# 國立台北科技大學

光電工程系

專題論文

# 光纖環型雷射於長距離感測系統之研究

# Long-Distance Sensor System Based on Fiber Ring Laser

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# List

# I. Motivation and Methods

## A. Motivation

Fiber Bragg grating (FBG) has been used in fiber translations widely. It has many advantages like high sensitivity, anti-electromagnetic interference and easily to make because of small volume. It also has big potential of application in structural engineering, fiber monitoring system, pressure sensor, vibration sensor and temperature Sensor.

How long can be transmitted in the fiber sensor is a point in long distance sensing system. So, there're many people propose some methods to add the monitoring distance of fiber sensor. By Erbium Doped Fiber Amplifier (EDFA) we can use amplifier spontaneous emission (ASE) as broadband light source and sensing with fiber grating.

However, the amount of monitor and the distance are limited by power of broadband light source. That is, we propose this fiber laser structure to improve. It concludes erbium fiber, resonator mirrors and Bragg grating to be monitoring devices. It has higher signal-to-noise ratio (SNR) and power than traditional structure.

## B. Research Methods

After we refer to so many papers, the new structure is developed. By the designed network and applying fiber grating, we will show you a new fiber network monitoring system. The application of fiber grating is conclude Large Structural Engineering, Aerospace engineering, Nuclear Engineering and Hydraulic Power. Following shows the advantage of fiber grating.

1. High sensitivity, Optical fiber splice loss is small, long distance measurements sense is applicable.
2. Small size and a typical use of 125um diameter, Embedded in the composite material does not affect the structural properties.
3. Corrosion resistance and electromagnetic interference: the changing natural environment can be used without affecting the quality sensing.
4. Temperature: about 300 ° C, suitable for high temperature environments.
5. Long life: fiber grating after proper exposure and annealing process can be stable for more than 25 years, reflectivity degradation does not produce.
6. Use of broad: Large multi-point measurement system architecture simplifies the measurement range.

# II. Reference Architecture

Fiber Bragg grating (FBG) sensors are very attractive in many applications due to their high versatile advantages such as high sensitivity, electro-magnetic immunity, compactness, the FBG has great potential to be applied to health monitoring of engineering structures nondestructive testing of composite materials, smart structures, and traditional strain, pressure and temperature sensing[1-4]. In long-distance FBG sensing, the most important problem is Rayleigh scattering in the transmission fiber connecting the FBGs and interrogation. Due to the noise and loss induced by the Rayleigh scattering and attenuation along the fiber respectively, the maximum transmission distance with a broadband light source is limited up to 25km [5]. Because of that, the measurement distance and time delay of FBG sensor system comes out to be an important issue [6]. In order to increase the measuring distance and to achieve a long-distance, several methods have been proposed [7-9], which used too much EDF, make the setup system complicated. In summary, because of the measurement length limitation by the loss and attenuation along the fiber, increasing the pump power to be the most effective method to get a longer distance and high spectral density broadband light sources would be needed. However, lasing effects were induced when the pump power was increased to a threshold, which is the main reason why it is hard to get longer distance FBG sensor system. In practical, usage simple and easily long distance sensor system are desired.

In this letter, a novel 110-km FBG sensor system with signal-averaging functionality is proposed and demonstrated. A signal-averaging module is introduced into the fiber laser to reduce the impact of noise on the system performance, increasing the SNR of the system. We proposed a technique to reduce the Rayleigh effect for long-distance FBG distributed sensing. This fiber Bragg grating sensor system based on the utilization of different fibers to send and collect the optical signals from sensors. In real applications, the cost of the system does not have a significant added increment if two single mode fibers (SMF) are used inside the fiber optic cable instead of only. On top of that, this kind of scheme with two optical paths becomes easy-going sensor systems which address some of the dominating limitation factors such as double Rayleigh scattering. This 110-km long distance FBG sensor system was achieved by using a fiber ring. The following section will experimentally demonstrate the operation of the control center (CC) based on the proposed fiber ring laser. Finally, this FBG sensor system scheme with signal-averaging functionality is able to detect the FBGs placed 110 km away with a signal to noise of 10dB.

# III. System Architecture and Design

## A. System Design

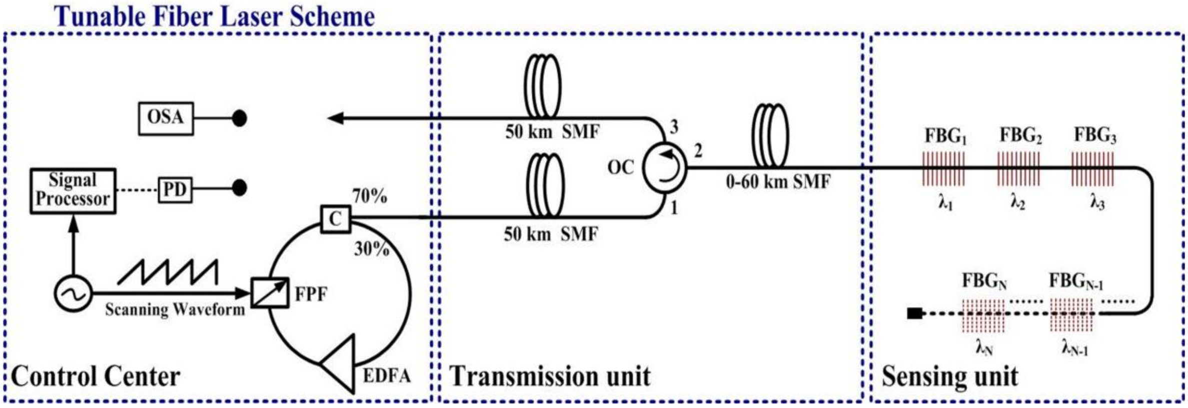


Fig.1 Experimental setup for demonstrating feasibility of proposed long-distance FBG sensor system (C: 1×2 coupler, EDFA: erbium-doped fiber amplifier, FPF: Fabry-Perot filter, PD: photodetector, OSA: optical spectrum analyzer, OC: optical circulator, SMF: single-mode fiber, FBG: fiber Bragg grating).

The schematic diagram of the proposed FBG sensor system is shown in Fig.1, the system could be divided into three essential sections. The sensor unit is composed by three multiplexed FBG sensor, the FBGs are disposed in serial configuration and located within the fiber ring laser wavelength band. The peak reflectivity of each FBG is around 94% and the Bragg wavelengths of the FBGs $\lambda_i$ (i = 1, 2, 3) are 1548.26, 1551.1 and 1553.871 nm respectively. The back reflected sensing signals from each FBG finally propagated through the circulator and into the photodetector (PD) and optical spectrum analyzer (OSA). The control center (CC) is responsible for providing the light source and discriminating among the back reflected sensing signals from the sensor unit. The fiber ring laser was constructed by an erbium-doped fiber amplifier (EDFA), a Fabry-Perot filter (FPF) with 50-nm tunable range, a signal processor and a 1×2 30/70 coupler (C). Its lasing wavelength is determined by the tunable FPF.

Seventy percent of any lasing light is fed into the sensing FBG chain via the 1 × 2 fiber coupler to interrogate the deployed FBG sensors. Figure 2 displays the output spectra at the 70% lasing port when the FPF is tuned with a voltage controller. To tune the voltage to within the above operating range, a lasing wavelength in the waveband 1525.51–1575.37 nm is chosen. The lasing peak power from this 70% output port is about 10.76 dBm. Figure.3 shows the stability of the laser with a central wavelength of 1552.48 nm, which is measured at the 70% lasing port within 15 mins. From the measured power curve, the variation in the output laser power is $(P_{max}–P_{min})/\overleftarrow{P}_{out}$= 0.58%, where $P_{max}$, $P_{min}$ and $\overleftarrow{P}_{out}$ represent the maximum, minimum and average output laser powers, respectively. The average wavelength variation is 0.04 nm. The stability of a long-distance fiber sensor system that is based on the fiber laser scheme as its CC depends on the above two metrics and the adopted electronic signal-processing method.

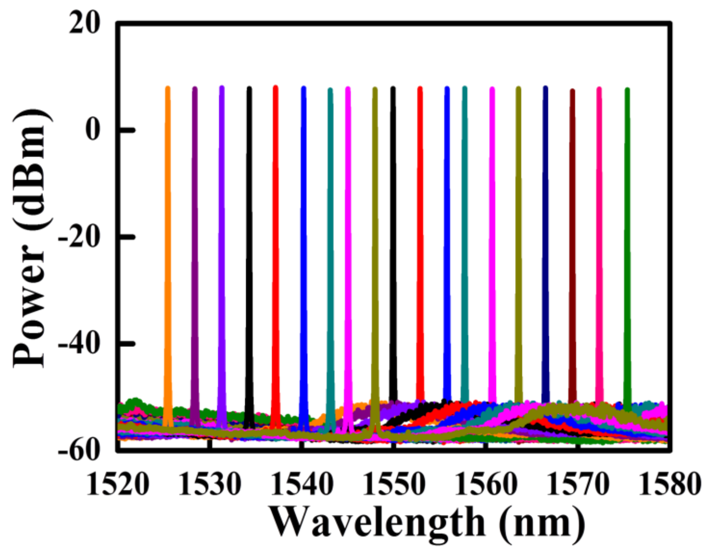


Fig.2 Output spectra from 70% lasing port within range from 1525.51 to 1575.37nm

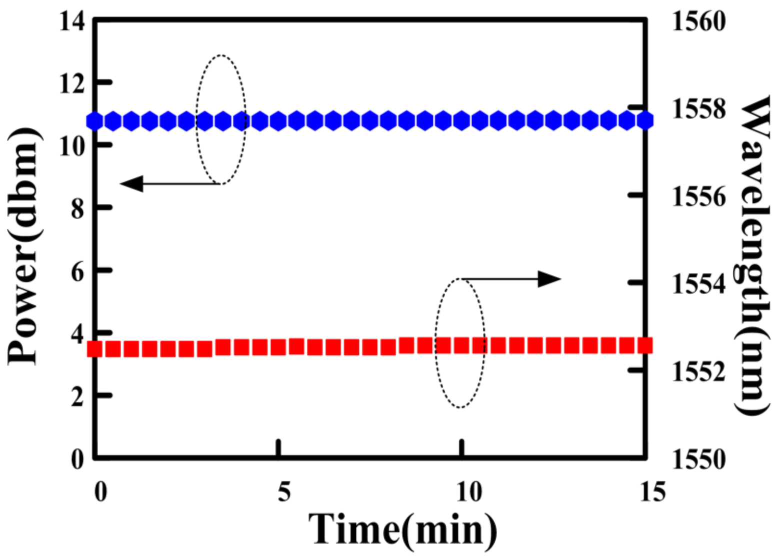


Fig.3 Laser stability in terms of output power variation and wavelength drift, measured at 1552.48 nm over 15 minutes

The transmission unit consists of two identical-length optical paths, a circulator which redirects the reflected signals towards the reception system and a 0~60km single-mode fiber (SMF). The first one intended to launch the laser signal by the fiber ring laser and the other one is employed to guide the reflection signal to the reception system. Signals propagating in the opposite directions using the same wavelength in the bidirectional transmission system suffer from impairment because of unavoidable Rayleigh backscattering. This kind of scheme with two optical paths becomes easy-going sensor systems which address some of the dominating limitation factors such as double Rayleigh scattering.

For the sake of brevity, our exposition is focused on a component FBG sensor $G_i$ in the proposed system. Let k denote the scanning frequency that the FBG sensor $G_i$ would be scanned in its corresponding time slot, while $x_{ij}$ , j=1,2, ⋯,k, be the jth signal reflected from $G_i$ and received at the CC. Note that $x_{ij}$ has the desired sensing signal component $S_i$ and the noise component $n_{ij}$. The $n_{ij}$'s, j=1,2, ⋯,k, are modeled as independently and identically distributed random variables with distribution $N(0,\sigma_{ni}^2)$. Therefore, those k signals reflected from the FBG sensor $G_i$ and collected by the CC can be expressed as

$$x_{ij}=S_i+n_{ij},\ j=1,2,\cdots,k \qquad (1)$$

Their average is obtained as

$$\begin{aligned} Y_i &= \frac{1}{k}\sum_{j=1}^{k} x_{ij} \\ &= \frac{1}{k}(k\cdot S_i + n_{i1} + n_{i2} + \cdots + n_{ik}) \\ &= S_i + \frac{1}{k}(n_{i1} + n_{i2} + \cdots + n_{ik} \\ &\cong S_i + n_i' \end{aligned} \qquad (2)$$

Where $n_i'=\frac{1}{k}(n_{i1} + n_{i2} + \cdots + n_{ik})$.Because the k gaussian noise random variables $n_{i1}, n_{i2}, \cdots$and $n_{ik}$ are independently and identically distributed, the variance of their arithmetic mean $n_i'$ is given by

$$\begin{aligned} \sigma_{n_i'}^2 &= \frac{1}{k^2}(\sigma_{n_1'}^2+\sigma_{n_2'}^2+\cdots+\sigma_{n_k'}^2)=\frac{1}{k}\sigma_{ni}^2 \\ \sigma_{ni1}^2 &= \sigma_{ni2}^2=\cdots= \sigma_{nik}^2 = \sigma_{ni}^2 \end{aligned} \qquad (3)$$

Hence, the SNR with respect to the FBG sensor $G_i$ can be formulated as

$$SNR_i = \frac{S_i^2}{\sigma_{n_i'}^2} = k \cdot \frac{S_i^2}{\sigma_{ni}^2} \qquad (4)$$

It is quite obvious that the larger the parameter k is, the higher the metric $SNR_i$ is. For each of the other component FBG sensors in the proposed system, such dependence between its scanning frequency and its corresponding SNR metric also holds. However, a large k leads to a long interrogation process. Thus a tradeoff exists between the system SNR performance and scanning time in designing its interrogation scheme.

## B. Experimental Results

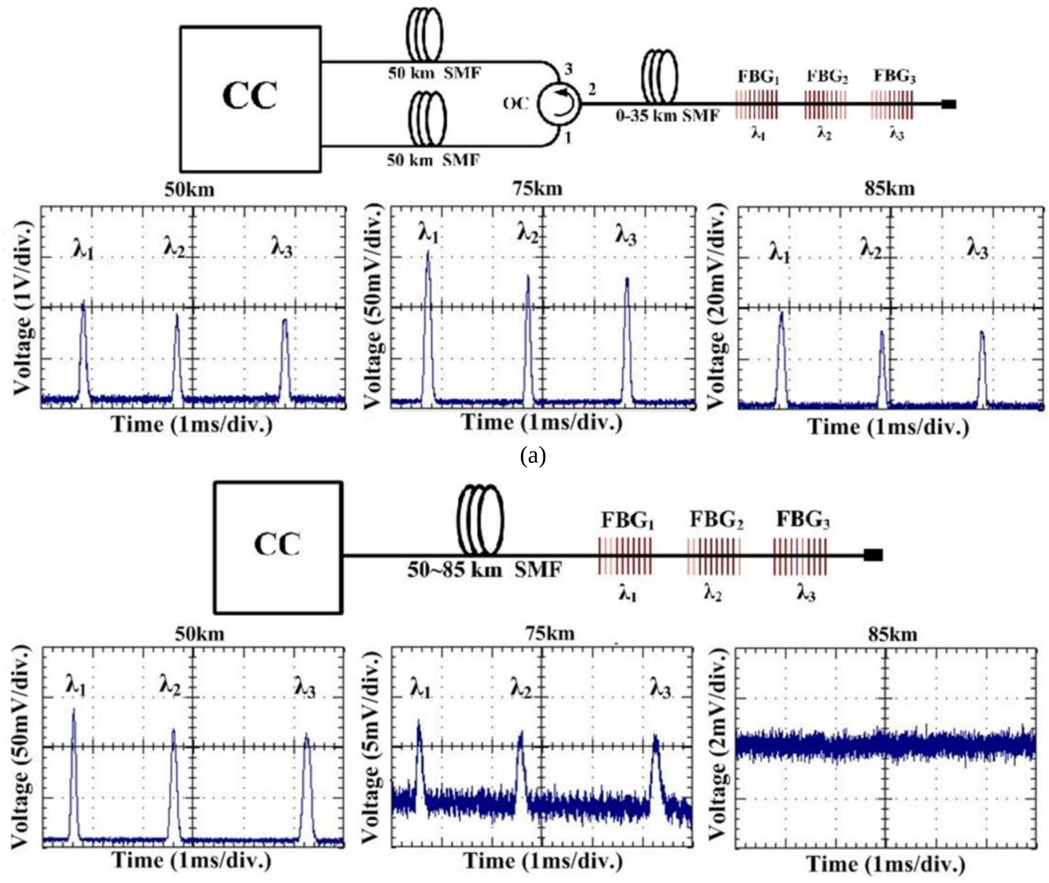


Fig.4 In the time domain: 50km、75km and 85km of (a) proposed (b)classical FBG sensor system

In this experiment, three sensing FBGs were examined. These three sensing FBGs generated a triple-wavelength fiber laser for the proposed long-distance sensor system. Figures.4(a) plot the output signals obtained without signal-averaging processing when 50、75 and 85 km FBG sensor arrays in time domain and the $\lambda_2$ side mode suppression ratio (SMSR) are 35、24 and 17 dB, respectively, are attached to the fiber ring laser in the proposed long-distance FBG sensor system. To compare the characteristics of different schematic, experiments with only the one optical path were performed. Figures.4(b) plot the output signals obtained without signal-averaging processing when 50、75 and 85 km FBG sensor arrays in time domain and the $\lambda_2$ side mode suppression ratio(SMSR) are 16dB、4dB and less than 1dB, respectively, are attached to the fiber ring laser in the classical long-distance FBG sensor system.

Such a fiber laser incorporates signal-averaging functionality inside the CC. In our scheme, each component FBG sensor would be scanned many times in a given time slot and those sensing signals reflected from an FBG would be averaged at the CC. This enables a significant improvement in the SNR performance of the proposed system, whose theoretic basis is addressed in the following.

Next, they are sampled, digitized and buffered in that order. After the above process has been carried out 256 times, signal-averaging is performed by the signal processor and the average SNR for each FBG sensor is thus calculated. Figures 5(a) and 6(b) plot the output signals obtained without and with signal-averaging processing when 110 km FBG sensor arrays, respectively, are attached to the proposed fiber ring laser. The SNR of the system declines as the distance between the fiber laser scheme and the FBG sensors increases. The signals that have undergone signal-averaging processing, displayed in Fig.5(b) is not as rough as the output signals in Fig.5(a).Accordingly, the signal-averaging operation increases the SNR of each remote FBG sensor.

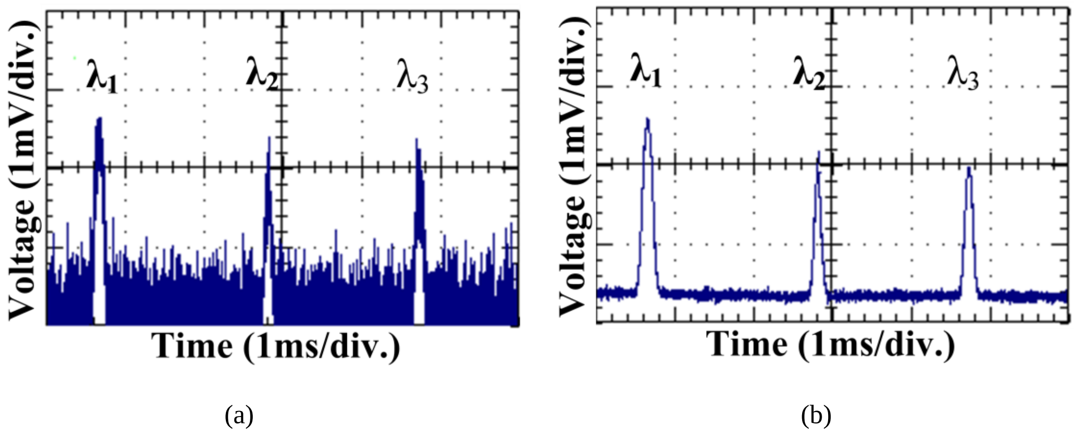


Fig.5 Output signals (a) without and (b) with signal-averaging processing when a 110 km FBG sensor array are attached to the fiber laser.

# IV. Future

We used a fiber ring laser with one erbium-doped fiber amplifier (EDFA) on 110-km fiber Bragg grating sensor system .Experimental results showed our FBG sensor system was located 110-km away from the monitoring station, and signal to noise ratio of 14 dB was reached.

The future of our purposed, fiber ring laser can facilitate a long-distance or a large-scale fiber sensor system and can be easily extended for multipoint sensing applications.

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