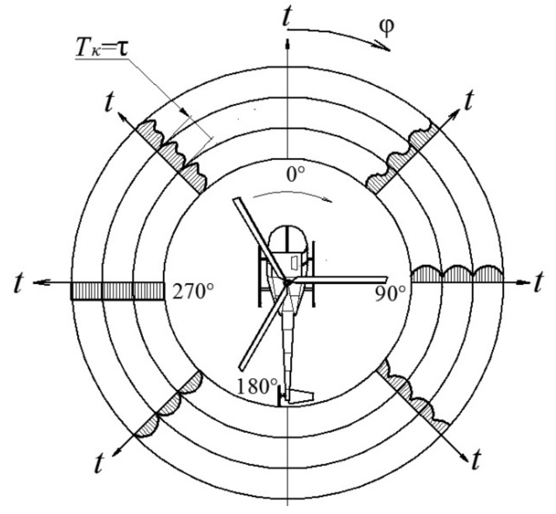

Fig. 2. Examples of instantaneous values of directivity diagram of helicopter antenna system in the azimuthally plane

Thus, at intervals of time recurrence for any angle the form of directivity diagram looks like a sequence of video pulses identical to this angle, which are adjacent to each other, creating continuous monotone curve $s(t)$ without junctions and are at certain level. The form of a separate envelope of video pulses for the angle φ depends on the geometrical features of the metal fuselage of the helicopter, and its main screw. The character of the normalized dynamic directivity diagram at any time t, as follows from fig. 2, is determined by their instantaneous values for different spatial angles.

Nonlinear process, under which influence a form of directivity diagram is changed over time, is not of electrical origin. Therefore, it is advisable to classify it as parametric process that does not add power signal, to which it affects, but changes it spectral composition. From the above it follows, that modulated radio signal, that is radiated or perceived by helicopter antenna, takes parametric undesired distortion as parasitic amplitude modulation of unipolar periodic process $s(t)$ of the fluctuation type. The frequency F_1 of the first harmonic of this process is determined by the period T of video pulses and equals their duration τ and is defined by obvious relation, Hz:

$$F_1 = \frac{1}{\tau} = \frac{nN}{60}, \tag{1}$$

where n – number of helicopter screw turns per minute (usually from 240 to 350 turns/min and remains constant); N – number of screw vanes (from two to eight). Thus the frequency of parametric transformations F_1 takes the value from eight to fifties hertz tentatively. Permissible levels of relative instability of carrier frequencies of modern on-board radio equipment are in the range of values from 10^{-8} to 10^{-6}. Therefore indicated frequencies and their harmonics may prove additional factor that affects the inadmissible absolute fluctuation of frequency spectra modulated signals in case of their unaccounted parametric transformation of system "base antenna – fuselage of helicopter". The system is parametric both in transmission mode signal, and reception mode. Therefore the spectral composition of the signal at its input and output is not the same. In the well-known publications, we have not found information on the implementation of theoretical investigations of the influence of periodical variation of geometric shape of antenna system helicopter on the spectral composition of the output signal. Therefore it is necessary to investigate the characteristics of radio signals spectra of individual classes if they are accepted or radiated by helicopter antenna system.

Problem. It is necessary to substantiate mathematical model of parametric antenna system and on its basis to investigate the distortion spectrum of amplitude-modulated (AM) signals and signals with angular modulation.

Justification of mathematical model of parametric antenna system. Change in the time of geometrical shapes of AS and its electrical characteristics are interrelated. Therefore you first need to detect such characteristic of antenna system which temporal changes have clear physical meaning, and it is uniquely associated with normalized directivity diagram of helicopter AS. According to such characteristic we can take effective length (height) of antenna l_e, that is the proportionality coefficient between the values of the electrical driving forcee u, that arises in the receiving antenna of any design, and the electric field E, under the influence of antenna:

$$u(t) = E\,l_e(t). \tag{2}$$

This coefficient $l_e(t)$ is a parametric function of time since the right part of the ratio (2) depends only on the spatial position of the screw vane. The law of changes this function in time coincides with the law changes of pulsating normalized directivity diagram antenna onboard radio-engineering system for any spatial angle (see fig. 2).

Amplitude values u and E that are directional characteristics of the transmitting and receiving antennas, have no effect on features of the frequency spectrum of the received signal. Therefore, in order to simplify the final expressions in the ratio (2) the multipliers which contain relevant angular dependency in explicit form are absent.

Instant value of the dynamic effective length of the antenna $l_e(t)$ can be expressed as a sum of a constant component l_{e0} which is related to the value of the normalized directivity diagram AS helicopter if its screw does not rotate, and the fluctuation component, which occurs when screw rotates:

$$l_e(t) = l_{e0} - \Delta l_e(t) = l_{e0}\left[1 - \frac{\Delta l_e(t)}{l_{e0}}\right]. \tag{3}$$

Graphic models of these components can be considered as a continuous periodic processes, examples are shown in fig. 2 as a sequence of video pulses of arbitrary shape. They define the features fluctuation electrical driving forcee depending on the values of the spatial angles in the horizontal and vertical planes for helicopter of any type.

To analyze characteristics of the frequency spectrum of fluctuations, we can choose random periodic sequence of video pulses that conforms to the above specified requirements. Convenient mathematical model of periodic fluctuation is the sequence, formed by cosine pulse of positive polarity and of duration τ, which are adjacent to each other. In this case the instantaneous values of fluctuation of active length of onboard AS can be given in the form:

$$\Delta l_e(t) = \Delta l_e \left|\cos\frac{\pi}{\tau}t\right| = \Delta l_e \left|\cos\frac{\nu_1}{2}t\right|, \tag{4}$$

where

$$\nu_1 = \frac{2\pi}{\tau} = 2\pi F_1$$

– the first harmonic, circular frequency of the periodic parametric functions, and Δl_e – the maximum value of the function (4), that depends on the shape of the fuselage of the helicopter and screw designs. It is obvious that the ratio (3) becomes $\Delta l_e < l_{e0}$.

Decomposition of function (4) in a Fourier series leads to the relation [4]:

$$\Delta l_e(t) = \Delta l_e \left|\cos\frac{\nu_1}{2}t\right| = \frac{2}{\pi}\Delta l_e\left[1 + \sum_{p=1}^{\infty} 2\frac{(-1)^p}{1-(2p)^2}\cos p\nu_1 t\right], \tag{5}$$

which reflects the main features of the frequency spectrum functions $\Delta l_e(t)$ in any spatial directions of relative coordinate origin (see fig. 1). In relation (5) p is number of harmonics frequencies ν_1.

Frequency spectrum of fluctuations of electrical driving forcee that distort useful, for example, AM signal at the output of parametrical AS, can be define on the basis ratio (2):

$$\Delta u(t) = E\,\Delta l_e(t). \tag{6}$$

Ratio (2), taking into account ratios (3) and (5), can be assumed as a mathematical model suitable for the study of the spectra of modulated signals at the output of parametrical antenna system. Ratio (6) allows us to identify the characteristic features of distorted signals.

The distortion of the spectra signals with amplitude modulation. Suppose that in point of basic onboard antenna installation the electric field strength of useful AM signal is expressed by the general ratio:

$$\begin{aligned} E &= E_0\left[1 + \sum_{i=1}^{\infty} M_i\cos(\Omega_i t + \Phi_i)\right]\cos(\omega_0 t + \psi_0) = \\ &= E_0\left\{\cos(\omega_0 t + \psi_0) + \sum_{i=1}^{\infty}\frac{M_i}{2}\cos[(\omega_0 - \Omega_i)t + \psi_0 - \Phi_i] + \sum_{i=1}^{\infty}\frac{M_i}{2}\cos[(\omega_0 + \Omega_i)t + \psi_0 + \Phi_i]\right\}, \end{aligned} \tag{7}$$

where ω_0 and ψ_0 – circular carrier frequency and its initial phase; M_i – partial coefficients of modulation depth; Ω_i – circular frequency of the corresponding component of the modulating signal; Φ_i – its initial phase. Then on the basis of ratios (3), (5) and (7) spectral composition of electrical driving forcee (2) can be detected after its parametrical conversion. The corresponding ratio is served in the form of a structured type (7), characteristic of multifrequency AM signal:

$$u(t) = E_0\, l_{e0} \left\{ \left[1 + \sum_{i=1}^{\infty} M_i \cos(\Omega_i t + \Phi_i) \right] \cos(\omega_0 t + \Psi_0) - \right.$$
$$- \frac{2}{\pi} \frac{\Delta l_e}{l_{e0}} \left[1 + 2\sum_{p=1}^{\infty} \frac{(-1)^p}{1-(2p)^2} \cos p\nu_1 t \right] \cos(\omega_0 t + \Psi_0) -$$
$$- \frac{1}{\pi} \frac{\Delta l_e}{l_{e0}} \left[1 + 2\sum_{p=1}^{\infty} \frac{(-1)^p}{1-(2p)^2} \cos p\nu_1 t \right] \sum_{i=1}^{\infty} M_i \cos\left[(\omega_0 - \Omega_i)t + \Psi_0 - \Phi_i \right] -$$
$$\left. -.\frac{1}{\pi} \frac{\Delta l_e}{l_{e0}} \left[1 + 2\sum_{p=1}^{\infty} \frac{(-1)^p}{1-(2p)^2} \cos p\nu_1 t \right] \sum_{i=1}^{\infty} M_i \cos\left[(\omega_0 + \Omega_i)t + \Psi_0 + \Phi_i \right] \right\}. \quad (8)$$

The first component in ratio (8) characterizes the main AM signal and subtrahends are the products of its parametrical transformations and do not contain useful information. The totality of these subtrahends, after multiplication of the corresponding harmonic functions, determines the spectral composition of fluctuations (6).

From expression (8) following conclusions can be made:

– each spectral component of the desired signal (7), i. e. its carrier frequency ω_0 and components to lateral frequency $\omega_0 \mp \Omega_i$, which are in the first member ratio (8), is accompanied by the appearance of undesired spectral components at the combinational frequencies $\omega_0 \mp p\nu_1$, $\omega_0 \mp \Omega_i \mp p\nu_1$;

– appearance of these components distorts the spectrum of high-frequency desired signal;

– distortions are stored after detecting high-frequency oscillations;

– the frequency signal distortions arise during reception and radiation by onboard helicopter antenna system;

– the effect of parametric transformations of AM signal may manifest as undesired frequency distortions of voice messages, deterioration of intelligibility of speech, the amplitude fluctuations of desired signal after detecting, intersymbol interference of digital signal, errors of separate onboard radio navigation systems.

The emergence of undesirable components spectrum at the output of parametric antenna system of helicopter, that are describe the second, third and fourth subtrahend in ratio (8), that is the emergence of fluctuations $\Delta u(t)$ in (6), requires appropriate capacity cost of useful AM signal.

From ratio (8) it also follows, that during rotation of the helicopter screw the amplitude E_0 of primary desired signal at the output of the antenna decreases by an amount $\frac{2}{\pi}\Delta l_e E_0$, i. e. in $\left(1 - \frac{2}{\pi}\frac{\Delta l_e}{l_{e0}}\right)^{-1}$, times, which will inevitably lead to a deterioration in ratio *signa / noise* at the input of corresponding radio receiver device.

The function $\left|\cos\frac{\nu_1}{2}t\right|$ can be considered as multiplier directional characteristics of antenna of any radio engineering system, installed on the board of the helicopter. Therefore, in the worst case, if $(\Delta l_e = l_{e0})$ the characteristic directional onboard antenna advisable be multiplied by value of the maximum attenuation of the carrier frequency, which is equal to $1 - \frac{2}{\pi} = 0{,}363$. This unforeseen attenuation of the carrier of desired signal may be the most important negative phenomenon, which leads to deterioration of normal operation of radio equipment onboard the helicopter on the stages of flight and landing.

According to generalized experimental data, given in [1], the signal power costs that occur when rotating the helicopter screw in some cases may reach 12 dB.

In ratio (8) the implicitly also provides information on the possible amplitude-frequency signal distortion in onboard radio electronic systems, which use variations of amplitude modulation and amplitude manipulation.

Distortion of the spectra of signals with angular modulation. Based on the above named mathematical models we consider the fundamental features of the signal spectrum with an angular modulation, if it undergoes parametric transformations in the antenna system of the helicopter. We consider modulating signal as single-frequency. In this case, the electric field intensity of modulated signal at the point of its receiving can be granted in the following form:

$$E = E_0\{ \mathrm{J}_0(m)\cos(\omega_0 t + \psi_0) + (-1)^n \sum_{n=1}^{\infty} \mathrm{J}_n(m) \cos[(\omega_0 - n\Omega)t + \psi_0 - \Phi_n] +$$

$$+ \sum_{n=1}^{\infty} \mathrm{J}_n(m) \cos[(\omega_0 + n\Omega)t + \psi_0 + \Phi_n]\}. \quad (9)$$

In ratio (9)

$$\mathrm{J}_n(m) = \sum_{k}^{\infty} \frac{(-1)^k (0,5m)^{2k+n}}{k!(k+n)!} \quad (10)$$

– Bessel functions of n-th order from the argument m, and k – number of member of the series, which this function is granted. Accordingly expression (9) in ratio (10) value n coincides with the numbers of harmonics frequency modulating signal, and m is the index value of possible varieties in the angular modulation – phase or frequency [5].

Spectral composition of EMF for the considered case can be identified on the basis of ratios (2) and (9):

$$u(t) = E_0\, l_{e0}\{ \mathrm{J}_0(m)\cos(\omega_0 t + \psi_0) + (-1)^n \sum_{n=1}^{\infty} \mathrm{J}_n(m)\cos[(\omega_0 - n\Omega)t + \psi_0 - \Phi_n] +$$

$$+ \sum_{n=1}^{\infty} \mathrm{J}_n(m)\cos[(\omega_0 + n\Omega)t + \psi_0 - \Phi_n] -$$

$$- \frac{2}{\pi}\frac{\Delta l_e}{l_{e0}}\left[1 + \sum_{p=1}^{\infty} 2\frac{(-1)^p}{1-(2p)^2}\cos p\nu_1 t\right] \mathrm{J}_0(m)\cos(\omega_0 t + \Psi_0) -$$

$$- (-1)^n \frac{2}{\pi}\frac{\Delta l_e}{l_{e0}}\left[1 + \sum_{p=1}^{\infty} 2\frac{(-1)^p}{1-(2p)^2}\cos p\nu_1 t\right] \cdot \sum_{n=1}^{\infty} \mathrm{J}_n(m)\cos[(\omega_0 - n\Omega)t + \Psi_0 - \Phi_n] -$$

$$- \frac{2}{\pi}\frac{\Delta l_e}{l_{e0}}\left[1 + \sum_{p=1}^{\infty} 2\frac{(-1)^p}{1-(2p)^2}\cos p\nu_1 t\right] \cdot \sum_{n=1}^{\infty} \mathrm{J}_n(m)\cos[(\omega_0 + n\Omega)t + \psi_0 + \Phi_n]\}. \quad (11)$$

In the aforementioned ratio (11) the first three components are useful signal, and three subtrahends are amplitude-modulated hindrance, which have internal origin. Because of their presence the spectral composition of desired signal (9) is distorted, by the appearance of the components at the carrier frequency ω_0 and combination frequencies $\omega_0 \mp p\nu_1$ and $\omega_0 \mp n\Omega \mp p\nu_1$. The components at the indicated frequencies subtracted energy from desired signal, that is excites the antenna both in acceptance mode, and transmission mode, reducing its capacity power. Elimination this of complex embedded in the signal nois of parametric origin, is principally impossible.

If the modulating signal is multi-frequency, then ratio (11) accordingly will increase the number of combinational components which contain modulation frequency Ω_i and its harmonics $n\Omega_i$.

Conclusions. The analysis has discovered the characteristic features of amplitude-frequency distortion of AM signals and signals with angular modulation, that arises in the antenna devices the helicopter during rotation its metal main screw. Parametric distortions of the spectra of signals, that have been tested, have signs of amplitude modulated oscillations. In the spectra of signals are arisen undesired components on combination frequencies, the value of which, ceteris paribus, depends on the number of blade on main screw helicopter and speed of its rotation. At the output antenna device, which thus acquires the properties of parametric sistem, the level of the carrier frequency of useful signal is decreased. The distortion does not depend on origin antenna to the radio receiver or transmitting tract. Therefore, in both cases, normalized characteristic directional of antenna placed on metal body of helicopter necessary to reduce at least in 0,363, which corresponds theoretically substantiated weakening signal capacity on 9 dB. Is not taking into account additional attenuation, which is determined by the energy losses by undesired radiation on combinational components the spectrum, which arise as a result of parametric conversion the useful signal and may reach 3 dB, but given the previously mentioned the total losses in 12 dB.

The discovered peculiarities of distortion of frequency components of the signal can be considered as characteristics for radio signals of any other classes.

References

1. *Prigoda B. A. Kokun'ko B. S.* 1979. Antennas aerial vehicles. Moscow, Voenizdat. – 160 p. (in Russian).
2. *Lavrov A. S. Reznikov G. B.* 1974. Antenna-feeder devices. Manual for high schools. Moscow, Sov. radio, – 368 p. (in Russian).
3. *Barabanov Ju. M., Ivanov V. O., Tsernjavsri I. I., Morgun O. A.* 2007. Field flagpole antenna that mounts on the body of the aircraft. Electronics and Control Systems. No.3 (13). P. 88–95. (in Ukrainian).
4. *Tomasi U.* 2007. Electronic communication systems. Moscow, Tekhnosfera. 1360 p. (in Russian).
5. *Denisenko A. N.* 2005. Signals. The theoretical radiotechnics: Reference supplies. Moscow, Gorjachaja linija, Telecom. 704 p. (in Russian).

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Спотворення спектрів радіосигналів параметричною системою «штатна антена–фюзеляж вертольоту»

Встановлено що, діаграма спрямованості системи «штатна антена – фюзеляж вертольоту» стає функцією часу через наявність металевого несучого гвинта, який під час обертання періодично змінює геометричну форму корпуса літального апарату. При цьому радіосигнал, який приймається або випромінюється антеною системою вертольота, піддається небажаним параметричним перетворенням. Запропоновано математичну модель параметричної перетворювальної системи на основі якої досліджуються спектральні складові спотворених сигналів з амплітудною та кутовою модуляцією. Отримані результати аналізуються та узагальнюються.

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Искажения спектров радиосигналов параметрической системой «штатная антенна–фюзеляж вертолета»

Установленно что, диаграмма направленности системы «штатная антенна – фюзеляж вертолета» оказывается функцией времени из-за наличия металлического несущего винта, который при вращении периодически изменяет геометрическую форму корпуса летательного аппарата. При этом радиосигнал, который принимается или излучается антенной системой вертолета, подвергается нежелательным параметрическим преобразованиям. Предложена математическая модель параметрической преобразующей системы на основе которой исследуются спектральные составы искаженных сигналов с амплитудной и угловой модуляцией. Полученные результаты анализируются и обобщаются.