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MULTI-POINT IN-FIBRE GRATING STRAIN SENSING SYSTEM WITH A COMBINED SPATIAL AND TIME DIVISION MULTIPLEXING SCHEME

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Introduction

In-fibre Bragg grating (FBG) sensors represents one of the most exciting developments in the field of optical fibre sensors in recent years and are currently subject to intensive research. They have a number of advantages compared with other implementations of fibre-optic sensors. One of the main features is that they can be multiplexed in a manner similar to that used for fibre-optic sensors, such as wavelength division multiplexing (WDM), time-division multiplexing (TDM), and their combinations [1-4], etc, making quasi-distributed sensing feasible in practice. However, for many practical applications where FBG sensors must be located randomly in a network for multi-point measurements, interchangeability and ease of replacement in the event of damage without recalibration will be a critical issue. For such applications, it is not feasible to employ series multiplexing topologies, such as WDM and TDM, which are based on a single fibre link arrangement. In order to overcome problems associated with series multiplexing topologies, a parallel topology based on spatial division multiplexing (SDM) was demonstrated very recently by the authors [5]. This parallel multiplexing topology has the following advantages when compared with series multiplexing topologies : the operational wavelength ranges of the sensors can be identical and are unaffected by the number of sensors to be multiplexed, which minimises the cost of fabricating the FBG's; (2) flexibility in deployment as there is one FBG per fibre; (3) easy sensor interchange and replacement in the event of damage.

In this paper, we describe a modification of this topology which combines both spatial and time division multiplexing (SDM + TDM). An eight-element FBG sensor system based on this (SDM + TDM) topology is demonstrated for quasi-static strain measurement. A drift-compensated phase-sensitive detection scheme is used to eliminate the thermal drift of the wavelength scanner, which employs a local reference FGB held at constant strain and temperature in conjunction with the sensing FBG [6].

Experimental System

A schematic diagram of this system is shown in Fig.1. A 1.5mW single mode pigtailed temperature-stablized superluminescent diode (SLD) with a bandwidth of ~18.5 nm (818-836.5 nm) supplied by Superlum Ltd (Moscow, Russia), was used as the light source. The 1 x 8 fibre-optic splitter shown in Fig.2 was specially designed for this system. There are four output ports, with each port containing two fibre transmission lines wtih differential delay lengths of 40 m corresponding to a time delay of 400 ns. FBG sensors were connected to the ends of these fibre lines by fibre connectors (FCs). Eight FBG's were deployed in this network as indicated in Fig.1, and a further eight FBG's could be interrogated without reduction in the signal-to-noise of each sensor. The source was pulsed at a frequency of ~1.1 MHz with a pulse width of ~ 300 ns (duty cycle ~1/3). The pulsed light was launched into the wavelength scanner (WS) and the 1 x 8 splitter. The return pulse signals from the FBG sensors were coupled back into the splitter and detected by an array of four avalanche photodetectors (APD) with integral high-speed amplifiers. The signals from the APD array were selected by a switch (SW1). Thus each APD receives the returned signals from two FBG's separated in time by ~400 ns. These two signals were separated by two high-speed switches (SW2 and SW3) controlled by the delayed electric pulses produced by the pulse generator.

The phase information contained in the interference signal was recovered by the pseudo-heterodyne technique [7]. The WS used in this research was a bulk Michelson interferometer developed by Queensgate Instruments Ltd. The piezoelectric transducer in the WS was driven by a ramp (serrodyne) modulation function at a frequency of 300 Hz. As the optical path difference (OPD) of the WS determines the free spectral range or the total absolute measurement range, it is necessary to determine the OPD of the WS precisely. In this study we achieved this by using a white-light interferometric scheme [8].

The OPD of the WS was ~0.7 mm (equal to a free spectral range of ~0.98 nm). After bandpass filtering (BP's) at the fundamental frequency of the serrodyne signal, the phase of the sinusoidal output corresponding to each sensing FBG was determined relative to the phase to the reference FBG (FBG1). The resolution of the phasemeter was 0.1 degree, corresponding to a wavelength resolution of ~0.27 x 10^{-3} nm for the FSR of the WS (0.98 nm). The sensing and reference FBG's used here were made from a standard 800 nm single-mode fibre that was sensitized by soaking in a high-pressure hydrogen atmosphere. The nominal Bragg wavelength and reflectivity of the FBG's were all ~830 nm and ~90%, with a bandwidth of ~ 0.2 nm. The reference FBG was deployed strain-free and located in the same temperature environment as the sensing FBG's.

Results

The detected signals from this eight-element FBG array are shown in Fig. 3(a) to show the delayed pulses clearly, the amplitudes of these pulses were adjusted by changing the joint loss within the FC's. The demultiplexed signals corresponding to four FBG sensors are shown in Fig 3(b). Cross talk between two adjacent TDM channels was measured to be <-36dB. The experimentally measured static strain-to-phase shift responsivity Fig 4 was ~237 degree /mε , corresponding to a strain-to-wavelength coefficient to ~0.64 x 10^{-3} nm/με. For the thermal drift-compensated measurement, we introduced a quasi-static strain by applying a known displacement to the sensing FBG. The experimental results of the quasi-strain measurement are shown in Fig 4(b) We applied several ~0.2 Hz strain steps of ~9 με peak-to-peak amplitude to the sensing FBG. It can be seen that a strain resolution of ~1.2 με, determined by the noise level, was achieved in a 30-Hz measurement bandwidth. The overall strain range shown in Fig 4(a) was ~1.5mε; hence the achieved range-to-resolution ratio was 1250:1. The interchangeability of this system was demonstrated by moving FBG sensors between the different output ports, virtually no change in sensor performance occured during this procedure.

Summary

In summary, we have demonstrated a combined spatial-and time division multiplexing topology with drift-compensated high-resolution wavelength-shift detection for a fibre Bragg grating sensor system. An eight-element grating sensor array based on this topology is demonstrated although the network can support 16 FBG sensors without affecting the signal-to noise ratio of each sensor. A range-to-resolution ratio of 1250:1 for quasi-static strain measurement has been achieved with a measurement bandwidth of 30 Hz (~0.22 $\mu\varepsilon/\sqrt{Hz}$).

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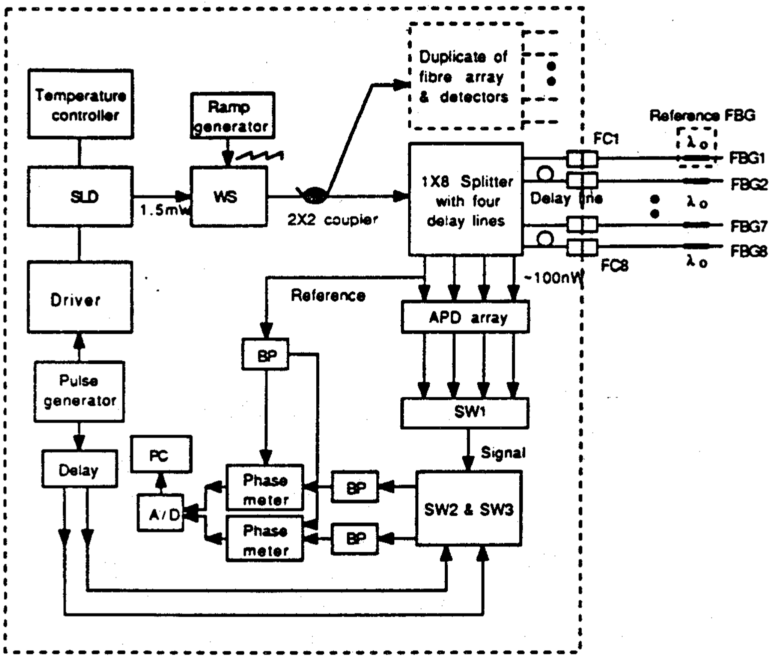


Fig. 1. Schematic diagram of the multiplexing system
SLD: superluminescent diode; WS: wavelength scanner;
FC1-8: fibre connectors; BP: bandpass filter; SW: switch;
FBG: Fibre Bragg grating; APD: Avalanche photodetector.

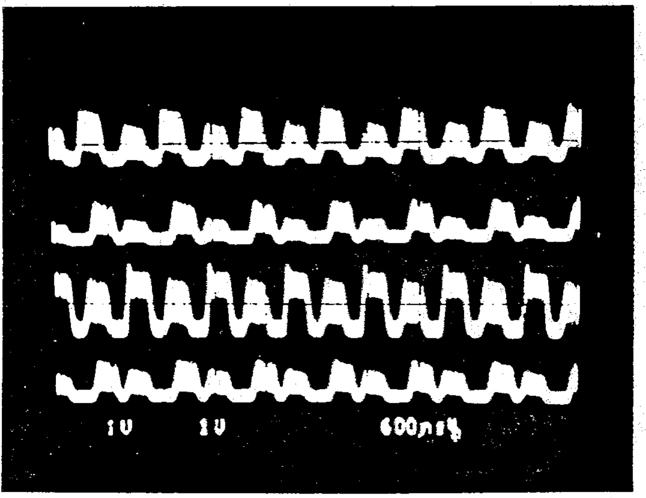
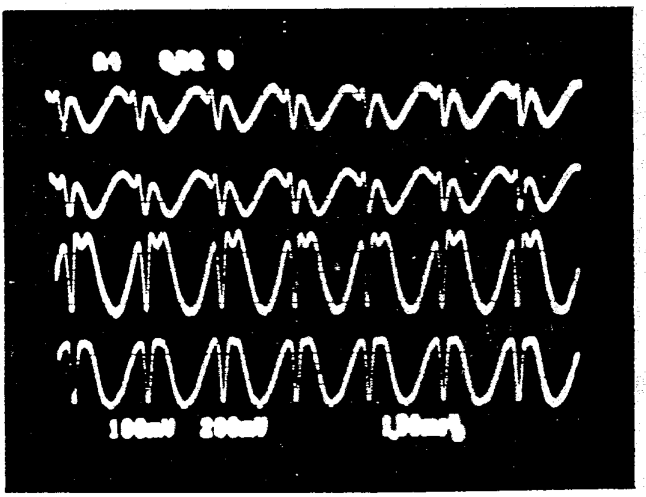


PHOTO DETECTED RETURN PULSE SIGNALS FROM EIGHT GRATINGS EACH TRACE CORRESPONDS TO THE SIGNALS FROM TWO GRATINGS WITH TDM



DEMULTIPLEXED SIGNALS FROM FOUR GRATINGS

FIG 3

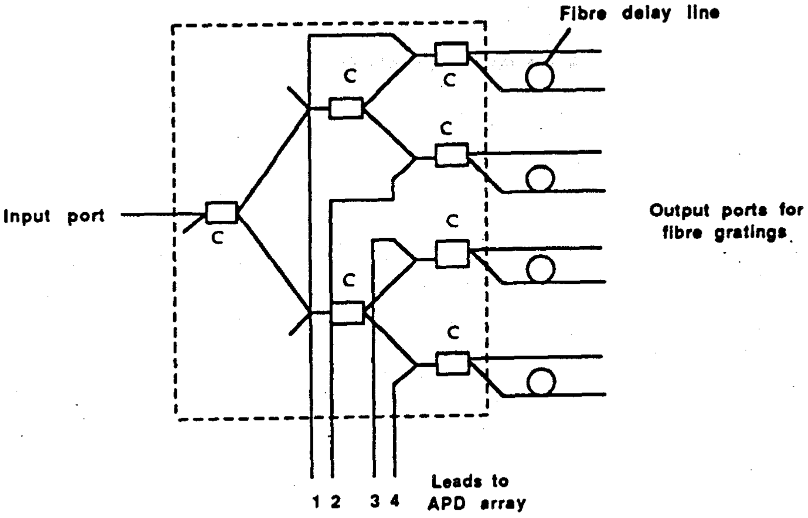


FIG 2 DETAILS OF THE 1*8 COUPLER

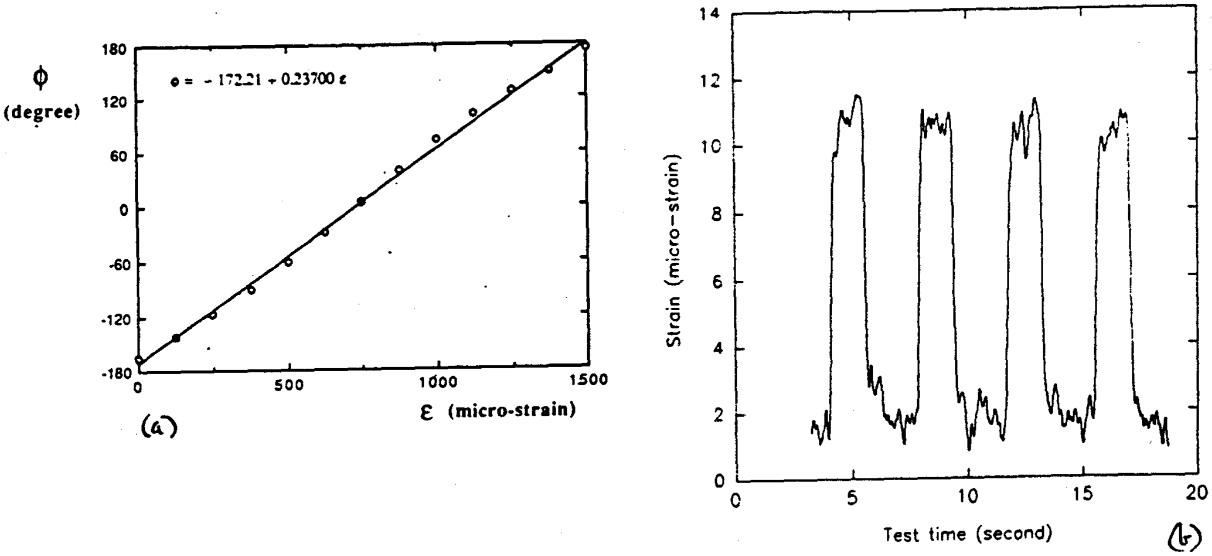


FIG 4 EXPERIMENTAL RESULTS OF THE STRAIN MEASUREMENTS
(a) STATIC STRAIN - PHASE CHANGE AGAINST MICRO -STRAIN
(b) QUASI -STATIC-STRAIN PERTURBATION

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