FREQUENCY CHARACTERISTICS FEMTOSECOND PULSES. CLASSICAL AND QUANTUM APPROACH

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Abstracts

Enormous value of femtosecond pulses in a modern science and the engineering demands all-round studying of their spectral and time characteristics. Femtosecond pulses represent a special kind of electromagnetic pulse signals, and time and spectral description is being under doubts in known references. In this work results of calculations of supershort radio pulses are presented with number of the periods from one to ten. This calculations have universal sense for any frequencies of harmonious oscillations.

I. INTRODUTION

A major way of laser technology development is creation shorter optical pulses, because they can explore high speed processes, taking place in light reaction with substance, the chemical and photochemical reactions, in plasma physics (Fundamental Research), to create accurate time and length measurement systems. Femtosecond pulses are used for creation of electromagnetic fields with intensity above subatomic. Intensive researches on optical computers creation are conducted. Application femtosecond pulses with GHz frequency will provide a sharp increase of volume and speed of computer memory. Femtosecond lasers become also a basis of new technology of optical communication which can pass terabytes of information per second.

The history of creation of short light impulses begins in 1962 (two years after construction of the first laser) when nanosecond pulses have been received. Following step became creation pulses shorter in hundreds and in thousand — first in tens, and then and in units of picoseconds. Creation picosecond lasers (they have appeared in 1965) became possible due to application of a so-called mode-synchronization method.

However for research of many high speed occurring processes even shorter pulses are required entering the femtosecond range. Breaking into femtosecond range for the first time was carried out by the continuous action laser on dye when it was possible to receive pulses duration 0,1 ps, or 100 fs.

The further development of femtosecond lasers is connected with use of nonlinear properties of material which are caused by powerful laser radiation. By 1990 the new way of passive mode-synchronization without a clarified absorber - self-synchronization has been realized. For the first time nonlinear properties of material were used for reception of supershort pulses in the laser of continuous action on the titan-sapphire. These third generation lasers can generate pulses duration from tens femtosecond up to 5-6 fs, such limiting values conform to two-three and to even one period of light oscillation [1].

All above told, makes actual frequency and time characteristics femtosecond pulses researches.

II. THE SUBJECT

Today classical methods where femtosecond pulse is considered as a form of an analytical signal are applied to the description of spectral-time characteristics of femtosecond pulses. In an analytical signal the information content is concluded in its complex envelope curve. In particular methods which are based on correlation procedures are used. In them power spectra of signals are Fourier transformations of their autocorrelation functions.

Autocorrelation function of an analytical signal is considered as the high-frequency function, envelope curve of which is equal to autocorrelation function of complex envelope curve. But concept of an analytical signal and its complex envelope curve are applied only to narrow-band signals. But femtosecond pulses are not narrow-band signals [2].

Experimental measurement of duration femtosecond pulses is challenging because of their small duration. Traditional methods of time measurements with use of photoelectronic devices together with the most high-speed oscillographs provide temporary resolving which is much lower to duration femtosecond pulses. Indirect methods for a finding of duration of ultrashort pulses are known – by Fourier inversion (spectra have been experimentally measured). But they have not got any further progress. All this shows that theoretical and experimental researches of femtosecond pulses demands further researches. Therefore the objective of the given work is theoretical research of spectra of the ultrashort pulses containing small number of the periods, beginning from one period.

III. THE PROCEDURE AND RESULTS OF CALCULATIONS OF PEAK SPECTRA ULTRASHORT PULSES

In this work results of calculations of supershort radio pulses are presented with number of the periods from one to ten. This calculations have universal sense for any frequencies of harmonious oscillations.

The basis of classical consideration of spectral-time characteristics of a signal is the theory of integrals of Fourier in which objective relation between time and frequency characteristics of signals is established.

$$S(\omega) = \int_{-\infty}^{\infty} S(t) \cdot e^{-i\omega t} dt$$

$$S(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} S(\omega) \cdot e^{i\omega t} d\omega$$

Calculations were spent for the sine wave oscillation, one period (2π) per unit of time.

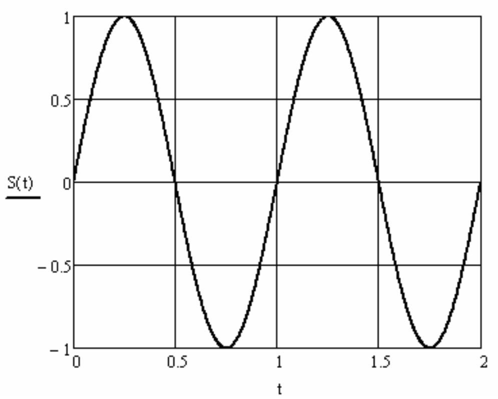

Fig. 1 Harmonious sinusoidal oscillation

In the further by means of mathematical program Mathcad spectra of oscillation (fig. 2, 3) various duration (from one till ten periods) with use of the theory of Fourier integrals have been calculated. For example for one period:

$$S_1(\omega) = \int_{0}^{1} S(t) \cdot e^{-i\omega t} dt$$

Calculations for other spectra were similarly carried out.

The presented calculations of spectra are executed within the limits of the theory of integrals Fourier which is a basis of classical consideration of spectral-time characteristics of a signal. In this theory objective relation between time and frequency characteristics of signals is established. These calculations have shown that spectral distribution of energy of impulses with small number of the periods has significant levels near to zero frequency. The possibility of occurrence of such low-frequency spectral components in a spectrum of optical radiation causes serious doubts. It is necessary to consider, that the first mod is raised by the resonator is in MICROWAVE range, and oscillation with smaller frequencies cannot arise by definition of the resonator. On the basis of Wiener-Paley theorem energy of a single pulse signal is continuously distributed in an infinite strip of frequencies, and its value can become zero only on countable number of values which are radicals of this whole function. However $\omega \to \infty$ has no physical background.

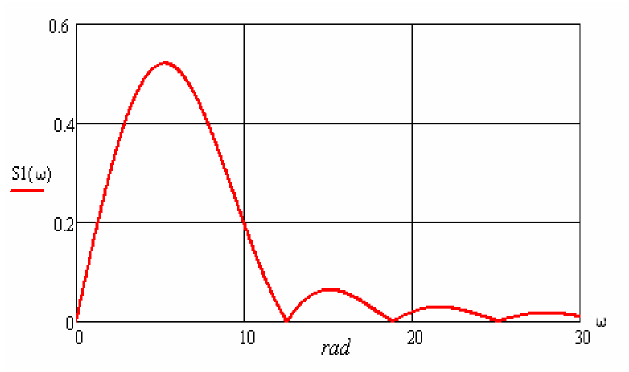

Fig. 2. Spectrum of a 1 period duration pulse

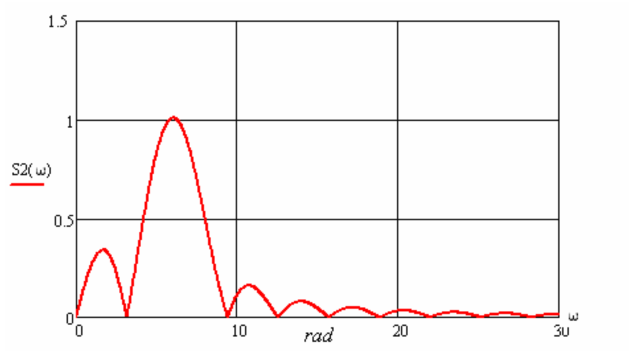

Fig. 3. Spectrum of a 2 period duration impulse

The objective relation between time and frequency characteristics of signals at research femtosecond pulses has been called in a doubt [3, 4], that proves by availability of significant levels of energy near zero frequency, at that femtosecond pulses are formed in optical range. Should be added, that the primary goal of the spectroscopy consists in a photons function distribution establishment on frequencies. Photons are carriers of energy of an electromagnetic field. That’s why the theoretical description of femtosecond pulses demands considering their quantum nature. Elements of the theory of signals in view of their quantum nature are shown in works [5 – 7].

IV. THE QUANTUM DESCRIPTION OF FEMTOSECOND PULSES

Laser radiation is a result of transition of particles in working substance (molecules, atoms, ions) from a condition with greater energy in a condition with smaller energy. The atom can be in various power conditions with energies E1, E2, etc. In the Bor's theory these conditions are stable. Actually a stable condition in which the atom for the lack of external disturbs can be infinitely long is the condition with the least energy. This condition is it's basic. All other conditions are non-stable. The excited atom can stay in these conditions only very short time, about 10^{-8}s after that it spontaneously passes into one of the lowest conditions, thus the atom lets out quantum of light. Frequency of quantum can be measured from the second Bor's postulate. Radiation which is let out at spontaneous transition of atom from one condition to another is spontaneous. At some power levels the atom can stay significantly longer, about 10^{-3} s. Such levels are called metastable.

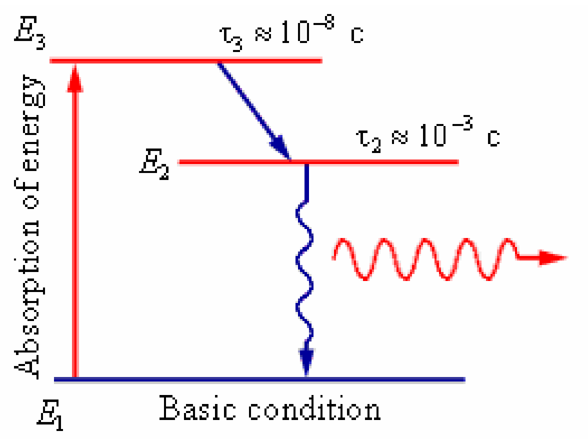

Fig. 4. The three-level scheme of an optical pumping

Atom transition to a higher power condition can occur at resonant photon absorption, which energy is equal to a difference of energies of atom in final and basic conditions. Therefore in spectra of femtosecond pulses, there can be only carriers of energy (photons) with those frequencies for which equal to $h\nu = E_m - E_n$, where ν - frequency of optical radiation , E_m, E_n - power conditions of atom (molecules, ion). Presence of these spectral components, according to the primary goal of spectroscopy, should be considered as a result of spectral measurements.

V. CONCLUSION

The completed calculations within the limits of the classical theory of signals have shown that frequencies near to zero content large part of spectral distribution of pulse energy containing small number of the periods of oscillation. This result isn't coordinated with representation of femtosecond pulse as quantum system, where photons as carriers of energy of electromagnetic field have frequencies in optical range. The given work accent on research of spectral characteristics of oscillations with small number of the periods in the range of low frequencies, in particular in frequencies near zero, however, the classical theory of signals demands presence of carriers of energy on significantly higher frequencies, that is not possible. The question of sense of spectral components was discussed with significantly higher frequencies in works [5 – 7] and not considered here. The general conclusion of this work is the statement that theoretical research in range of femtosecond pulses should consider their quantum nature.

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