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CHARACTERIZATION OF OPTOELECTRONIC OSCILLATOR BASED ON COLLINEAR ACOUSTO-OPTIC CELL

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ABSTRACT

Optoelectronic oscillators (OEO) - the class of physical systems characterized by the presence of a nonlinear element and feedback loop (FL). Feedback allows controlling the nonlinear element operation and makes it possible to implement various OEO operating regimes - from stationary to chaotic. The presence of a FL time delay is fundamental. We present the results of OEO operation characterization, when the nonlinear element is the collinear acousto-optic (AO) filter. The AO filter provides the time delay existence due to the acoustic wave propagation time through the AO crystal. The fulfilled experiments have shown that the collinear AO filter OEO gives the possibility to adjust the time delay between input and output optical pulses by changing the FL gain. It was also found that changing the electrical signal phase shift in the FL allows OEO multistable states observation, characterized by a difference in the amplitude and frequency of the electrical signal in the FL and, accordingly, the intensity and structure of the light beam at the system optical output.

Keywords: *acousto-optics, feedback, time delay, collinear diffraction*

1. INTRODUCTION

This paper represents the results of the acousto-optic (AO) system with hybrid feedback the examination. The system is operating above the self-excitation threshold, we investigate the feedback loop (FL) parameters influence on its time characteristics and operation frequency.

The examined system is based on the collinear AO diffraction implemented with $CaMoO_4$ AO tunable filter (AOTF) [1]. The hybrid FL connects the AOTF optical output and its piezoelectric transducer [2–8].

The system may be attributed to the so-called optoelectronic oscillators (OEO) [9] - the class of optoelectronic systems that combine the nonlinear element with FL that controls the operating parameters of this nonlinear element. Here the role of a nonlinear element is assigned to the collinear AOTF [7, 8, 10, 11]. The FL is hybrid as it implements the conversion of the part of AOTF output optical signal into an electrical one and controls the parameters of the AO diffraction.

As the examined system operates above the self-excitation threshold, it does not require an external RF generator to arouse ultrasound in the AOTF, and can be treated as AO generator, providing both optical and RF output signals [12, 13].

It is known that the behavior of AO systems that include FL is extremely diverse as well as other OEOs architectures. Various types of oscillations may be observed in such systems, including harmonic, self-modulation, multistable and chaotic [4]. The multistable operation is characterized by the existence of several stable states differing in amplitude, frequency, and direction of diffracted light waves propagation [3, 6, 14].

It is shown that the FL gain variation allows to control the time delay between the optical seeding input optical pulse and the system output optical pulse. It is also shown that the FL time delay and phase shift variation allow one to manage the system operation frequency and,

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consequently, the output optical beam intensity and transmission function.

2. EXAMINED SYSTEM DESCRIPTION

The scheme of the examined AO OEO is shown in Fig.1. The collinear AOTF [1], placed between polarizers (α, β, γ), and providing 4 cm AO interaction length, is the main element. The FL operation is based on the AO heterodyning effect implemented with collinear AO diffraction optical radiation polarization peculiarities [15]. The interference between diffracted and non-diffracted optical beams after the output polarizer β makes it possible to obtain the optical radiation amplitude modulation with the frequency of ultrasound aroused in the AOTF for a certain mutual orientation of the input α and output β polarizers polarization planes [15] (α should be along Z or Y $CaMoO_4$ crystallographic planes and angle between α and β should be 45°).

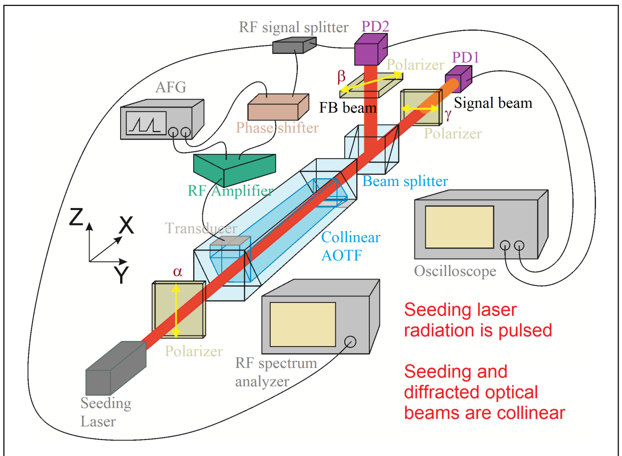

Figure 1. The examined AO OEO scheme.

The amplitude modulation is registered with the photodetector (PD2) that forms the FL input signal. The RF signal in the FL is amplified and phase shifted. Both amplifier gain and phase shifter operation are controlled by bias voltage fed from arbitrary function generator (AFG). The RF signal in FL is analyzed in time domain with a digital oscilloscope and in frequency domain - by the RF signal spectrum analyzer. The FL output feeds into the AOTF piezoelectric transducer.

The AO OEO optical output is organized as follows. The beam splitter is displaced at the AOTF output. It splits the output optical radiation (containing orthogonally polarized incident and diffracted light) into two beams - feedback beam and signal beam. The feedback beam passes through β polarizer and goes to PD2. The signal beam passes through γ polarizer with polarization plane orthogonal to α. This polarizer transmits only diffracted optical radiation. The signal beam intensity is registered by PD1 connected to the oscilloscope.

3. SYSTEM TIME DELAY DEFINITION

By the delay time τ_d we mean the time between the appearance of a laser pulse at the optical input of the system and the registration of diffracted optical pulse by the PD1. There is also another delay time characterized by the signal propagation time throughout the system τ_{fb}, including the FL and the propagation time of the acoustic wave along the entire length of the AOTF. Further, we will show that the τ_d delay time for high FL gain tends to the τ_{fb}.

Figure 2 represents the diffracted pulse intensity on time measurements obtained for FL gain μ values varying from 650 to 100 and optical seeding pulse with 1.3 ms duration.

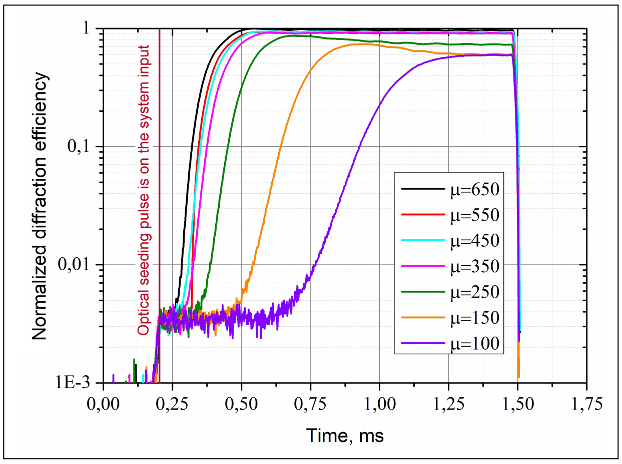

Figure 2. System response for 1.3 ms optical seeding pulse, observed for various FL gain μ magnitudes.

The analysis of the dependencies represented in Fig.2 allows to determine AO OEO time characteristics and follow the AO diffraction efficiency dependence on FL gain.

The obtained results show that the delay time τ_d depends on μ strongly. For the gain variation from 100 to 700, the τ_d decreases from 70 μs to 12 μs while the system time delay $\tau_{fb} \approx 14$ ms. The signal beam AO diffraction efficiency increases by 40%. The minimum τ_d value is close to the acoustic wave propagation time along the entire AO cell, which seems to be a natural result.

Thus, we have shown that tuning the FL parameters allows one to vary the time characteristics of the examined system in a broad range.

Further we will show that FL phase shift variation, implemented by changing the phase shifter bias voltage, makes it possible to control the AO OEO operating frequency f and, consequently, the output signal beam intensity.

4. MULTISTABILITY OBSERVATION

Another feature of the examined system is the dependence of its operation on the phase shift χ introduced by the phase shifter. The χ magnitude is controlled by bias voltage fed from the AFG.

Figure 4 illustrates the dependence of the signal beam intensity I_s registered by PD1 on the AFG signal magnitude. It can be seen that the intensity (PD1 signal) variation has a rather complex shape. The reason for this is the dependence of the system operating frequency f on phase shift χ magnitude.

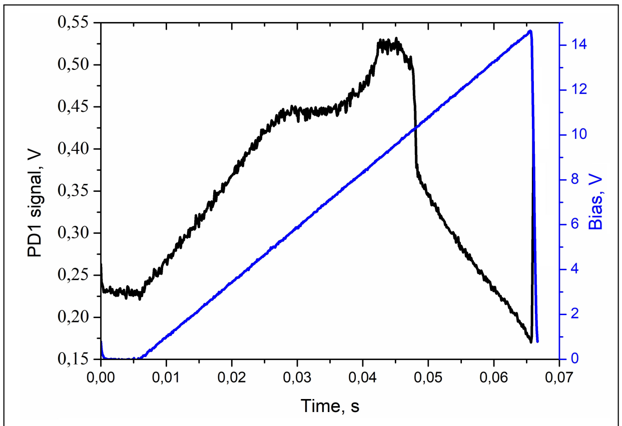

Figure 3. PD1 signal variation in time for varying phase shifter bias voltage.

To obtain the $I_s(\chi)$ dependence in explicit form, it is necessary to measure the χ dependence introduced by the phase shifter on the bias voltage for the AO OEO operating frequency (about 43.5 MHz). This dependence is shown in Fig.4a. It shows that the bias voltage variation from 0 to 15 V provides the χ/π variation from 0.2 to -0.9. It is interesting that the maximum absolute value is achieved for the bias voltage of about 12 V. Thus, the bias voltage variation may be limited by the range 0–12 V.

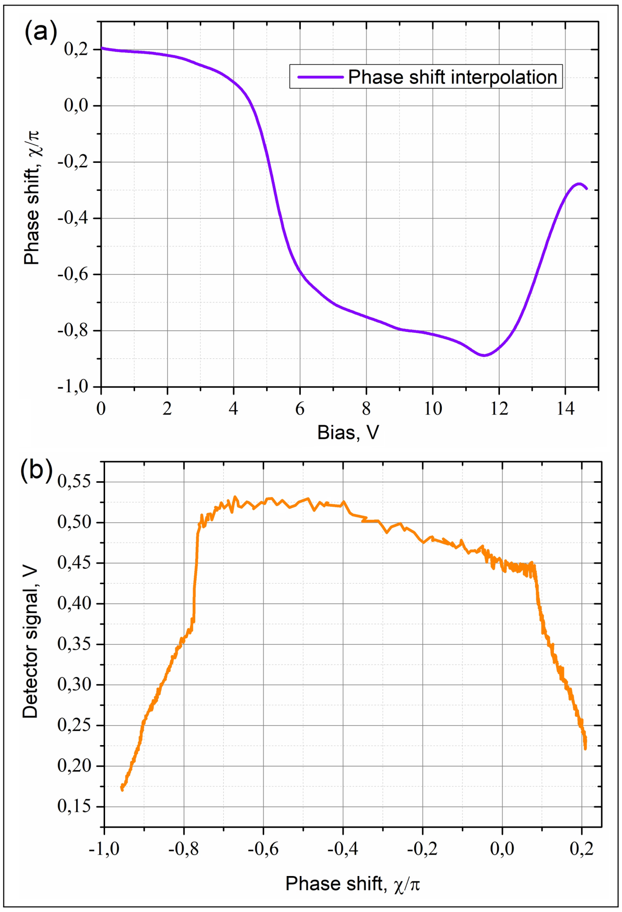

Figure 4. The dependence of normalized phase shift introduced by FL on bias voltage (a) and signal beam intensity dependence on the normalized phase shift magnitude (b).

Finally, the $I_s(\chi)$ dependence (in the form of PD1 signal magnitude) is shown in Fig.4b. It can be divided into three areas: 1 – signal growth between -0.95 and -0.75; 2 – a sharp leap and the second area where the signal beam intensity does not change much ($-0.75 < \chi/\pi < 0.1$); 3 – another leap follows and the third area is observed where the intensity drops significantly ($\chi/\pi > 0.1$).

The I_s variation is caused by the f tuning . Therefore, the leaps in intensity correspond to the frequency ones, and the slow intensity variation is caused by its smooth change.

The mechanism of f tuning with χ variation was considered previously [16]. It is based on the phase balance condition for the examined AO OEO, acting in conjunction with the amplitude balance condition - the frequency dependence of the system transmission coefficient (the feedback beam AO diffraction efficiency dependence on the ultrasound frequency).

The broadest band of f tuning may achieve 200 kHz, while the tuning band for the case shown in Fig. 4 is approximately 100 kHz.

5. CONCLUSION

We have examined the influence of FL parameters (introduced phase shift, time delay,gain) on the collinear AOTF OEO functioning.

The FL phase shift variation may cause a smooth change in the operating frequency and the output radiation intensity and the abrupt one. The operating frequency variation magnitude may exceed 200 kHz.

It was discovered that the FL gain variation allows one to control the AO OEO delay time. In the studied range of gain magnitudes, the delay time varies by about 6 times. It was found that the minimum delay time approximately equals the time required for an acoustic wave to propagate along the entire length of the AO cell.

6. ACKNOWLEDGMENTS

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