APPLICATION OF FEMTOSECOND Ti-Sa LASERS FOR MEASURING OF AMPLITUDE-FREQUENCY CHARACTERISTICS OF WIDE-BAND PHOTODEVICES

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A possibility of an application of the femtosecond Ti-Sa lasers for a measuring of the amplitude-frequency characteristics (AFC) of the wide-band photodevices is considered. The results of the measuring of the AFC in a frequency range 1.5 GHz for a high-speed photodiode S5972 of the firm "Hamamatsu" are presented.

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A progress in a creating of the wide-band photodevices is driven by the needs in such areas as the optical communication systems, the study of the fast processes, a creating of the highly informative systems. In this regard, a great importance has a knowledge of the amplitude-frequency characteristics (AFC) for such the photodevices. A femtosecond Ti-Sa lasers can solve this problem most simply. The presence in the consumer market of the lasers generating the pulses with a duration shorter than 50 fs gives on principle possibility of the study of the ultra-wide band photodevices in a frequency range up to $50{\cdot}10^{12}$ Hz. However, the real use of the femtosecond lasers for this purpose requires of an investigation of some the features associated with the realization of the proposed methodology.

The method is based on the following suppositions. The laser operates in mode-locked longitudinal modes TEM_{00N} (Fig. 1). The net instantaneous intensity at which the photodevice responds in the case of mode-locked with same amplitudes of the electric field E_0 is on the form [1]:

$$I(t) = |E_0|^2 \frac{\sin^2 N\pi\Omega t}{\sin^2 \pi\Omega t}\cos\omega_0 t, \qquad (1)$$

where ω_0 – average frequency, N – number of generated longitudinal modes, Ω – pulse repetition frequency equal to the intermode interval:

$$\Omega=\Delta f = c/2L, \qquad (2)$$

where c – speed of a light in vacuo, L – length of the laser cavity.

A mixture of the optical signals frequencies is in the photodevice, this signals can be given off in the output current i(t) of the photodevice by a band-pass filter tuned to the beat signals with radio frequencies Δf, $2\Delta f$, $3\Delta f$, ..., $(N-1)\Delta f$, the instantaneous values which are on the form:

$$i(t) = D\{\sum_{i=1}^{N-1} E_iE_{i+1}\cos\Delta f\, t + \sum_{i=1}^{N-2} E_iE_{i+2}\cos 2\Delta f\, t + \sum_{i=1}^{N-3} E_iE_{i+3}\cos 3\Delta f\, t + \ldots + E_1E_N\cos(N-1)\Delta f\, t\}, \qquad (3)$$

where E_i – the amplitude of the electric field i-th mode for the case when the amplitudes of the of the electric fields of the different modes are different, D – the transformation factor of the photodevice.

The method of the measuring of AFC of the wide-band photodevices is based on the use of the beat signals at the difference frequencies of the modes TEM_{00N} registrated at photodevice within its bandwidth and then measured by a spectrum analyzer.

It should be noted that the positive fact of the using femtosecond Ti-Sa lasers to measure the AFC of the wide-band photodevices that under the condition of the full mode-locking power output fluctuations Ti-Sa lasers do not exceed 1…2% [2] under an extremely low value of the frequency intermode interval Δf fluctuations [3].

The specificity of the application of the Ti-Sa lasers to measure the AFC of the wide-band photodevices is connected with either the fact that the emission spectrum of this laser has a Gaussian shape or the form $sech^2$. It is known that it is necessary to give at the input of the investigated photodevice the signals of the equal amplitudes within the investigated frequency range for the standard method for measuring AFC of any receivers, include photodevices.

We consider inserting a limit on the measurement AFC of the wide-band photodevices the shape envelope of the emission spectrum Ti-Sa laser.

Let Ti-Sa laser generates pulses whose shape is $sech^2$ and the emission spectral width at half of the level is 41 nm, width corresponds to the frequency range $\Delta F = 18.97{\cdot}10^{12}$ Hz. Calculations made on the basis of the measured spectral characteristics of the laser radiation (Fig. 2) show that the greatest slope of the spectrum envelope amplitude of its spectral components differ by 2% in the frequency range of $200{\cdot}10^9$ Hz.

Therefore, the applying of Ti-Sa laser for measuring AFC of the wide-band photodevices with the error 2% in this frequency range satisfies to the demand of the standard method for determining AFC of the receivers.

Another feature of this method is reducing the number of components in the summary signal of the beats with the increase of the difference frequency. It is clear from the formula (3). For example, the number of the components of the beat signal for the value of the intermode interval Δf = 100 MHz in the frequency within the generation band $\Delta F = 10^{13}$ Hz will be the value 10^5. And the number of the components of the beat signal for the value of the intermode interval Δf = 1000 MHz in that frequency will be nine less than Δf = 100 MHz. This will give the difference of the number of the beat signal at these frequencies on the value of 0.009%. Therefore, the methodical error will be equal to the value 0.009%, when measuring AFC of the photodevice with a bandwidth 1000 MHz.

The calculation show that the methodical error 2% will correspond to the measuring of AFC of the photodevice in the frequency range of about 200 GHz.

Thus, the use of the femtosecond Ti-Sa lasers for the measuring AFC of the wide-band photodevices generates the wide research prospects in an extremely wide range of the frequencies.

The Ti-Sa lasers can be tunable on the frequency in the range of about 50 MHz for a more detailed research of AFC in the frequency range of interest areas. This can be accomplished by the changing of the cavity length L (2).

The practical realization of the method illustrated on the block-scheme in Fig. 1.

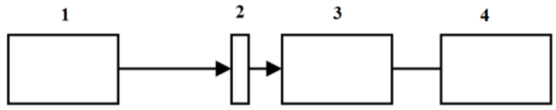

Fig. 1

Ti-Sa laser 1 generated longitudinal modes TEM_{00N}. The linearly polarized laser beam passed through a polarizer 2, which served as an adjustable attenuator, and fell on the investigated wide-band photodevice 3. The intensity of a radiation at the input of the photodevice was controlled and maintained at a certain level. The output signal from the photodevice 3 enters to the input of the spectrum analyzer 4. This analyzer measures amplitudes and frequencies of the beat signals.

The Ti-Sa laser developed at IPENMA NSC KIPT was used in the experiments. It generated the pulses at a wavelength 782 nm spectral width at half that level was $18.97 \cdot 10^{12}$ Hz (41 nm). The fluctuations of the laser output power did not exceed 1.5%. The frequency stability of the intermode frequency interval was no worse than 10^{-5}. Fig. 2 shows the laser spectrum.

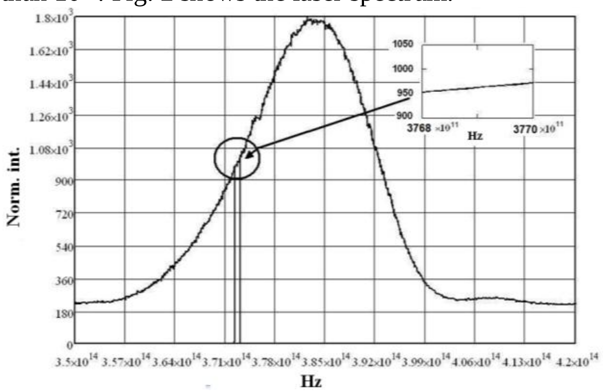

Fig. 2

The high-speed photodiode S5972 firm "Hamamatsu" used as investigated wide-band photodevice. A feeding voltage was 15 V. The measurements were performed at ambient temperature 20°C.

The signals detected at the photodevice output by the spectrum analyzer C4 - 27 with 50-Ohm input.

Fig. 3 shows the results of the combined measuring for the AFC of the photodiode S5972 with taking into account on it the influence of the coaxial cable and connectors.

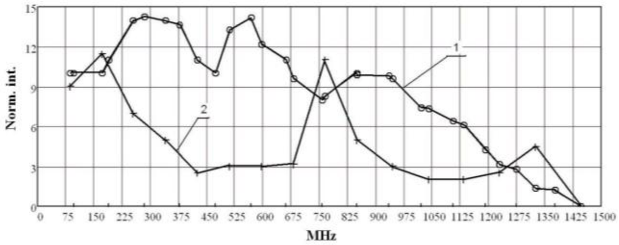

Fig. 3

That combined AFC extends closely to 1.4 GHz. It can be seen from Fig. 3 (see curve 1). Its irregularity is probably caused by the losses and the re-reflections in the coaxial cable and connectors. AFC was measured at frequencies which are multiple to the intermode interval Δf = 85.86 MHz for the resonator length of the Ti-Sa laser 174.7 cm and at the frequencies which are multiple to the intermode interval Δf = 94.5 MHz for the resonator length of the Ti-Sa laser 158.7 cm. The connecting of the photodevice without the concordant coaxial cable to the spectrum analyzer is illustrated in Fig. 3 (see curve 2). The investigated photodevice S5972 was connected to the spectrum analyzer by the short (2 cm) conductors. The uniformity of AFC of the spectrum analyzer in the measurements was controlled by the generator G4-67A.

Thus, the grounding of the possibility of the using of the femtosecond Ti-Sa lasers to measure the AFC of the wide-band photodevices in the frequency band up to 200 GHz with a methodical error not exceeding 2% is presented.

REFERENCES

1. W. Kleen, R. Muller //*Laser*. Berlin (West), Heidelberg, New York; Springer-Verlag, 1969.
2. A. Sting, C. Spielmann, F. Krausz. Generation of 11-fs pulses from a Ti-Sa laser without the use of prisms // *Optics Letters*. 1994, v. 19, №3, p. 204-206.
3. P.G. Krykov. Lazery Ultrakorotkih impulsov // *Kvantovaya elektronika*. 2001, v. 31, №2, p. 95-119 (in Russian).

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ПРИМЕНЕНИЕ ФЕМТОСЕКУНДНЫХ Ti-Sa-ЛАЗЕРОВ ДЛЯ ИЗМЕРЕНИЯ АМПЛИТУДНО-ЧАСТОТНЫХ ХАРАКТЕРИСТИК ШИРОКОПОЛОСНЫХ ФОТОПРИЕМНИКОВ

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Рассмотрена возможность применения фемтосекундных TI-Sa-лазеров для измерения амплитудно-частотных характеристик (АЧХ) широкополосных фотоприемников. Представлены результаты измерения АЧХ в диапазоне 1,5 ГГц для высокоскоростного фотодиода S5972 фирмы “Hamamatsu”.

ЗАСТОСУВАННЯ ФЕМТОСЕКУНДНИХ Ti-Sa-ЛАЗЕРІВ ДЛЯ ВИМІРЮВАННЯ АМПЛІТУДНО-ЧАСТОТНИХ ХАРАКТЕРИСТИК ФОТОПРИЙМАЧІВ З ШИРОКИМ ДІАПАЗОНОМ ПРИЙМАННЯ

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Розглянуто можливість застосування фемтосекундних Ti-Sa-лазерів для вимірювання амплітудно-частотних характеристик (АЧХ) фотоприймачів з широким діапазоном приймання. Наведено результати вимірювання АЧХ у межах 1,5 ГГц для високошвидкісного фотодіода S5972 фірми “Hamamatsu”.