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Nonlinear Dynamics, Bifurcation Maps and Signal Encryption and Decryption Using Acousto-Optic Chaos Under a Variable Aperture Illumination

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Abstract: The nonlinear dynamics (NLD) and bifurcation characteristics of a Bragg cell under first-order feedback are examined for a variable aperture. Corresponding chaotic encryption and recovery of low-bandwidth signals are examined for fixed (optimal) photodetector aperture (at about 73%), and subsequent sub-optimal aperture variation. Device performance and tolerances are evaluated and compared relative to the optimal fixed aperture, and the dynamical impact of the encryption system is evaluated in terms of possible variations in the photodetector illumination area.

OCIS codes: (070.1060) acousto-optic signal processing; (060.4785) optical security & encryption; (190.3100) instabilities and chaos

1. Introduction

The acousto-optic Bragg cell is a piezoelectric oscillator in which acoustic vibrations lead to a diffraction grating thereby causing an input light beam to undergo scattering into two well-defined orders. The device behavior may be studied using the so-called Klein-Cook parameter (Q) [1]. Under first-order feedback, the device exhibits interesting dynamical behavior including mono-, bi- and multistability leading to various degrees of chaos. The chaos in the feedback loop has been utilized for a variety of signal encryption and recovery applications [2,3]. The *key* parameters such as acoustic bias $\hat{\alpha}_0$, feedback gain $\tilde{\beta}$, time delay (TD) and incident light intensity (I_{inc}) enable encrypted information to be communicated securely over arbitrary distances [3]. Recent work has included examining the dynamical system for conditions of variable feedback gain, whereby it is found that chaotic passbands may be extended and consequently higher signal dynamic ranges may be possible. This paper examines a corresponding problem relative to a photodetector with variable illumination aperture. To that end, the overall dynamical behavior for a variable aperture (with openings from 0-100%) is first studied, and it is found that optimal chaotic passband occurs at around 73% preferably at higher $\hat{\alpha}_0$ -centered passbands. The problem is then numerically studied at the 73% aperture point (whereby encrypted signals are recovered with reasonable fidelity), and $\tilde{\beta}$ -tolerances are calculated. A variable aperture is then introduced around of the optimal opening, and the system is examined both in terms of the resulting NLD and pass/stopband bifurcations, and also the signal encryption properties of the system.

2. Band Selection

For simplicity the input light beam is assumed as a uniform plane wave; the first-order output at the photo detector is given by [2]:

$$I_1(t) = I_{inc} \sin^2 \left[\frac{\hat{\alpha}_0}{2} + \frac{\tilde{\beta}}{2} I_1(t-TD) \right]. \quad (1)$$

The amount of light incident on the photo detector ($\propto I_{inc}$) would vary in practical applications. This can be viewed as a variable aperture illuminating the photo detector. From this perspective, it may be shown that the incident light intensity itself varies with time, since the power incident is related to the integral of the Poynting vector. Thus, I_{inc} may be treated as $\tilde{A}(t)$. To identify and choose better parameters for signal transmission in the chaotic region bifurcation maps are developed for a fixed feedback gain and varying bias. In this case the Eq. (1) may be re-written

as

$$I_1(t) = \tilde{A}(t) \sin^2 \left[\frac{\hat{\alpha}_0}{2} + \frac{\tilde{\beta}}{2} I_1(t-TD) \right]. \quad (2)$$

From these maps the pass band and stop bands for the transmission of the message signal can be inferred. $\tilde{A}(t)$ is varied from 0 to 3, and there is an optimally large pass band ($\hat{\alpha}_0$) from .0287- 2.246 when \tilde{A} is 2.18 (i.e., 73% aperture opening). The blue regions and gaps in the Figs.1 and 2 indicate the pass bands (PB) and stop bands

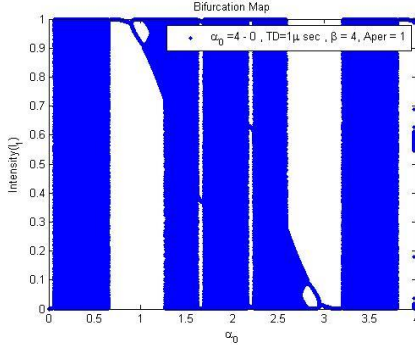


Fig.1 Bifurcation map for $\tilde{A} = 1$

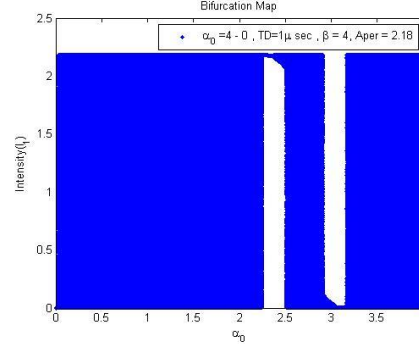


Fig.2 Bifurcation map for $\tilde{A} = 2.18$

with $TD = 1\mu s$, $\tilde{\beta} = 4$, $\hat{\alpha}_0 = 4$ to 0. Thus, the dynamic range varies from $\hat{\alpha}_{0,max} - \hat{\alpha}_{0,min}$ in the chosen PB.

3. Encryption and Decryption

For modulation or encryption the message signal ($s(t)$) is added to a dc value, which is center of the pass band and fed as an input bias to the Bragg cell is set at about as $\hat{\alpha}_{dc} = 1.123$. A heterodyne receiver is designed for the

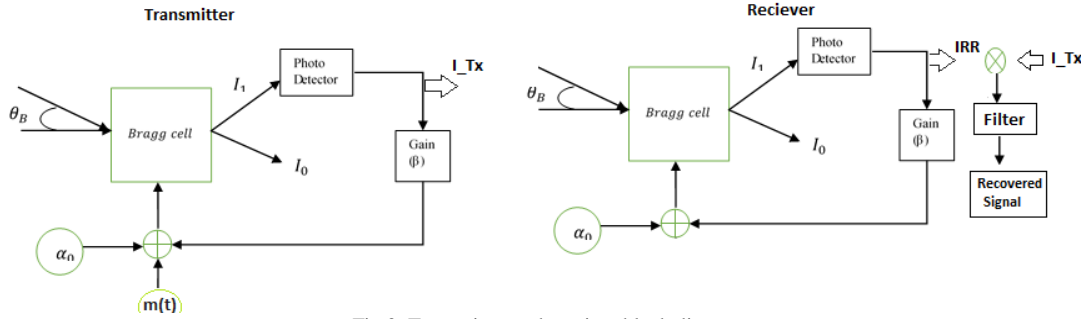


Fig.3. Transmitter and receiver block diagram

decryption of the modulated message signal which would be matched to the transmitter *keys*, generating an unmodulated chaos.

At the receiver the transmitted signal (I_{Tx}) is multiplied with the generated chaos wave at the receiver (IRR) and filtered through a low pass filter for the recovery of the signal. The input (red) and output (blue) wave forms are normalized for comparison in Figs.4 and 5.

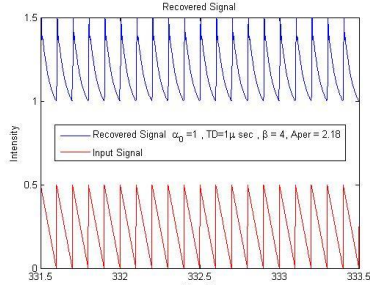


Fig 4. Encrypted 10 KHz trailing sawtooth recovery at 73% aperture.

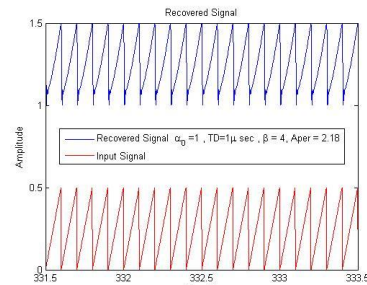


Fig.5. Encrypted 10 KHz rising sawtooth recovery at 73% aperture.

4. References

- [1] A.Korpel, "Acousto-Optics," 2nd edition (Marcel Dekker, New York, 1997).
- [2] M.R. Chatterjee and M. Al-Saedi, "Examination of chaos- based encryption and retrieval in a hybrid acousto- optic device," Frontiers in Optics, OSA Technical Digest(CD), paper # FCW3, Rochester, NY(2008).

[3] M.R. Chatterjee and F.S. Almeahmadi, "Information encryption, transmission, and retrieval via chaotic modulation in a hybrid acousto-optic Bragg cell under profiled beam illumination," Proc.SPIE 9216,92160S (2014).