Compact FBG interrogator based on a customized integrated optical arrayed waveguide grating

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Abstract—**Fiber Bragg gratings (FBG) are attracting more and more attention for use in aeronautical systems. We present an integrated optical robust interrogator for fiber Bragg gratings based on a customized arrayed waveguide grating. The interrogator is capable of simultaneously monitoring four FBGs with strong anti-aliasing capabilities and a cutoff frequency of 20 kHz.**

Keywords-FBG, Arrayed wavgeuide grating, structural monitoring, Fiber Bragg Gratin, interrogator

I. INTRODUCTION

Fiber Bragg grating sensors have great potential for sensing applications, especially where conventional electrical sensors are not reliable, as it is the case, for example, under the influence of high electromagnetic fields. Several interrogation methods for FBGs are well known, as there are for example spectrometers, scanning lasers, etc.[1]. However, these approaches suffer from issues like cost, size and the ability to implement anti-aliasing filtering, which is crucial for sensing applications with dynamic signals. Within the scope of an ESA (European Space Agency)-funded project we developed an interrogator based on a customized manufactured integrated optical arrayed waveguide grating (AWG). The interrogation of FBGs with an AWG-based interrogator was first demonstrated by Sano et al, whereas a commercial of the shelf AWG was used. Our interrogator design allows high speed interrogation of up to four FBGs. The interrogator is being tested at INTA (Instituto Nacional de Técnica Aeroespacial).

II. SPECIFICATION

A. Interrogator specification

The measurement task poses a number of restrictions with respect to the useable wavelength range per sensor and to the minimum acceptable wavelength resolution and accuracy. A minimum of four sensors has to be interrogated at the same time. Each sensor has an wavelength operation range of approx. 5 nm, which corresponds to a temperature range of ±100°C at a dynamic axial mechanical load of approx. 1500 µstrain [2].

The dimensions of the interrogator unit need to be in accordance with the very tight size restrictions of the Ariane launcher electronic interface system. The main task of the interrogator is to monitor structural loads during lift off of the launcher, so the system has to be constructed considering the potentially occurring high vibrational and thermal loads on the interrogator during operation. The minimum permissible measurement frequency is 20 kHz.

III. MEASUREMENT PRINCIPLE

For the intended measurement task, an interrogator based on an arrayed waveguide grating as an optical filter was developed, as AWGs offer the potential for integrating a large number of optical filter edges at minimum device size. Together with the possibility of integrating passive optical devices as PIN photodetectors on the AWG die and thus due to the ability to precisely control the temperature of all electro-optical and optical parts of importance for the measurement, this interrogation device allows good performance for this measurement task.

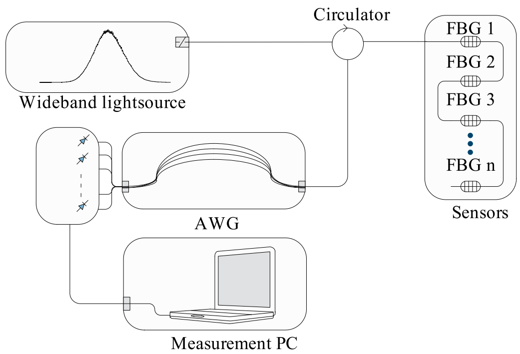

Figure 1 Schematic of the designed AWG-based FBG-interrogator

In AWG based FBG interrogators, a number of serially multiplexed FBGs are illuminated by a large bandwidth light source. Depending on the load acting of an FBG, a spectrally well defined part of the illuminating spectrum is reflected by each FBG. The reflected light portion is guided to the input waveguide of an AWG. A schematic of the measurement setup is shown in Figure 1. Depending on the reflection wavelength of the FBG, this fact gives rise to light intensities in two adjacent output channels of the AWG, which are measured by photodiodes.

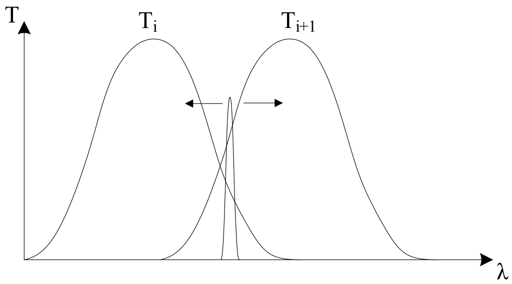

Figure 2 AWG-based measurement principle. narrow peak indicates FBG reflection. Broad Peaks indicate two adjacent output channel transmission characteristics

The measurement principle is indicated in Figure 2. The narrow spectral peak indicates the spectral FBG reflection. The two broad spectral curves indicate schematically the spectral transmission of two adjacent AWG output channels. The FBG center wavelength is determined by the logarithmic ratio of the measured intensities in the adjacent channels [3]

$$\rho = \frac{\log(I_i - I_b)}{\log(I_{i+1} - I_b)},$$

where I_i and I_{i+1} denote the light intensities in the adjacent channels caused by the FBG and I_b denotes the photocurrent contribution of the background reflected light in the fiber.

The spectral measurement uncertainty of the interrogator is dependent on a number parameters [6], as there is for example the light source intensity, the FBG peak reflectivity, the AWG channel spacing and channel width.

For the described measurement task, a measurement uncertainty of 10 pm at a maximum frequency of 20 kHz is acceptable. Considering this restriction in combination with the desired spectral measurement range per sensor, simulations according to [6] were performed. An AWG with a channel spacing of 3.33 nm and a spectral channel FWHM of 2.33 nm, considering a Gaussian channel transmission profile, is applied in the simulations.

Inevitable noise contributions present in the detected signals in the adjacent channels give rise to measurement uncertainties. Figure 3 shows the estimate useable measurement bandwidth for a system with a standard draw tower grating, dependent on the first stage amplifier electronics bandwidth and on the AWG channel width. The useable measurement range decreases for with increasing electronic bandwidth. On the one hand high electronics bandwidth is needed for precise measurement of high frequency loads on the sensor, on the other hand signal amplitudes larger than the adjacent channel spacing desire high electronic bandwidths for the necessary amplification of higher signal frequency harmonics, as it is discussed below.

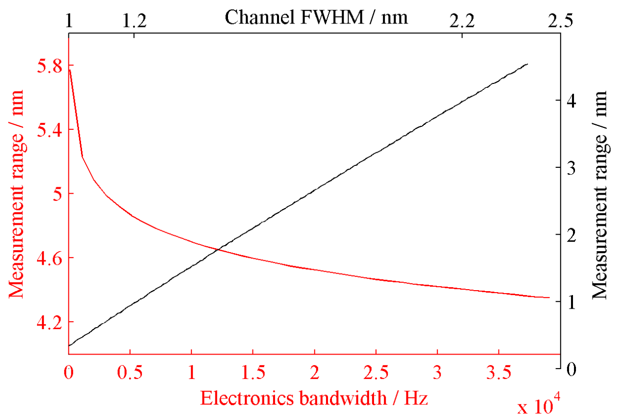

Figure 3 Measurement range at a measurement accuracy below 10 pm, dependent on (black) AWG channel FWHM and on (red) amplification electronics bandwidth

Larger spectral channel widths give rise to higher signal levels at the detectors, reducing the noise contribution for signal evaluation. Thus, considering quasi-static signals, the useable measurement range per channel pair can be increased by designing the AWG for larger output channel widths at a fixed channel spacing.

Large signal amplitudes, i.e. large dynamic wavelength shifts of the FBGs, lead to the generation of higher signal harmonics at the opto-electronic detector due to the nonlinear shape of the channel transmission functions at the channel center wavelengths. Thus, a first amplification stage needs to have a cutoff frequency much higher than the expected signal frequencies, in order to provide distortion free signal sampling. This seems to be partially in conflict with the above mentioned increasing measurement uncertainty with increasing electronics bandwidth. However, this can be encountered by proper signal oversampling, averaging and application of appropriate deskewing filters.

IV. System Realization

A. Arrayed waveguide grating

A planar photodiode array has been integrated in the output channels of the manufactured AWG after device characterization and the device has been integrated in a customized butterfly package. The packaging is prepared for a hermetic sealing which is needed during the intended operation on the ARIANE launcher during lift off, as influences from condensing moisture on the optical performance of the AWG have to be eliminated.

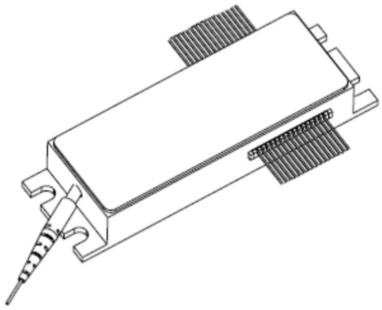

Figure 4 AWG packaging with implementable hermetic sealing for space applications

B. Device performance

From the measured AWG channel transmission curves, the performance of the interrogator can be estimated. Figure 5 exemplarily shows the evaluation function for the two adjacent output channels of the customized AWG. The evaluation function shows a good linear behavior over a wavelength range of approximately 4.6 nm. This is in very good accordance with the expected useable measurement range of approximately 4.5 nm, considering the measurement system electronical and optical configuration.

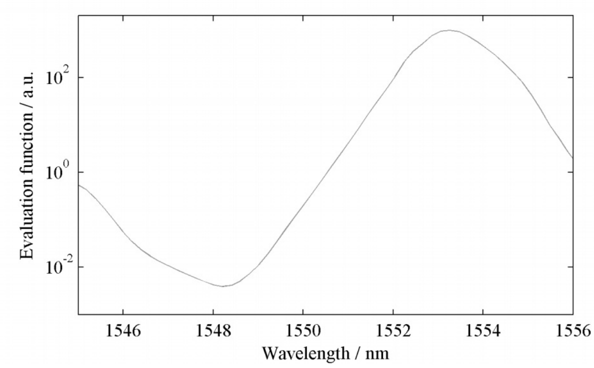

Figure 5 Exemplary interrogation function for a FBG sensor

C. Conclusion and Outlook

We have developed an AWG-based compact FBG interrogator for use under harsh environmental conditions. The interrogator is designed for a measurement uncertainty below 10 pm at a maximum signal frequency of 20 kHz. The optical core component is packaged packaging adapted for use in space.

The device will be extensively tested at the test facilities at INTA.

For further improvement of AWG-based FBG interrogators, further investigation with respect to on shaping the spectral transmission curves of the AWG output channels needs to be carried out

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