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16-bit multilevel reconfigurable phase encoder for all optical header generation/recognition based on a Uniform Fibre Bragg Grating

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Abstract

We demonstrate a simple, dynamically tunable phase encoder/decoder for use in reconfigurable all-optical packet switched networks. The device is based on a uniform fibre Bragg grating and has 16 independent phase-tunable elements. Excellent auto-/cross correlation features and error free BER operation are obtained.

Introduction

The Fibre Bragg Grating (FBG) has become a crucial element in optical networks. Both passive and active grating devices have been demonstrated for applications such as dynamic dispersion compensation [1], tunable add-drop filtering and gain equalisation [2]. Recently, phase encoders/decoders based on FBGs have been demonstrated and used for coding applications in optical code-division multiple access (OCDMA) systems and also for header generation/recognition in all-optical packet switched networks [3]. These previous works have used phase coders with fixed superstructure profiles, however dynamically reconfigurable coding devices will be required within many instances to allow for maximum network flexibility and utility. Previously, we demonstrated the principle of a simple tunable device based on a uniform Bragg grating with discrete heating elements along its length, and demonstrated the generation of an 8-bit bipolar code [4].

In this paper, we demonstrate the application of this device in a header generation/recognition system based on a combination of fixed and tunable gratings which employ quaternary phase-shift-keying (QPSK). The tunable device is capable of reconfiguring 16-bit QPSK codes with a bit rate of 20 Gbit/s. We present auto-correlation and cross-correlation results that demonstrate the quality and reliability of the system and show that error free operation can be obtained with a modest power penalty. We consider that our results highlight the potential of tunable grating based coding devices for applications in reconfigurable IP routers.

Device Principle and Description

Phase-shifted gratings can be produced by shifting the phase of the rapidly varying refractive index during the grating writing process. Alternatively, a phase shift can be imposed within an otherwise uniform pitch grating by locally increasing the background effective refractive index. The refractive index is both temperature and strain sensitive [5]. Subsequently, a thin resistive wire in series with a variable resistor can provide localized heating and thus a controllable phase-shift. In accordance to the phase matching condition, the variation in the effective refractive index will appear as a modulation of the local Bragg wavelength $\Delta\lambda_B$. The corresponding accumulated phase shift $\Delta\phi$ associated with each Bragg wavelength variation at the bit boundary, can be derived from a simple mathematical consideration given by

$$\Delta\phi \approx \frac{4\pi n_{eff}}{\lambda_B^{\,2}} \int_{-\Delta z/2}^{\Delta z/2} \Delta\lambda_B(T(z))dz \qquad (1)$$

where λ_B is the grating initial Bragg wavelength, Δz is the width of the heated segment, n_{eff} is the effective refractive index of the fibre core and $T(z)$ is the temperature shift at position z relative to the overall temperature of the uniform grating.

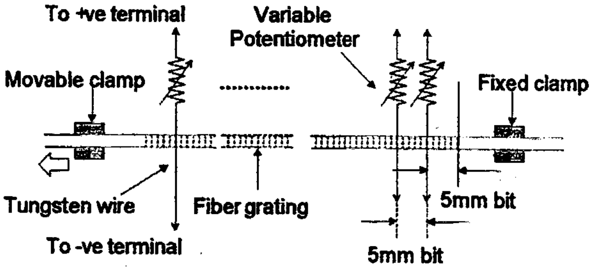

Fig. 1. Schematic structure of the 16-bit code reconfigurable encoder

The code-tunable encoder consists of a uniform fibre Bragg grating, written using our continuous grating writing technique. The total length of the grating is 80mm. The peak reflectivity of the uniform grating is about 57% corresponding to a uniform coupling coefficient in the grating of approximately 12m^{-1}. A 16-bit encoder/decoder with a bit duration of 50ps is constructed by positioning 16 parallel tungsten wires (18μm diameter) 5mm apart along the fibre grating with the first wire being placed 5mm from the start of the grating (see Fig. 1). In addition, the fibre grating is mounted on a stretcher to allow flexible tuning of the overall grating central wavelength. The value of the electrical current required to induce a π-phase shift in the back-reflected light is predetermined through measurements of the dynamic spectral behaviour of the grating when heated in the centre of the grating [4]. From these measurements, we found that the electrical currents required to generate 0.5π, π and 1.5π are 30mA, 60mA and 90mA respectively.

System Experiment and Results

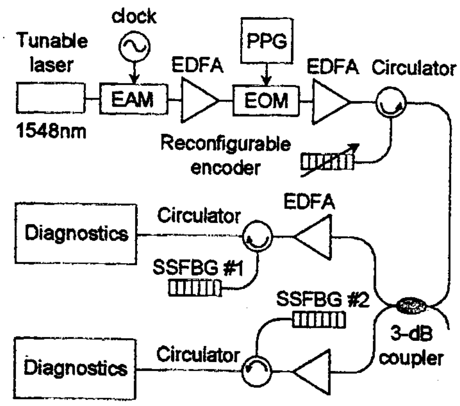

Fig. 2. Experimental setup.

The optical header generation and recognition setup, shown in Fig. 2, was constructed to demonstrate the viability of this device in a system context. A 10 GHz pulse stream (pulse duration 20ps) was generated using an electro-absorption modulator (EAM) fed by a CW laser operating at 1548nm. This pulse stream was then modulated with 2^7-1 pseudorandom electrical data from a pattern generator (PPG), with a mark space ratio of 8:1 (622 Mbit/s) using an electro-optic modulator (EOM). By independently controlling the electrical current flow at each wire heater within the encoder, we can obtain a four –level phase shift keyed (QPSK) code that can be encoded onto our pulse stream by reflecting it from the grating via a circulator. The encoded waveform has duration of 800ps, and contains 16-bit QPSK code with a bit duration of 50ps. At the receiving end, the encoded signal is split into two channels using a 3 dB coupler, with each channel having a fixed superstructure grating with a different phase-code profile written into it. Hence by programming the tunable encoder to produce an encoded code that matches either one of the fixed gratings, we can measure the autocorrelation signatures (correctly matched code) and the cross-correlation signatures (incorrectly matched code) of the decoded signal in both channels simultaneously, as shown in Fig. 3. The overall extinction ratio between auto- and cross-correlation is found to be approximately 71% for both cases. Such an extinction ratio is sufficient for recognizing an optical header ahead of the data payload in a packet switched network.

The bit-error-rate measurements made for the two phase codes in Fig. 4 reveal a power penalty of only 2.5dB when compared to the laser back-to-back response. This power penalty may stem from the fact that the phase shift induced by the tunable encoder is not totally discrete along the grating and minor uncertainties/variations in the electrical current values applied to the wire heaters.

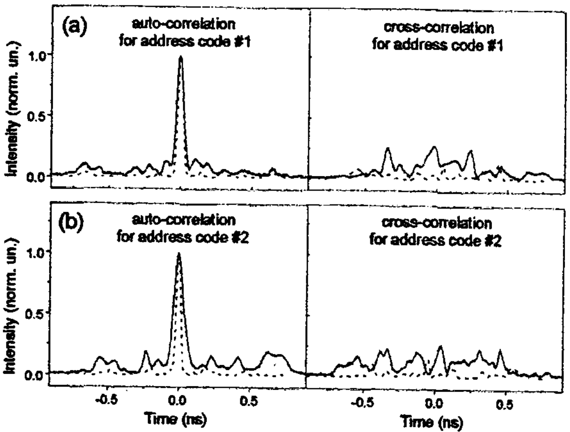

Fig. 3. Traces of the intensity auto- and cross-correlation (solid lines: measured, dashed lines: calculated) for (a) address code #1 (π, π, π, 0.5π, 0.5π, 1.5π, 0.5π, 1.5π, π, 0, 0.5π, 1.5π, π, 1.5π, 0, 0), and (b) address code #2 (1.5π, 1.5π, 0, 0.5π, 0, π, 0.5π, 1.5π, 0.5π, 0, 1.5π, 0, π, 1.5π, 0.5π, 1.5π).

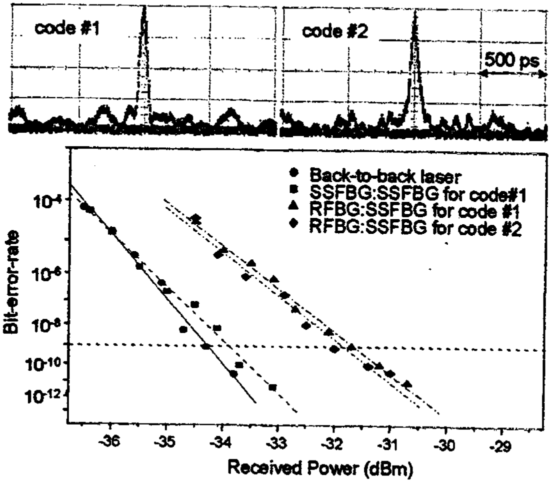

Fig. 4. Bit-error-rate curves of the 622Mbit/s signals (RFBG: reconfigurable encoder, SSFBG: fixed-code decoder). Inset shows eye diagrams of the decoded signals for address code #1 (left) and address code #2 (right).

Conclusions

We have demonstrated a 16-bit, 20Gbit/s reconfigurable FBG-based coder for application in optical header generation/recognition. Error free operation and good auto-/cross-correlation signatures confirm successful operation of the device.

References

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