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Examination of the Nonlinear Dynamics of A Zeroth-Order Acousto-Optic Bragg Modulator with Feedback

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Abstract: In recent work, the first-order acousto-optic Bragg diffraction has been shown to be a practical technique for chaotic modulation. The motivation for zeroth-order modulation is that spatial deflections of the first-order AO beam may potentially cause tracking problems at the receiver, a problem that is avoided by switching to the zeroth-order beam that remains spatially undeviated.

Keywords: acousto-optics, Bragg regime, scattering, Gaussian, Klein-Cook, chaos, modulation, encryption.

1. Background

A typical Acousto-optic (AO) device consists of a piezo-electric transducer bonded to a transparent crystal. An incident laser beam undergoes scattering due to acoustic vibrations created by the transducer, and in general multiple scattering orders occur. Such devices have application in many areas of signal processing. The specific type of scattering that occurs depends on several parameters, especially the thickness of the crystal and the wavenumbers for the sound and light waves. These parameters are combined into a figure of merit called the Klein-Cook parameter (Q), the value of which determines the regime of operation. The most useful regime of operation is Bragg operation, in which a single diffracted order occurs when the light beam is incident at the Bragg angle. It was shown by Chatterjee and Chen that Q should be larger than 8π for Bragg operation [1]. AO devices with positive feedback gain can exhibit such characteristics. To create a closed-loop AO device, the Bragg regime is used, and a photodetector collects the zeroth order diffracted light beam. The electrical signal from the photodetector is amplified, added to a DC offset, and fed back into the acoustic driver for the piezoelectric device. Using the DC offset as an input and taking the output from the photodetector, the closed-loop system becomes a non-linear signal processing device, capable of mono-, bi-, multistable and chaotic behavior. These characteristics can be utilized for signal processing applications including, in the case of chaos, encryption and decryption.

2. Acousto-optic feedback dynamics in closed-loop hybrid devices

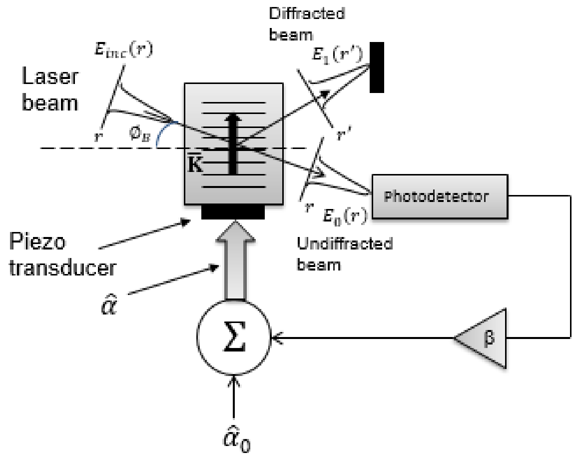

Fig.1. A-O closed-loop hybrid system with an arbitrary incident beam profile.

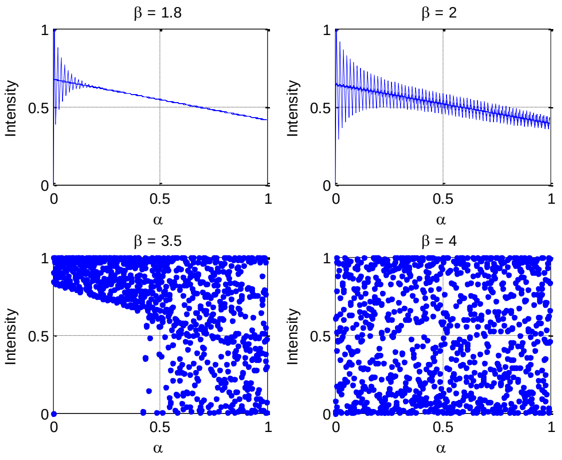

Fig.2. Nonlinear dynamics with three different values of the effective feedback gain.

The full closed-loop system based on an AO Bragg cell is shown in Fig.1, in which the photodetected intensity signal is amplified and fed back into the acoustic driver. The resulting nonlinear system displays complex bistability behavior which was first observed in 1978. Under the assumption of a uniform plane wave input, which makes the analysis tractable, the output from the photodetector follows the nonlinear equation [2]

$$I_1(t) = I_{inc}\cos^2\left[\frac{1}{2}\left(\alpha_0(t)+\tilde{\beta}\, I_1(t-Td)\right)\right] \quad .$$

(1)

In this equation, I_{inc} is the intensity of the incident light, $\hat{\alpha}_0$ is the peak phase delay, $\tilde{\beta}$ is the feedback gain, and TD is the feedback time delay. The time delay is created by the accumulated delays of the circuit components. Depending on the values of these parameters, this equation leads to *monostable*, *bistable* and *multistable* behavior, as well as chaos. Simulations of such behavior are shown in Fig.2 consists of plots of intensity versus the optical phase shift at with four different values of $\tilde{\beta}$ (1.8, 2, 3.5, 4). The optical phase shift varies linearly back and forth from minimum to maximum values, as a triangular wave. These demonstrate the feedback gain tuning sensitivity of this hybrid closed-loop system. As $\tilde{\beta}$ is increased, chaotic behavior occurs as shown where the transition to chaos is evident.

3. Chaos and modulation using zeroth-order feedback under non-uniform incident beam

To apply chaos as a means of encrypting a signal waveform, the signal is added to the bias driver such that the peak phase shift has the form of ($\hat{\alpha} = \hat{\alpha}_0 + signal$). The resulting chaotic photodetector current is then viewed as a modulated version of the input signal. One potential motivation for studying zeroth-order modulation is that spatial deflections of the first-order AO beam may potentially cause tracking problems at the receiver [3, 4], which is avoided by switching to the spatially undeviated zeroth-order beam. The dynamic behavior of the closed-loop system using the zeroth order beam, and non-uniform input beams, is modeled in the same manner as the 1st order beam case. One significant difference is that the demodulated signal for the zeroth order case does not require a 180 degree phase shift correction at the receiver. Figure 3 shows an example simulation of modulation with the zeroth order beam using a triangular waveform and several values of the gain parameter $\tilde{\beta}$. For $\tilde{\beta}$=2.1, the system is only driven to chaos at the peaks of the triangular waveform, and the signal is therefore not modulated. A gain of $\tilde{\beta}$=3 is high enough to push the system into chaos for nearly all of the triangular input. With a gain of $\tilde{\beta}$=5, the signal is fully modulated, although the triangular shape is apparent in the envelope. With $\tilde{\beta}$=7, the signal is fully modulated and hidden within the chaos.

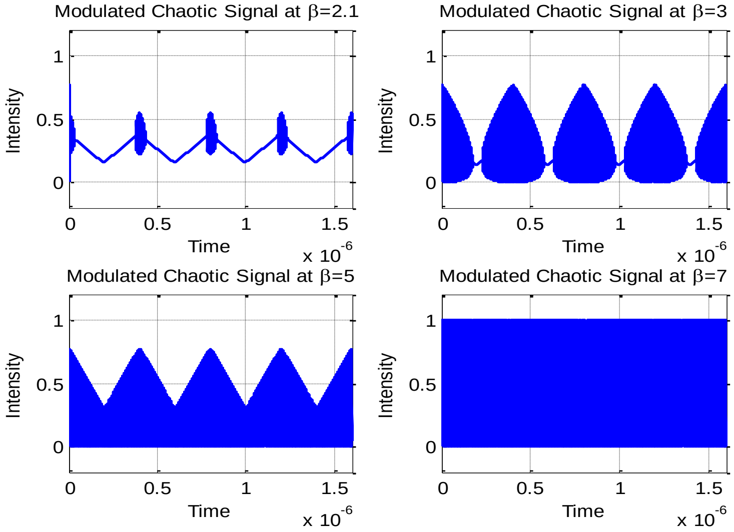

Fig.3. Zeroth-order modulation of a triangular waveform for four different gain values.

4. Conclusion

Although there is a need to fully explore zeroth-order modulation, this work focuses on the nonlinear dynamics of Fig.1. The simulations presented in the previous section clearly demonstrate that chaotic encryption using zeroth-order diffracted beam is feasible and has many significant advantages over the first-order case.

5. References

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