Acousto-optic communication line

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Method for selective transfer of an audio signal, developed on the basis of features of Bragg acousto-optic interaction, is described. By that the audio signal modulates the high-frequency acoustic oscillation by frequency. This is accompanied by a change in the direction of propagation of the declined light. Located in a certain way the screen provides a corresponding change of the power of the light, incident on the surface of the photodetector.

Basic advantage of optical communication system is their high spatial selectivity. It is especially necessary at the high level of the intensity of electromagnetic interferences. Such problem arises, for example, at railway stations during the organization of the centralized management of various services.

The modulation of the light is provided by one of the means of optoelectronics. One of important means of optoelectronics is the acousto-optic processors [1]. The principle of operating of acousto-optic processors is based on an acousto-optic effect. Acousto-optic modulator (AOM) is a device for realization of acousto-optic effect.

The AOM is the basic component of all acousto-optic processors. AOM consists of a photo-elastic medium (PEM), to one edge of which an electro-acoustic transducer (EAT), to other - acoustic absorber (AA) are attached.

There are two interaction modes: the Raman-Nath and Bragg modes. In the Raman-Nath mode the laser beam is incident roughly normal to the acoustic wave and several symmetrical diffraction orders with intensity given by Bessel functions appear. Raman-Nath diffraction is observed at relatively low acoustic frequencies, typically less than 100 MHz.

In the Bragg mode the laser beam is incident under the Bragg angle θ_B to the acoustic wave:

$$\theta_B = \arcsin(0.5\lambda f_0/\upsilon), \qquad (1)$$

where λ is the wavelength of the incident light wave (in a vacuum); f_0 and υ are respectively the frequency and the velocity of the acoustic wave in PEM. Usually, the f_0 is chosen equal to the AOM center frequency.

Bragg diffraction occurs at higher acoustic frequencies, usually exceeding 100 MHz. The observed diffraction pattern generally consists of two light beams; these are the zeroth and the first orders.

There is an intermediate area from 10 MHz to 100 MHz, where both of Raman-Nath and Bragg modes are possible.

Parameters of the optical wave may be modulated by varying the parameters of the acoustic wave, including the amplitude, phase, frequency and polarization. The acousto-optic interaction also makes it possible to modulate the optical beam by both time and spatial.

The purpose of the present work is to use the spatial modulation of optical beam obtained in acousto-optic processors for selective transfer of a sound.

The scheme of the acousto-optic system for transmission of an audio signal is shown in Fig. 1. The acousto-optic system of a sound transmission works as follows. The laser beam falls into aperture of AOM under Bragg angle θ_B (Fig. 1). As a result of acousto-optic interaction in PEM diffraction order appears, propagated under diffraction angle θ_d. The diffracted light beam is incident on photosensitivity surface of photodetector (PD) via screen. Audio signal from microphone apply to the input of the voltage controlled oscillator (VCO). The frequency of VCO is modulated respectively by audio signal from microphone. The variation of frequency of AOM input signal changes the direction of propagation of the diffracted order on an axis x. As a result, the power of the light beam falling on a surface of the PD is changing because of screen.
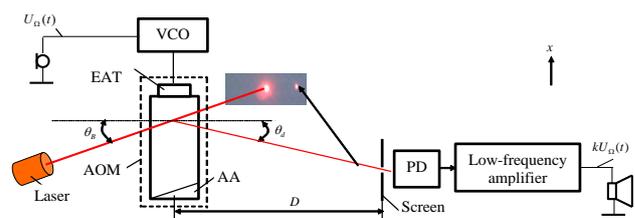

Fig. 1.

Let's notice, that in the absence of an audio signal from microphone, i.e. $U_\Omega(t) = 0$, the diffraction angle θ_{d0} equals to Bragg angle: $\theta_{d0} = \theta_B$. In such conditions only half of the diffracted light beam power is falling on surface of PD (Fig. 2). On the surface of the detector right (Fig. 2a) or left (Fig. 2b) half of the diffracted light beam falls. In the case of Fig. 2a an increase in frequency is accompanied by an increase of the light power incident on the surface of the detector, and in the case of Fig. 2b – it decreases.
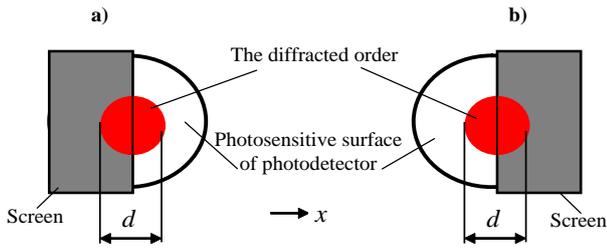

Fig. 2.

At relatively small changes of frequency $\pm \Delta f$ the diffraction angle will change according to the following equation [2]:

$$\Delta\theta_d = 0{,}5\,\lambda\,\Delta f / \upsilon. \tag{2}$$

In such conditions the diffracted light beam will be shifted on a distance

$$x \approx D \cdot \Delta\theta_d \approx 0{,}5 \cdot \Delta f \cdot D\lambda / \upsilon, \tag{3}$$

where D is the distance between AOM and screen.

Average power of frequency modulated oscillations is invariable and at any moment is equal to average power of not modulated carrier. Therefore power of diffracted light beam remains invariable and depending on deviation of elastic waves frequency only the diffraction angle changes. The changing of the diffraction angle can be found from following equation

$$\Delta\theta_d = \theta_d - \theta_{do}. \tag{4}$$

As we noted above, the changing of the diffraction angle causes the changing of the power of light beam falling on surface of the PD, because of screen.

Radiations of majority of lasers have a circular aperture. It is possible to show, that the cross-section area of the light beam $s(x)$ falling on a photosensitive surface of the PD, which is shown in Fig. 2a may be given by following equation:

$$s_r(x) = \int_x^{d/2} \sqrt{d^2 - 4x^2}\,dx, \text{ at}$$
$$-0{,}5d \le x \le 0{,}5d, \tag{5}$$

where d is the diameter of the diffracted beam.

In the case of Fig. 2b the cross-section area of the light beam $s(x)$ falling on a photosensitive surface of the PD, may be given by following equation:

$$s_l(x) = 0{,}25 \cdot \pi d^2 - \int_x^{d/2} \sqrt{d^2 - 4x^2}\,dx, \text{ at}$$
$$-0{,}5d \le x \le 0{,}5d, \tag{6}$$

The corresponding graphs are constructed for right $s_r(x)$ and left $s_l(x)$ offset (Fig. 3) according to the formulas (5) and (6). The diameter of the deflected light beam is equal to $d = 3\,mm$. Accordingly, the cross-section area of the deflected light beam is equal to 7,069 mm^2.
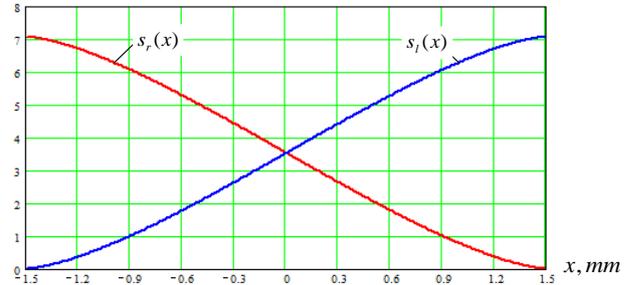

Fig. 3.

Let's accept that the energy distribution in cross-section of a laser beam is uniform. In the case of Fig. 2a we obtain the following dependence of power $p_r(x)$ of a light beam falling on photosensitive surface of the PD:

$$p_r(x) = \frac{4P}{\pi d^2} s_r(x), \text{ at } -0{,}5d \le x \le 0{,}5d, \tag{7}$$

where P is the power of the diffracted beam.

In the case of Fig. 2b the power of the light beam falling on photosensitive surface of the PD $p_l(x)$ will be determined by next dependence:

$$p_l(x) = \frac{4P}{\pi d^2} s_l(x), \text{ at } -0{,}5d \le x \le 0{,}5d. \tag{8}$$

The schedule of function $p(x)$ (Fig. 4) is constructed for following characteristic values of parameters of laser radiation: $d = 3\,mm$, $P = 1\,mVt$. Let's notice, that in the absence of modulating process, i.e. at $U_\Omega(t) = 0$, $\Delta f = 0$ and respectively $x = 0$.
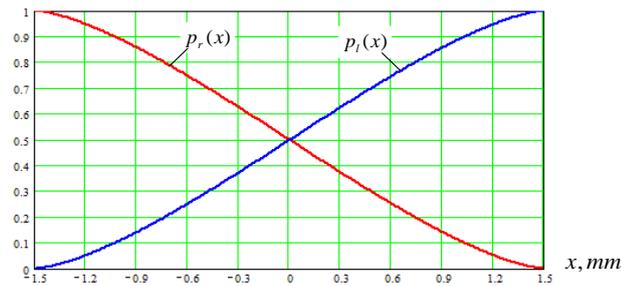
Fig. 4.

From Fig. 4 follows, that at displacement to $\pm0,75\,mm$ from average value the law of change of power falling on photosensitive surface of the PD is close to the linear.

Authors had experimentally checked up a principle of construction of acousto-optic system of the audio signal transmission, made under the scheme, shown on Fig. 5.
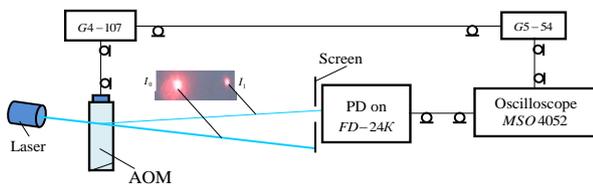

Fig. 5. The experimental setup

PEM was made of a glass $TF-7$ ($\upsilon=3,5\,кm/s$) and EAT – of a $LiNbO_3$. Central frequency of AOM is equal to 80 MHz. As a source of coherent light a semiconductor laser was used. PD was set up on $FD-24K$ (Fig. 6).

Generator $G4-107$ was used as a VCO. Generator $G5-54$ was used as an audio signal source. Deflected light beam incident on surface of $FD-24K$ via screen slot.
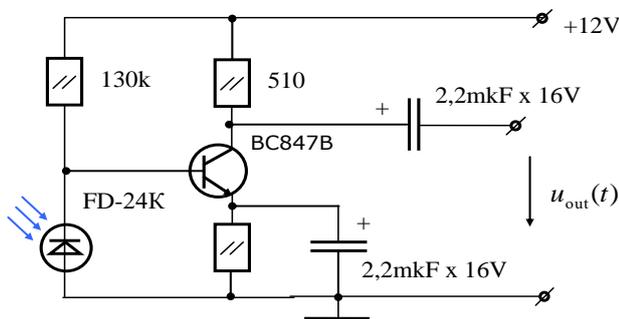

Fig. 6. Schematic diagram of PD

The measurements were performed in the following sequences. At the beginning generator $G4-107$ was tuned on frequency 80MHz (the central frequency of AOM) and the screen must be setup in such manner, that the right half of light beam falls on surface of the PD. Then changing the frequency of the generator $G4-107$, voltage at the collector of transistor BC847B was measured. The normalized measurements are shown in Table.

Table

f , MHz		75	76	77	78	79	80	81	82	83	84	85
u_{out}, normalized value	For offset to right	1	0,93	0,84	0,74	0,63	0,51	0,39	0,28	0,18	0,09	0,02
	For offset to left	0,02	0,09	0,18	0,28	0,39	0,51	0,63	0,74	0,84	0,93	1

Then the left half of light beam falls on surface of the PD. The rest of measurements were carried out similarly to the first. The normalized measurements are also shown in the Table.

The experimental graphs on Fig. 7 show the dependence of the output voltage of the input signal frequency for two cases: right and left offsets.
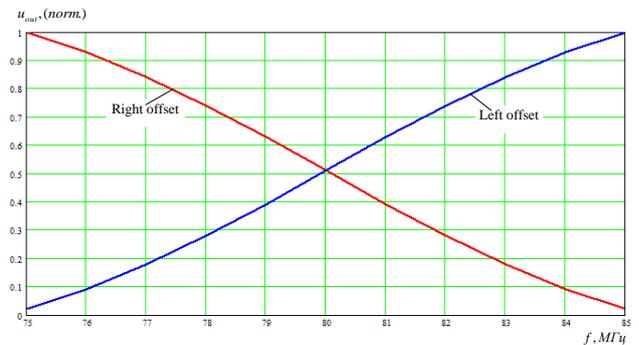

Fig. 7.

The graphs in Fig. 7 show that in the frequency range $77\div83\,MHz$ in both cases (left and right offset of the deflected beam) are observed close to a linear dependence of the output response amplitude from the frequency of the high frequency signal applied to the edges of the EAT.

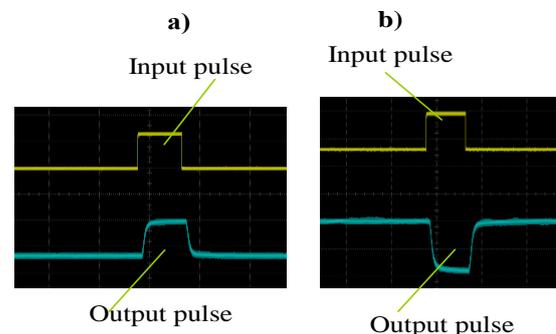Output pulse waveforms are shown in Fig. 8.

Fig. 8. Right (a) and left (b) offsets of the deflected beam

Fig. 8a shows a pulse waveform for the case when the right half of the diffracted light beam falls on the PD. In this case output pulse polarity coincides with the input pulse polarity. Fig. 8b shows a pulse waveform for the

case when the left half of the diffracted light beam falls on the PD. In this case output pulse is inverted.

Thus, the results of theoretical statements unequivocally by the results of experimental studies confirmed.

Conclusion

Requirements to characteristics of the laser are low. Satisfactory results manage to be received by means of the semiconductor laser. Using of semiconductor lasers lineup it is possible to increase the number of served points. The similar results can be obtained by splitting radiation of one laser. Thus adjustment of system does not demand special measuring devices.

References

[1] Christopher C. Davis, Lasers and Electro-optics, Cambridge University Press 720 (2014).

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