Numerical Simulation of Optoelectronic Sensors: Fiber Bragg Grating and Noise

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***Abstract*—A previous numerical model was used to simulate the interrogation of optical fiber Bragg grating sensing signals. The noise in the optoelectronic receiver, a photodiode, and transimpedance amplifier, has been incorporated into the model. The simulation results have enabled the comparison of various interrogation systems for optical fiber Bragg grating sensors. That is, utilizing the same sensing element and the same optoelectronic receiver, the choice between either edge filter detection or power detection can be compared and contrasted.**

***Index Terms*—Bragg Gratings, Fiber Gratings, Numerical simulation, Noise, Photodetectors.**

I. Introduction

FIBER Bragg Gratings (FBGs) are dielectric mirrors that reflect a specific portion of the spectrum incident upon them. As spectrally sensitive transduction elements, FBGs are ideal for multiplexing, where potentially 1000's of FBGs can be connected in series [1]. However, one of the major advantages of the FBG is its versatility. That is, with an appropriate transducer, an FBG can be used to sense a variety of measurands; including, temperature, static strain, static pressure, dynamic strain, ultrasound, acoustic emissions, acousto-ultrasonic, and corrosion etc.

The FBGs spectral response is immune to optical power fluctuation, and is an absolute measurement. However, spectral decoding is expensive and relatively slow, while also being processor intensive. This can limit the use of FBGs in very high frequency sensing applications. The use of optical domain photonic signal preprocessing means the wavelength modulation can be converted to intensity modulation rapidly. There are two configurations that can be used for these intensity based interrogation systems, referred to as 1) power detection and 2) edge filter detection [2].

In this work, the goal is to compare the two different intensity based interrogation methods for FBG sensing, and quantify the affect that noise in the photoreceiver (photodiode and transimpedance amplifier) has on the Signal to Noise Ratio (SNR). This work is a continuation of previous numerical modeling [3], which focused only on comparing sensitivity and dynamic range, parameters important for static measurements. By including noise into the numerical model, not only is it possible to quantify SNR, the corresponding dynamic resolution can also be quantified, which is significant for the sensing of dynamic signals.

II. Theory

A. Modeling

A general numerical model was developed to investigate the four different power detection based interrogation methods, and the vast array of edge filter detection methods [3]. The physical configuration of the model is represented by the optical circuit shown in Fig. 1.

The model, previously verified [3], gives the optical power transmitted and reflected from the sensors, which are then in turn transmitted and reflected from the two filters. Each of these 4 optical powers can then be converted into an electrical signal. The optical spectra (rx_n) incident on the receiver is converted into a photocurrent (i_{Rx}), given by,

$$i_{Rx} = q\eta \int_{-\infty}^{\infty} \frac{\lambda}{hc} rx_n d\lambda \,, \tag{1}$$

where q is the charge of an electron, η is the quantum efficiency, h is Planck's constant, c is the speed of light, and λ is the wavelength. The voltage from the transimpedance amplifier is then given by,

$$V_{Rx} = i_{Rx} R_f \,, \tag{2}$$

where R_f is the transimpedance, or feedback resistance in the current to voltage converter.

B. Noise

There are three noise sources considered in this model: shot noise, dark noise, and thermal noise. The root-mean-squared amplitude of the shot noise (V_{Shot}) component is determined

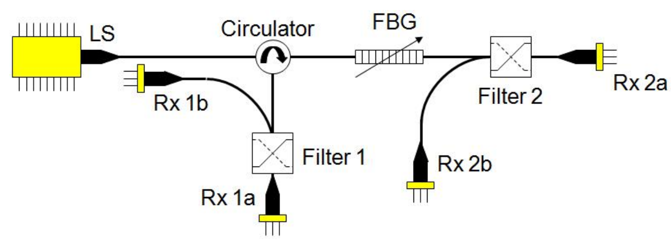

Fig. 1. Optical circuit for the model, with a light source (LS), sensing FBG, and 4 receivers (Rx) in addition to the circulator and filters

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from,

$$V_{Shot}^2 = 2qBR_f V_{Rx} , \quad (3)$$

where B is the receiver bandwidth. The root-mean-squared amplitude of dark noise (V_{Dark}) is determined from,

$$V_{Dark}^2 = 2qBR_f^2 i_{Dark} , \quad (4)$$

where, i_{Dark} is the dark current of the photodiode. The root-mean-squared amplitude of thermal noise ($V_{Thermal}$) is determined from,

$$V_{Thermal}^2 = 4BkTF_n R_f . \quad (5)$$

The total noise amplitude, peak to peak, is then given by combining (3) to (5). The noise was simulated by using 3 random numbers to generate values for the noise source amplitudes.

III. Results

A. Power detection

The result from the dynamic signal simulations are shown in Fig. 2. This used a laser with a total optical power of 6.4mW, and a FWHM of 0.082nm, centered about 1554.13nm. The FBG had a reflectivity of 1, with a FWHM of 0.8nm. Here the voltage signal is a function of time. Three signals are considered, transmitted, reflected, and the difference. It is worth noting that these signals are in excellent agreement with those signal measured experimentally [4].

From Fig. 2 a number of important parameters can be determined. Specifically, the peak to peak amplitude of the two individual signals was calculated numerically to be 1.3643V, and the peak to peak amplitude of the noise was 0.0912V, giving a SNR of 14.8. Also, from the peak to peak amplitude the rms voltage can be determined, which was 0.4824V. Since the peak to peak wavelength modulation applied was 0.4nm the sensitivity is then 3.41V/nm. Experimentally, the bandwidth of a 109kHz applied signal was measured as 19kHz [4]. Although this was for a specific application, it enables dynamic resolution to be calculated for comparative purposes. These parameters then give a dynamic resolution of 6.9×10^{-5}nm/√Hz.

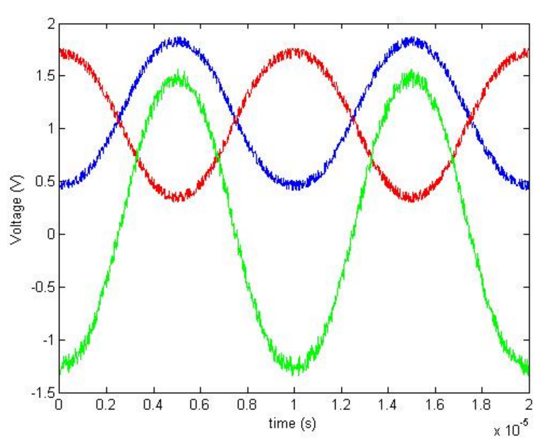

Fig. 2. The results of the dynamic wavelength shift signal with noise for the power detection system.

B. Edge filter detection

The source for the edge filter detection was a SLD with a total optical power of 25mW, and a FWHM of 40nm, centered about 1550nm. The linear edge filter used had a bandwidth of 1nm with a midpoint at 1553.63nm. The same FBG was used. The results of the numerical simulation are shown in Fig. 3. The peak to peak amplitude of the two individual signals, calculated numerically, is 0.057V, and the peak to peak amplitude of the noise was 0.0912V, giving a SNR of 0.625. From the peak to peak amplitude the rms voltage can be determined, given as 0.02V. Again, the peak to peak wavelength modulation was 0.4nm, and hence the sensitivity is then 0.1425V/nm. As before, the same signal bandwidth was used, since the exact optoelectronic components and interrogation method does not affect the quality of the signal transmitted and received by the FBG. Using all of the parameter then gives a dynamic resolution of 1.6×10^{-3}nm/√Hz; 20 times worse than for power detection.

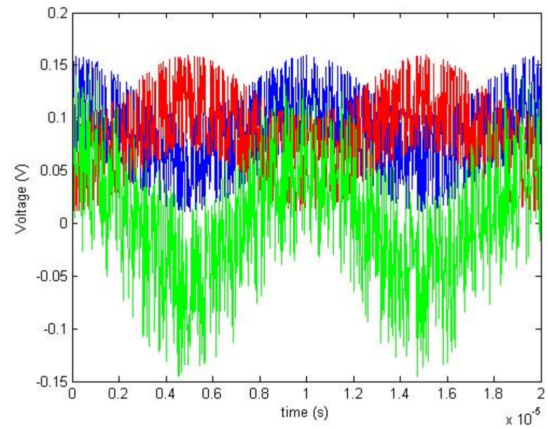

Fig. 3. The results of the dynamic wavelength shift signal with noise, using the edge filter detection.

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