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2009 Meas. Sci. Technol. 20 043001

(http://iopscience.iop.org/0957-0233/20/4/043001)

Meas. Sci. Technol. **20** (2009) 043001 (5pp) doi:10.1088/0957-0233/20/4/043001

RAPID COMMUNICATION

A simple self-restored fiber Bragg grating (FBG)-based passive sensing ring network

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Received 15 August 2008, in final form 10 February 2009
Published 10 March 2009
Online at stacks.iop.org/MST/20/043001

Abstract
In this investigation, we propose and experimentally investigate a simple self-restored fiber Bragg grating (FBG)-based sensor ring system. This proposed multi-ring passive sensing architecture does not require active components in the network. In this experiment, the network survivability and capacity for the multi-point sensor systems are also enhanced. Besides, the tunable laser source (TLS) is adopted in a central office (CO) for FBG sensing. The survivability of an eight-point FBG sensor is examined and analyzed. It is cost effective since the sensing system is entirely centralized in the CO. Experimental results show that the proposed system can enhance the reliability of the FBG sensing network for large-scale and multi-point architecture.

Keywords: fiber sensor, fiber Bragg grating, sensing network

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Using a fiber Bragg grating (FBG) to serve as a fiber sensor is an important field of research at present [1, 2]. In particular, for the distributed fiber sensing in intelligent architecture, the FBG-based sensor has been studied and identified to act as an important sensing component [3, 4]. For the FBG-based sensor system, multiplexing capability is one of the key characteristics. The multiplexing capability of FBG applications contains wavelength-division multiplexing (WDM), spatial-division multiplexing (SDM), time-division multiplexing (TDM), code-division multiplexing access (CDMA), etc [2–7]. Based on multiplexing technologies and their combinations, they can be easily used to build a large-scale FBG sensor system. Moreover, when a strain or a temperature variation is imposed on the FBG, the Bragg wavelength would drift and cause a detected wavelength shift. When the payload on the FBG approaches limitation, the sensing FBG may be broken. As a result, how to improve the reliability and survivability of FBG sensor systems becomes an important issue for a sensing network. For example, when a fiber cut occurs at bus topology, the fiber sensor cannot be sensed behind the fault point. To maintain the survivability of an FBG-based sensor system against a fiber fault due to environmental accidents, it is a necessary issue to build self-protection architecture for the practical fiber sensor application. Recently, use of star-ring architecture for a self-healing fiber sensor was reported and analyzed experimentally [8, 9]. However, the sensing protection mechanism of the fiber network needs to add active devices in each remote node (RN) for a self-healing function. The method would increase the control complexity and the total cost in the fiber network building.

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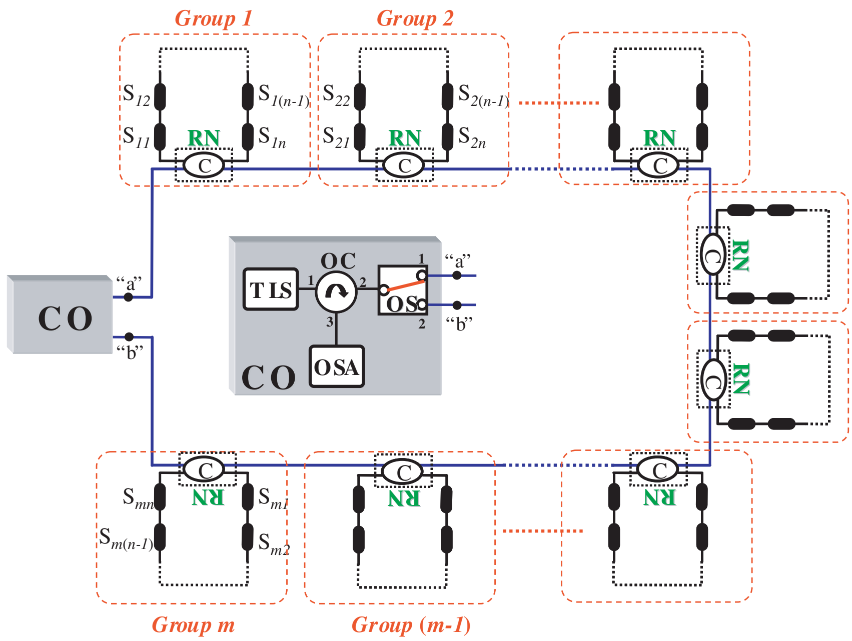

Figure 1. Proposed simple self-restored ring-based architecture for a passive FBG sensor system. S: sensor, C: coupler, CO: central office, RN: remote node, OS: optical switch, OC: optical circulator, OSA: optical spectrum analyzer.

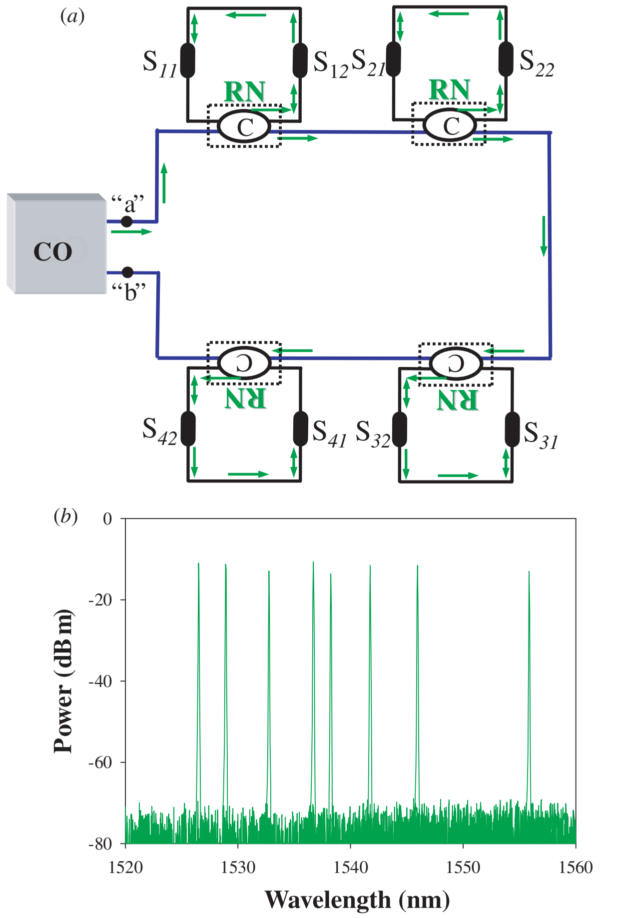

Figure 2. (*a*) Experimental setup for the self-restored passive FBG sensor system with eight FBS sensors from S_{11} to S_{42} at a normal state (without a fault). (*b*) Received output optical sensing spectra from the eight sensing FBGs in CO. (The green arrow presents the sensing transmission of the proposed network.)

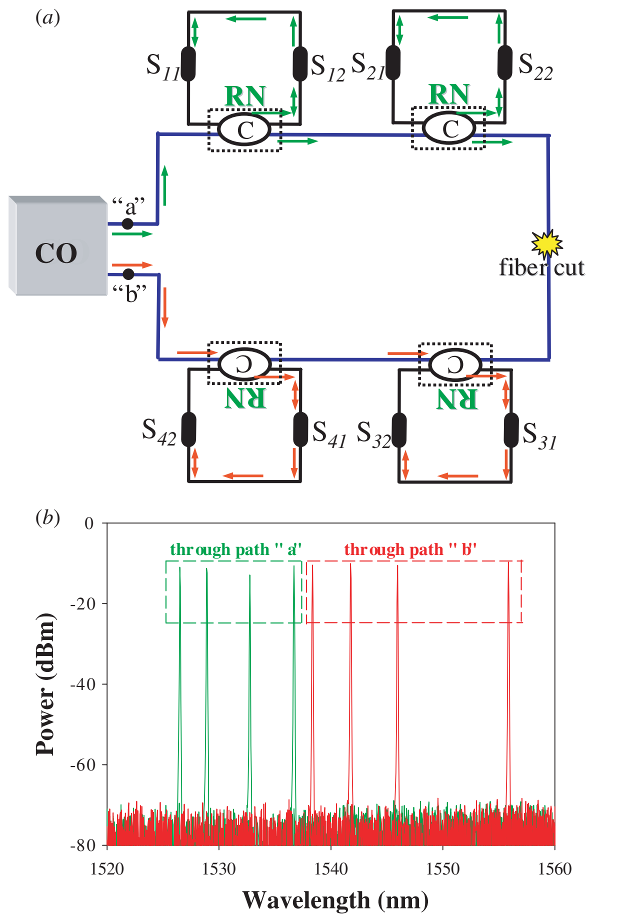

Figure 3. (*a*) When the sensor system has a fiber cut on the major ring between the groups '2' and '3'. (*b*) Received output optical sensing spectra of the eight sensing FBGs in CO. (The green and red lines represent the sensing transmission through paths 'a' and 'b', respectively.)

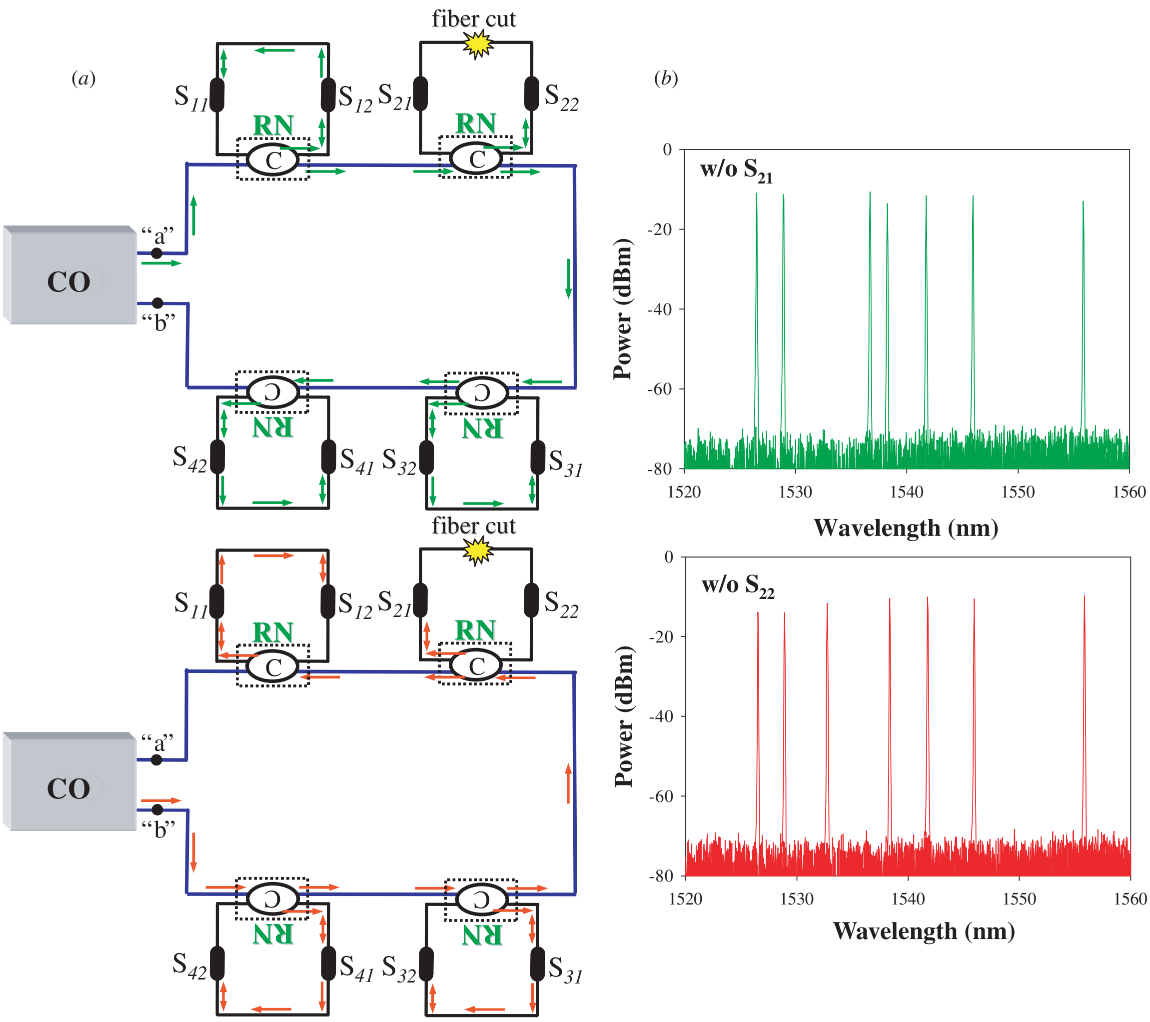

Figure 4. (*a*) When the sensor system has a fiber cut on the sub-ring sensor group '2' in the proposed sensing network. (*b*) Received output optical spectra of the eight sensing FBGs in CO. (The green and red lines represent sensing information through paths 'a' and 'b', respectively.)

In this paper, we propose and investigate simple self-restored ring-based architecture for passive FBG sensor systems to increase the reliability and survivability of the sensing network. Such a self-healing function can be performed promptly by the multi-ring scheme if any link fails. The sensing FBGs in our proposed system are simultaneously used as the feedback elements of the tunable laser source (TLS). Moreover, the benefits of the TLS to connect the multi-ring architecture can facilitate a highly reliable large-scale sensing system.

2. Sensing architecture

Figure 1 shows the self-restored ring-based architecture for a passive FBG sensor system. The central office (CO) is constructed by a tunable laser source (TLS), an optical circulator (OC) and a 1×2 optical switch (OS). Two output ports of an OS are used to connect to the major ring. Besides, the 1×2 OS can be used to select a fiber path 'a' or 'b' for the sensing transmission. We assume that there are m sub-ring sensor groups in the major ring sensing system and that each group has n FBG sensors, as illustrated in figure 1. Each RN uses a 2×2 optical coupler (C) to connect to the sensor group and also connect to the adjacent sensor groups. Thus, the proposed sensing system has $(m \times n)$ FBG sensors. The sensing laser source usually uses a linear-cavity erbium-doped fiber (EDF) ring laser for a fiber sensor because the laser has intense output power and a high optical signal to noise ratio (OSNR) [7]. In our proposed sensing network, the TLS is distributed to each FBG sensor. The TLS has the advantage of high output power and OSNR to detect the FBG sensor in the network. In the measurement, the TLS can be tuned in the wavelengths of 1520–1600 nm with 0.01 nm resolution. When the output wavelength of the TLS is tuned to align the corresponding wavelength of the FBG, the output light will be reflected by the FBG. Besides, the reflected wavelength of the FBG would shift while the strain or temperature change is applied to the FBG. Therefore, the FBG can be used to act as a sensor in the fiber sensing system in order to sense the environmental change based on monitoring the feedback wavelength.

In the sensing network, three fault locations could occur, such as in the major ring, sub-ring and fiber sensor itself.

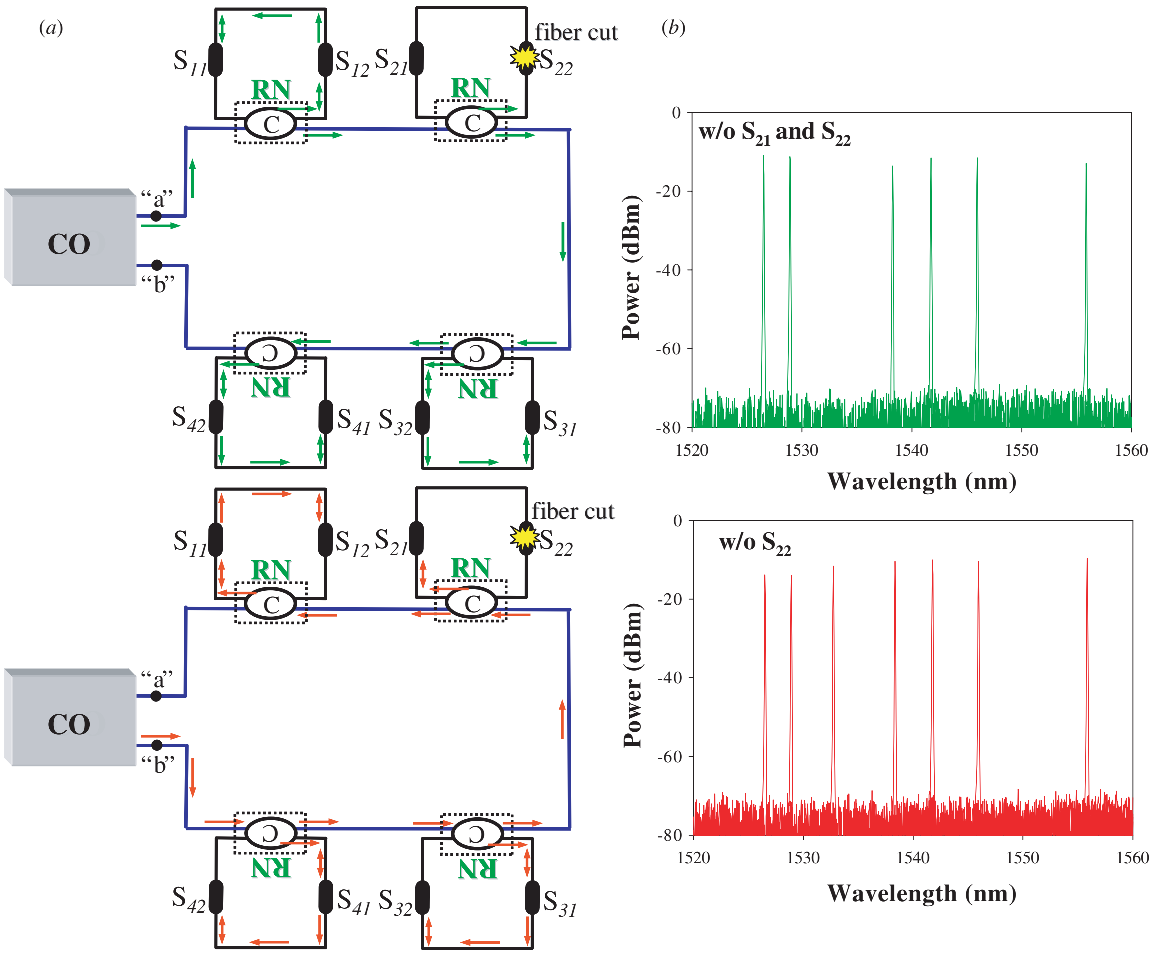

Figure 5. (*a*) When the sensor system has a fiber cut on the sensor S_{22} in the proposed sensing network. (*b*) Received output optical spectra of the eight sensing FBGs in CO. (The green and red lines represent sensing information through paths ‘a’ and ‘b’, respectively.)

In the following analysis, we will discuss and analyze the three situations based on the simple apparatus and ring-based architecture.

3. Experiments and discussions

To realize and evaluate our proposed self-restored ring-based architecture for a passive FBG sensor system, an experiment is performed as shown in figure 2. In the sensing system, *m* and *n* of the setup are equal to 4 and 2 in the experiment. That is to say, there are eight FBG sensors (S_{mn}) used in the sensing network experiment. Each of the sensing FBGs (S_{11} to S_{42}) is used to act as the reflected elements. In the CO, the lasing of the TLS is detected by these FBGs. The Bragg wavelengths of the eight FBGs used are 1526.63, 1528.87, 1532.64, 1536.57, 1538.24, 1541.88, 1545.83 and 1555.85 nm, respectively. In addition, the fiber sensing system can also be used to accurately measure the strain and temperature perturbations applied to the FBGs. The output power of the TLS is at 0 dBm. In normal status, the OS locates at point ‘1’ to connect the path ‘a’. Thus, the lasing wavelength from the CO passes through the path ‘a’ to detect FBG sensors. As illustrated in figure 2(*a*), the green arrows show the sensing transmission path when there is no fault in the sensor system. Figure 2(*b*) shows the received output optical spectra of the eight sensing sensors from S_{11} to S_{42} by using the TLS while the sensing transmission travels through the path ‘a’. When there is no fiber fault in the network, the CO would detect the eight fiber sensors in the proposed sensing system.

Initially, the sensor system will connect through the path ‘a’. When the proposed sensor network has a fiber cut on a major ring between the groups ‘2’ and ‘3’, as shown in figure 3(*a*), the CO can only detect the received output sensing spectra from S_{11} to S_{22} (as seen in a green line), as shown in figure 3(*b*). In order to detect the residual FBG sensors, the OS could switch automatically to point ‘2’ to link the fiber path ‘b’. The sensing transmission is shown in a red arrow, as also illustrated in figure 3(*a*). When the sensing transmission is switched to path ‘b’, the residual output sensing spectra from other sensors (as seen in a red line of figure 3(*b*)) can be detected. As a result, in accordance with the proposed operating mechanism, the self-restored ring-based sensor system could be protected from the fiber fault on major fiber and detect the fault location approximately. If two fiber cuts are between the groups ‘2’ and ‘3’ and the groups ‘3’ and ‘4’ in figure 2, respectively, then sensors S_{31} and S_{32} cannot be detected due to the two faults. However, the probability of producing two fiber faults simultaneously is very low in a real sensing system.

Then we will discuss the fiber fault in a sub-ring sensor group. When a fiber cut occurs between S_{21} and S_{22} in the sensor group '2' through the path 'a', as shown at the top of figure 4(*a*), the proposed sensing network cannot detect sensor S_{21}. Hence, as shown at the top of figure 4(*b*), the output sensing spectrum lacks sensor S_{21}. At the same time, the CO would control the OS to connect to the transmission path 'b', as illustrated at the bottom of figure 4(*a*). At the bottom of figure 4(*b*), the output spectrum of the sensor lacks information of S_{22}. Therefore, comparing the two output sensing spectra of figure 4(*b*), it can be easy to find the fault location by detecting the information of FBG sensors in the proposed network.

In a sensor system, it is necessary to ensure that each fiber sensor is in good condition. Thus, when a strain or temperature change is applied to the FBG due to the environment or artificial effect, the fiber sensor would cause a shift of the Bragg wavelength. When the payload of the FBG exceeds the limitation, the FBG will be broken. So, the proposed sensing system can also look for the position of the broken sensor. For example, while sensor S_{22} is broken in the proposed sensing network through the fiber path 'a', the sensing network cannot detect sensor S_{22} and sensor S_{21}, as shown at the top of figure 5(*a*). Thus, at the top of figure 5(*b*), the output sensing spectrum lacks sensor S_{22} and sensor S_{21}. To obtain and detect the disappeared sensors, the CO would control the OS to connect to the transmission path 'b', as illustrated at the bottom of figure 5(*a*). At the bottom of figure 5(*b*), the output spectrum of sensor information lacks sensor S_{22}. Then, by comparing the two output sensing spectra of figure 5(*b*), we can easily find that the fault is on sensor S_{22}. Besides, if two sensors of S_{22} and S_{32} are cut, the measured output spectra would lack sensors S_{21}, S_{22}, S_{31} and S_{32} through the path 'a'. When the sensing path passes through the path 'b', the measured output spectrum would lack sensors S_{22} and S_{32}. As a result, this proposed sensing network can find two or more sensor cuts.

4. Conclusion

We have proposed and experimentally investigated a simple self-restored FBG-based sensor ring system. There is no active component in the sensing architecture. In this experiment, the network survivability and capacity for the multi-point sensor systems are also enhanced. Besides, the TLS is adopted in the CO for FBG sensing. The survivability of an eight-point FBG sensor is examined and analyzed. Experimental results show that the proposed system can enhance the reliability of the FBG sensing network for large-scale and multi-point architecture.

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