COMPLETE DOPPLER FREQUENCY SHIFT COMPENSATION IN ACOUSTO-OPTIC DEVICES FOR WIDEBAND SIGNAL HOLOGRAPHY

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Abstract

The recording process for a time-integrated Fourier-hologram of a RF signal converted by an acousto-optic modulator (AOM) has been considered. A new complete frequency shift compensation method using an acousto-optic spectrum analyzer scheme in which the Bragg cell located in the reference beam path has been fed by Gaussian-shaped electric signal, has been proposed. The experimental device operating in this mode has been designed, and the experimental results of the RF signals holograms recording and reconstruction obtained due the proposed method application, have been presented. It has also been underlined that satisfactory results can be obtained only in the case if the recording medium insensitive to small spatial frequencies is used.

Keywords: Hologram recording, acousto-optic spectrum analyzers, photothermoplastic recording

1. Introduction.

Nowadays the problem of high-speed data flows and wideband signals recording is of a great importance for the data-processing systems. The solution of this problem can be found in combined application of holographic and acousto-optic methods. However, light processed by acousto-optic device (AOD) changes its frequency due to Doppler effect, and mutual coherence between initial and diffracted light is broken which prevents the hologram recording – Refs. 1,2.

In order to fix this problem we have to compensate this frequency in a reference beam, otherwise the maximum hologram exposure time must be less than a half-period of the most high-frequency component of a recorded radio signal. If a greater exposure time is used, the high-frequency part of the signal spectrum as well as a part of the information, carried by the signal, will be lost.

In order to set up a completely compensated reference, the first way to be offered was the scheme, based on the AOD fed by the square-shaped chirp signals – Refs. 1, 2. But this way is not easy to be technically realized, in addition some oscillations in the recorded pattern still occurred. Another approach to the complete frequency compensation was made using a double counter scanning method in combination with acousto-optic deflector with double diffraction – Refs. 3,4. In this case the beam, illuminating the signal AOD, and reference beam are simultaneously counter scanning, so that the interference pattern, being recorded, is integrated in recording plane during the signal beam scanning time. The scanning light sources, as well as a completely compensated reference source, are generated by acousto-optic deflector. In such a scheme it is possible to record holograms continuously in form of serial Fourier-holograms of signal parts as they enter the AOD, so it solves the problem of interruptions in continuous signals recording. Also, the recorded bandwidth is increased: it is equal to the sum of the scanning sources bandwidths. The main drawback of this scheme is the need in using a complicated chirp-pulse generator with high stability as well as fine adjustment of the device.

Below we offer another way of the complete frequency shift compensation, which eliminates the problems listed above. It is based on the application of the acousto-optic spectrum analyzer scheme, stimulated with Gaussian-shaped RF signals as a reference beam generator

2. Complete frequency shift compensation principle using gaussian signal spectrum.

A basic scheme for recording a time-integrated Fourier-hologram in acousto-optic recorder with complete frequency shift compensation by gaussian-shaped radio signals is shown in fig.1.

The scheme includes two similar acousto-optic modulators (AOM): AOM 1 for the signal channel and AOM 2 for the reference one; the Fourier-lens F, distanced from the AOMs by its focal length F and a photosensitive medium, located at the opposite (spectral) plane of the lens F.

The AOM 1 with processing time τ and ultrasonic velocity v is fed by RF signal $S_T(t)$ with duration T_S. Simultaneously, the AOM 2 with the same processing time and ultrasonic velocity, spaced from origin O by distance p is fed by a Gaussian-shaped RF signal (GRS) $R_T(t)$. Both AOM apertures are totally illuminated by laser beams. Lens F performs a joint Fourier-transformation of both fields in the input plane OX.

As both AOM are similar, so the light diffracted by the certain signal frequency is deflected to the same angle after each AOM. Hence, coincidence of the stripes one of which representing signal spectrum, and the other – reference spectrum, allows to create steady interference pattern in each point of the overlapped light intensity distributions.

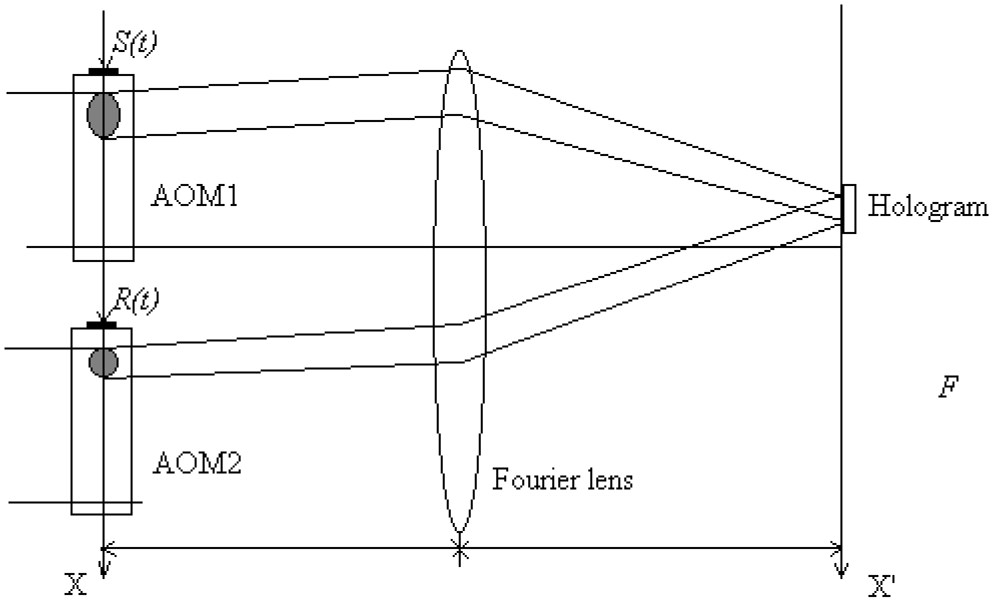

Fig.1 The principle of recording a Fourier-hologram of a signal $S_T(t)$, exciting AOM 1, with the help of the reference signal $R_T(t)$, feeding AOM 2.

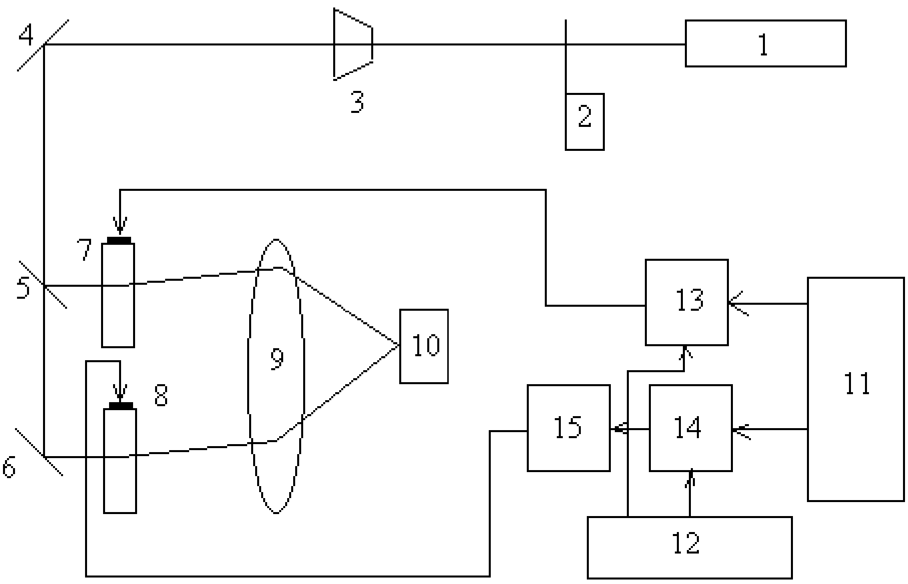

Fig.2. The time integrating holographic recorder with complete frequency shift compensation configuration. 1 – laser, 2 – shutter, 3 – beam expander, 4,6 – flat mirrors, 5 – beam splitter, 7 – signal channel AOM, 8 – reference channel AOM, 9 – spherical Fourier lens, 10 – phototermoplastic recording device, 11 – square-shaped pulse generator, 12 – carrier frequency generator, 13 – signal channel modulator, 14 – low-pass filter, 15 – reference channel modulator.

3. <u>Experimental performance of the proposed compensation principle.</u>

The main purposes of the experimental investigations were

1. to obtain a steady interference pattern at the recording plane;
2. to record a Fourier-hologram of square-shaped RF signals.

The experimental recordings were made with the optical setup shown on fig.2.

The He-Ne laser 1 effectively delivers 2mW at a wavelength of 0,63 μm in the TEM_{00} mode. After passing a shutter 2 , which is used as an exposure time controller, and a beam expander 3 the laser beam is divided by a beam splitter 5 into two paths:

- lower path – reference – forming the completely compensated reference beam;
- upper path – signal – forming the Fourier-image of the recorded signal in the recording plane.

Both paths include the AOM and a common spherical Fourier lens 9. In the back focal plane of this lens the interference pattern between the signal and the reference waves forms the time integrated Fourier-hologram of the signal, which is registered by a photosensitive medium.

The recorded signals had duration of 0,3 and 0,2μs. These pulses were formed by G5-56 square-shaped pulse generator 11 and after that they modulated the carrier frequency in modulator 13. The carrier frequency value was chosen equal to the central AOM frequency – 75MGz. The GRS had duration of 70ns and were formed from the square-shaped pulses by means of a low-pass filter.

The electric-to-ultrasonic transformation was made by the TeO_2 AOM, operating in the Bragg mode with bandwidth of 30MGz, acousto-optic interaction length of 2mm, sound velocity 620m/s and aperture time of 14μs. with the optical configuration considered the hologram dimensions were 3x0,8mm^2 with 265mm^{-1} spatial carrier frequency and total exposure energy density of 10^{-6}J/mm^2.

The phototermoplastic carrier with threshold sensitivity of about 10^{-7}J/mm^2 and optimal spatial frequency equal to the hologram spatial carrier frequency was used as a recording media. Such a media was chosen because of its following advantages: phototermoplastic makes possible high-quality phase holograms recording and is totally non-sensitive to low spatial frequencies, so the first two terms in eq. (3) can be neglected. Because of the low-power laser and losses in optical elements the total exposure was inadequate to record a high-quality hologram during the AOM aperture time, so we have to use the hologram registration with repeated signal and GRS pulses generation.

The CCD-device with pixel length of 0,026mm and lens with focal length of 1m were used for the hologram restoring. The results of the experiments are shown on fig.3.

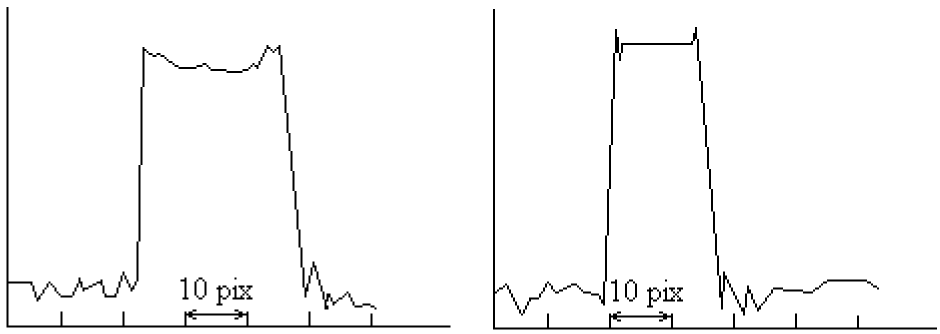

Fig.3. The experimental results on restoring time-integrated Fourier hologram of RF signals with duration 0,3μs (left) and 0,2μs (right).

4. <u>Discussion.</u>

Let us consider the results of the signals hologram recording. For the 0,3μs signal the distortions in the restored image are rather small: a hollow in the restored pulse center and oscillations near the pulse fronts. The main reason for the hollow-distortion is the phototermoplastic overexposure in the low-frequency region due to the small linear registration region and great difference between main and ±1, ±2 signal spectrum orders amplitudes. This means that the registration media acts as a low-pass filter.

The oscillations are associated with the restrictions on the registration frequency bandwidth, imposed by the GRS and acousto-optic interaction in Bragg mode (eq. (9)-(11)). According to eq.(11) the theoretical registration bandwidth for the 70ns GRS and AOM with central frequency, equal to 75MGz, and $Q = 6.6$ comprises approximately 20MGz. The restored pulse bandwidth can be estimated by the following expression

$$2\,\Delta f = 0.7\, v\, K_M / x_F \qquad (1)$$

where x_F is the pulse front length (between 0,1 and 0,9 max), $K_M = 3{,}67$ is the restored image magnification. According to eq.(11) the restored pulse bandwidth is approximately 18MGz; the difference between theoretical and experimental results is connected with the imperfect measurement of x_F – it was about 4 pixels of the CCD-device used for the hologram restoring.

As to the 0,2μs signal, the hollow-distortions in this case are negligible due to the absence of overexposure, but the front distortions are greater than in the 0,3μs signal case. It is associated with the fact that 20MGz bandwidth is enough to register only main and ±1 signal spectrum orders. The experimental recording bandwidth is also about 18MGz, i.e. it correlates with the 0,3μs signal image.

However, despite the restored signal distortions, the image dimensions are consistent with the initial signals. For example, from fig.3 the image width is 0,68mm, that coincides with the theoretical value: for the 0,3μs signal $\tau v K_M$ = 0.68mm. As for the 0,2μs signal the difference between the theoretical and experimental lengths is approximately 0,02mm (0,46 and 0,48mm).

5. Conclusions.

Our studies have been shown that the holograms of the wideband electric signals can be effectively recorded and reconstructed if an acousto-optic signal input into a holographic system had performed. The mutual coherence of the reference and object waves can be provided by acousto-optic processing of the reference wave using a reference electric signal with Gaussian form.

The basic deficiency of such performance – big value of the light intensity constant component – can be successfully avoided by use of the photothermoplastic recording media which are insensitive to zero spatial frequencies. However, the problem of background influence on the resulting signal-to-noise ratio is not yet solved, and it will be the subject of the further studies.

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