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DIFFRACTION OF MODULATED ELECTROMAGNETIC IMPULSES ON PERIODICAL GRATING

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The problem of diffraction of amplitude-modulated impulses with linear frequency modulation on the planar periodical grating consisting of infinitely thin and ideally conducting strips has been considered. The ability to provide the group impulse delay without distorting of their forms and changing their duration has been shown. Dependencies of group delay on grating parameters and the velocity of frequency change in the field of long waves have been given.

Constructing and elaborated making of functional devices and devices of the radar-tracking systems based on using of peculiarities of interaction of the composite electromagnetic impulses with different hindrances, including periodic shields, remains an essential problem of mm and sub-mm waves techniques. With their help the optimum filters providing the compression and the delay of signals dividers, transcribers of the velocity of the frequency sweeping can be constructed.

Expansion of initial frequency band, in view of modulated signal of presence additional parameter (frequency deviation) leads to the occurrence of idiosyncrasies of distribution and interaction with the periodic shields possessing different continuous properties.

Diffraction of amplitude-modulated (AM) electromagnetic impulses with the Gaussian enveloping and linear frequency modulation on the strip periodic grating, consisting of infinitely thin and perfectly conductive strips are investigated.

Initial and scattered fields satisfy the homogeneous Maxwell equations, the conditions of radiation, boundary conditions on the surface of periodic structure as

$$U^{(0)}(0,t) = \tilde{\Phi}(t), \tag{1}$$

$$\frac{\partial}{\partial z} U^{(0)}(z,t) = \frac{1}{c}\frac{d}{dt}\tilde{\Phi}(t) \equiv \tilde{\Phi}_1(t),$$

where

$$\tilde{\Phi}(t) = \exp\left\{-\frac{(t-t_0)^2}{2T_0^2}\right\} e^{-i\psi_0(t)},$$

$$\psi_0(t) = \omega_0(t-t_0) + \frac{1}{2}\beta_0(t-t_0)^2.$$

Here β_0 is a velocity of a frequency sweeping, ω_0 is a carrier frequency of the signal, $U(z,t)$ stands for the E_x or H_x-components of the electrical or magnetic field accordingly.

The solution to the wave equation is obtained as an expansion in Fourier integral on frequencies

$$U^{(j)}(y,z,t) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} F(\omega)\varphi^{(j)}(\omega,y,z)e^{-i\omega t}d\omega, \tag{2}$$

where j is the number of the domains to which the solution concerns; $F(\omega)$ is a spectral function of the initial field; $\varphi^{(j)}(\omega,y,z)$ are the functions, which provide realization of the above-stated requirements.

Proceeding from periodicity of considered hindrance along the axis Oy, we shall present the spectral function $\varphi^{(j)}(\omega,y,z)$ for each domain as a Fourier-series expansion. Unknown complex decomposition values will be determined thus from the solution of boundary problem for the plane simple harmonic wave normally incident on the strip grating, with the fixed frequency ω and amplitude $F(\omega)$. The scattered field is determined via its integral representation. Amplitude and phase characteristics of scattered field will depend on properties of spectral function of initial field $F(\omega)$ and the kind of transfer functions for the grating which are evaluated by a strict mathematical method for solution of boundary problems of diffraction.

For the case when the parameters of initial impulse satisfy the requirement of quasi monochromaticity $\Delta\omega \ll \omega_0$, in the paper [1] the analytical expressions for the scattered fields, allowing generalization on solving of diffraction for AM and LFM fields on some class of periodic structures, are obtained.

It is determined that in case of the frequency modulation of an initial signal owing to expansion of the frequency band occupied in initial impulse, and the account of the aspect of continuous curves of the module and phase of transfer functions for grating among the parameters describing the scattered field, occur additional ones (a phase and batch delay, shift of a carrier frequency). Such performances as spades amplitude, efficient duration, a velocity of the frequency sweeping, additional phase attack have more composite dependence on parameters of periodic structure.

Let's analyze the properties of zero harmonics of scattered field. Analytical expression for scattered field has in this case the form

$$U_0^{(i)}(y,z,t) = Q_0^{(j)} \exp\left\{-\frac{t - t_0 - z/c - \Delta t_0^{(j)}}{2\tilde{T}_0^{(j)2}}\right\} e^{-i\psi_0^{(j)}}, \quad (3)$$

and in the case when the dependence of amplitude and phase of transmission coefficients of the grating on frequency is practically linear, expressions for performances of scattered field look like

$$Q_0^{(j)} = \left|C_0^{(j)}(\omega)\right|; \quad (4)$$

$$\tilde{T}_0^{(j)} \approx T_0; \quad (5)$$

$$\psi_0^{(j)} \approx \omega_0\left(t - t_0 \pm z/c - \Delta\tilde{t}_0^{(j)}\right) + \frac{1}{2}\beta_0\left(t - t_0 \pm z/c - \Delta\tilde{t}_0^{(j)}\right)^2 + \tilde{\delta}_0^{(j)}; \quad (6)$$

$$\Delta\tilde{\omega}_0^{(j)} = 0; \quad \tilde{\beta}_0^{(j)} \approx \beta_0; \quad (7)$$

$$\tilde{\delta}_0^{(j)} = -\frac{1}{2}\operatorname{arctg}\left(\beta_0 T_0^2\right) + \omega_0\varphi_0'(\omega_0) - \varphi_0(\omega_0) - \frac{1}{2}\alpha_2^2\beta_0; \quad (8)$$

$$\Delta\tilde{t}_0^{(j)} \approx \varphi_0'(\omega_0) + \alpha_2\beta_0 T_0^2. \quad (9)$$

From the expressions (3)–(9) it follows, that as compared to incident impulse the zero harmonics of scattered field has a series of differences. At first, the smaller spades amplitude stipulated by factor $\left|C_0^{(j)}(\omega_0)\right|$, representing the module of coefficient of transfer function of a strip diffraction grating. And we shall mark, that parameters of zero harmonics will differ for domains above the grating $(j = 1)$ and under grating $(j = 2)$ owing to the available connection between coefficients $C_0^{(j)}(\omega_0)$

$$1 + C_0^{(1)}(\omega_0) = C_0^{(2)}(\omega_0) \text{ – for E-polarization,}$$

$$1 - C_0^{(1)}(\omega_0) = -C_0^{(2)}(\omega_0) \text{ – for H-polarization.}$$

Secondly, the zero harmonics have additional phase attack and the group delay, the phases of transfer function of the grating stipulated by linear dependence on frequency in the frequency band occupied by the initial impulse and presence of the linear modulation of frequency.

Thirdly, efficient duration, bearing frequency and the frequency deviation of zero harmonics, practically coincides with the corresponding magnitudes of initial impulse.

Thus, selection of parameters of a diffraction grating and initial impulse makes it is possible to realize group delay of LFM of impulses without distortion of its shape and modification of efficient duration.

Let's consider for example expression for a group delay of zero spatial harmonic for E-polarization. For the long wavelength case $\left(\kappa_0 \equiv \frac{\omega_0 \ell}{2\pi c} << l;\ \ell\right.$ – the grating constant) from known dependences of transmission coefficients on dimensionless frequency κ $\left(u = \cos\frac{\pi d}{\ell};\ d\right.$ is a breadth of a slot of the grating) it is obtained [2]:

$$\begin{aligned} \left|C_0{}^{(1)}(\kappa_0)\right| &= \left(1 + \kappa_0^2 \ln^2\frac{1+u}{2}\right)^{-1/2}, \\ \arg C_0^{(1)}(\kappa_0) &= -\operatorname{arctg}\left(\kappa_0 \ln\frac{1+u}{2}\right), \\ \arg C_0^{(2)}(\kappa_0) &= \operatorname{arctg}\left(\frac{1}{2\kappa_0 \ln\frac{1+u}{2}}\right). \end{aligned} \quad (10)$$

Relations (10) allow to determine immediately

$$\Delta t_0^{(1)} = \frac{l}{2\pi c}\frac{\ln\frac{1+u}{2}}{1 + \kappa_0^2\ln^2\frac{1+u}{2}} \times \left(1 + \kappa_0\ln\frac{1+u}{2}\beta_0 T_0^2\right), \quad (11)$$

$$\Delta t_0^{(2)} = -\frac{l}{2\pi c}\frac{\ln\frac{1+u}{2}}{1 + \kappa_0^2\ln^2\frac{1+u}{2}} \times \left[1 - \left(\kappa_0\ln\frac{1+u}{2}\right)^{-1}\beta_0 T_0^2\right].$$

Apparently, that the group delay has major magnitude for past impulse; depends on the phase and fill factor of grating, and also from the primal pulse duration, its carrier frequency.

In Fig. 1 the graphic dependences of the relative group delay $\left(\frac{\Delta t_0}{T_0}\right)$ on the parameter of grating filling d/ℓ for the case AM ($\beta = 0$, a dotted line) and LFM impulse ($\beta = 0.2$, solid curves), calculated with the formulas (11) are presented. One can see that with increasing of breadth of the slot in the field of admissible structure parameters, defined by the inequality $\left|\kappa_0 \ln\frac{1+u}{2}\right| \ll 1$, the group delay increases, reaching at $d/\ell = 0.7$ the maximum values ($\frac{\Delta t}{T_0} \sim 2\ldots4\ \%$).

The broadening of the frequency band occupied of the initial signal by the frequency modulation or the decreasing of initial duration leads to the increasing of group delay. So at the modulation of the initial signal with the frequency deviation $\frac{\omega_\partial}{\omega_0} \sim 1\ \%$ ($\beta_0 = 0.2$) at $T_0 = 0.05$ ns the group delay increases on 0.5 %, and at $T_0 = 0.03$ ns on 1 % as compared to AM signal. Graphics in Fig. 2 illustrate the dependence of the relative group delay on parameter $\beta = \omega_\partial T_0$ for reflected (solid curves) and transmitted (dotted line) fields.

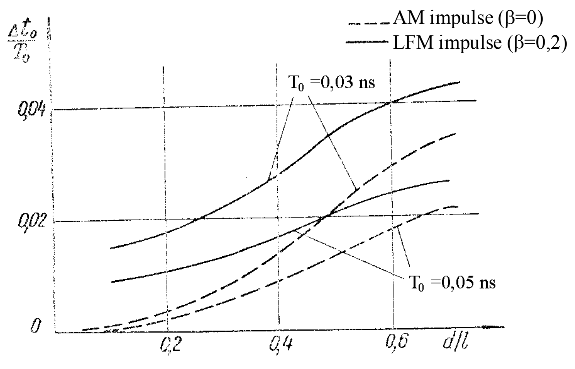

Fig. 1.

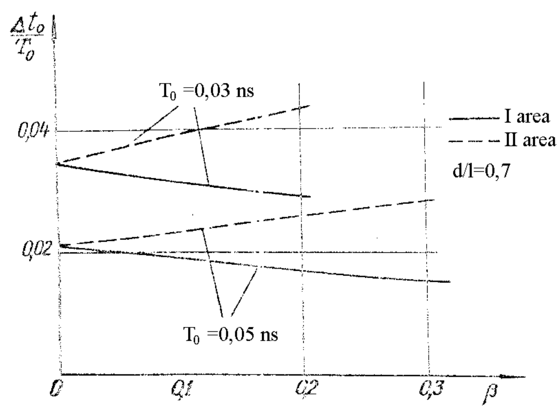

Fig. 2

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ДИФРАКЦИЯ МОДУЛИРОВАННЫХ ЭЛЕКТРОМАГНИТНЫХ ИМПУЛЬСОВ НА ПЕРИОДИЧЕСКОЙ РЕШЕТКЕ

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Рассмотрена задача дифракции амплитудно-модулированных импульсов с линейной частотной модуляцией на ленточной периодической решетке, состоящей из бесконечно тонких и идеально проводящих лент. Показано, что возможно осуществить групповую задержку сигналов без искажения их формы и изменения длительности. Приведены зависимости групповой задержки от параметров решетки и скорости качания частоты в длинноволновой области.

ДИФРАКЦІЯ МОДУЛЬОВАНИХ ЕЛЕКТРОМАГНІТНИХ ІМПУЛЬСІВ НА ПЕРІОДИЧНИХ ГРАТКАХ

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Розглянуто задачу дифракції амплітудно-модульованих імпульсів з лінійною частотною модуляцією на стрічковій періодичній ґратці, що складається з нескінченно тонких та ідеально провідних стрічок. Показано, що існує можливість створити групову затримку сигналів не змінюючи їх форму та тривалість. Наведено залежності групової затримки від параметрів ґратки та швидкості качання частоти у довгохвильовій області.