Chapter 3. Design and Implementation of the SCIIB Sensor Systems

This chapter will describe the design and implementation of two SCIIB sensor systems. One system is multimode fiber-based at a low cost used for short distance applications. The other is a single-mode sensor system designed for long distance applications.

3.1. Multimode Fiber-Based SCIIB System

Multimode fibers have a large core diameter. Therefore, optical power can be coupled from the source into the fiber efficiently and cheaply. However, because of the relatively high loss of the multimode fiber at this wavelength, the system is mainly designed for short distance applications at a low cost, typically less than 1km from the actual sensing region to the signal processing unit.

The multimode fiber-based SCIIB sensor system, with its schematic design shown in Figure 3-1, and the photo of the system shown in Figure 3-2, is designed to operate at the central wavelength of 850 nm and uses 62.5μm/125μm standard telecommunication fibers.

The source used for the multimode SCIIB system is an LED (Honeywell, HEF 4854-014). The spectrum of the LED is given in Figure 3-3, with its central wavelength of 850 nm, spectral width of 70 nm, and the typical output power of 120 μW to a 62.5/125μm multimode fiber. In the multimode fiber system, a polarization insensitive cubic beam splitter with the splitting ratio of 50:50 is used to split the light from the sensor head into two channels. One portion of the light from the beam splitter passes an optical bandpass filter with the central wavelength of 850 nm and the full width at the half maximum

(FWHM) of 10 nm. Two silicon detectors with large effective areas (31 mm^2) are used to receive the signals of the channels. After amplification using two trans-impedance amplifiers, the two signals from these two channels are sampled and converted to digital data by a high-precision A/D converter. The ratio function of these two channel signals is then performed by a host computer.

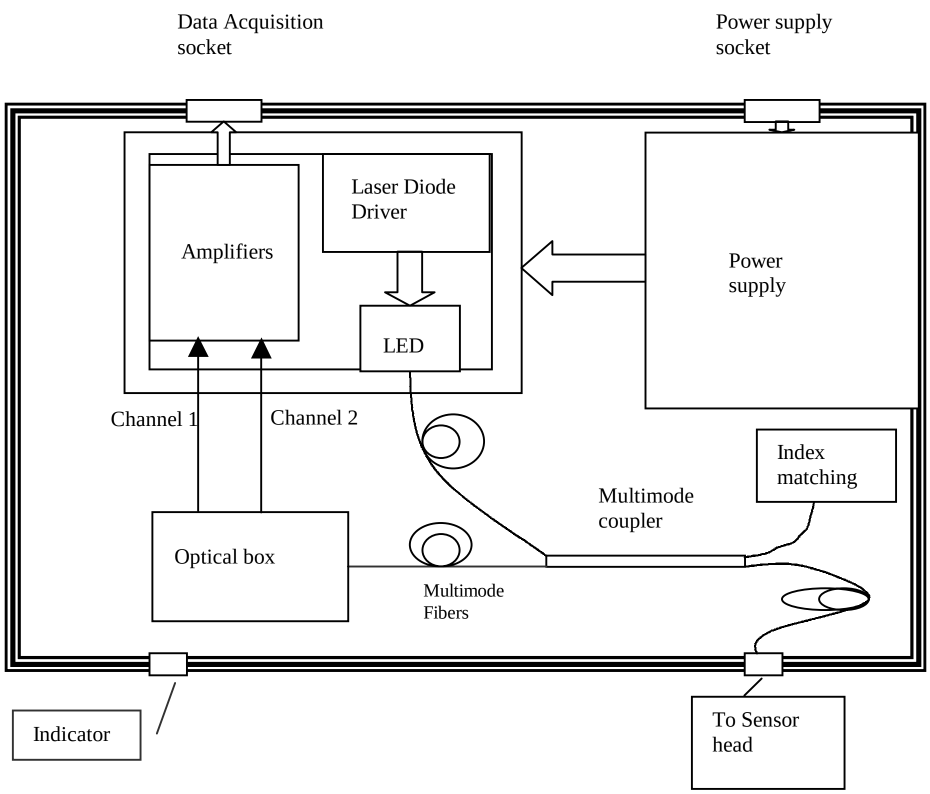

Figure 3-1. Schematic of the multimode SCIIB sensor system

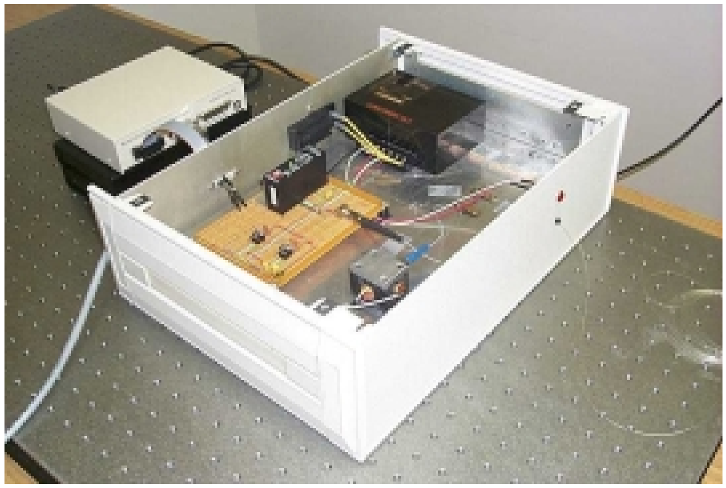

Figure 3-2. Photograph of the developed multimode fiber-based SCIIB sensor system

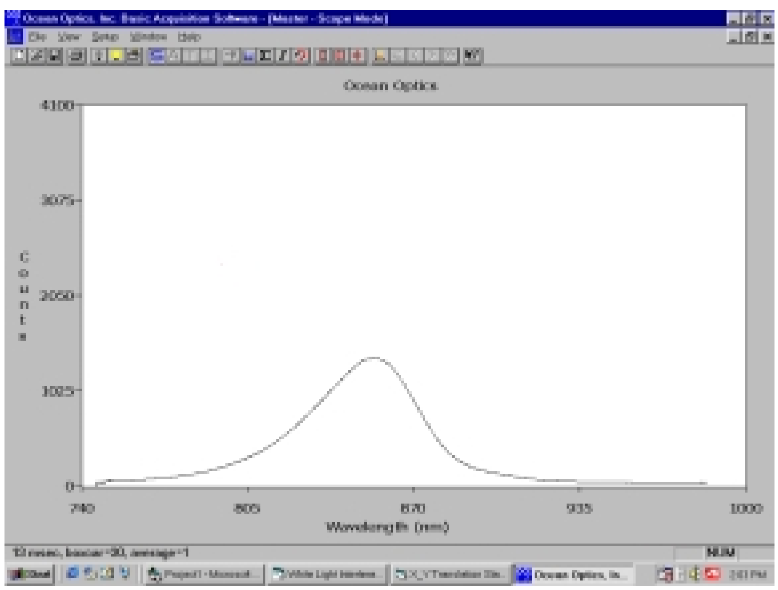

Figure 3-3. Optical spectrum of the source LED

3.2 Self-Compensation Capability Test for the Multimode SCIIB System

One unique advantage of the SCIIB sensor is its capability of self-compensation for fiber loss variation or source power drifting. The SCIIB sensor uses two channels with different coherence lengths for sensing and referencing respectively. The self-compensation results from the fact that the optical power received at these two channels comes from the same source and experiences the same transmission path. The common unwanted effects can therefore be eliminated by taking the ratio of the two output signals of the two channels.

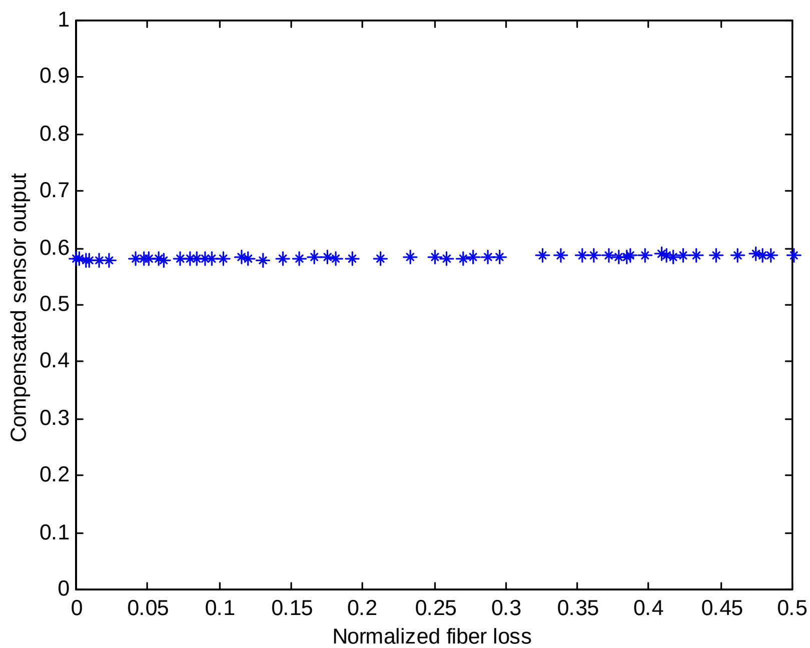

Figure 3-4. SCIIB sensor compensated output for fiber bending loss

Figure 3-4 shows preliminary test results of the fiber loss compensation capability of the multimode fiber-based SCIIB system. The fiber used in the test was a standard telecom 62.5/125 μm graded index multimode fiber. We introduced power loss to the system by manually bending the fiber to various diameters without changing the sensor cavity length. Two multimeters were used to record the output voltages from each channel. As expected, although the outputs of the two channels changed due to the increase of the power loss, the ratio of the two channel outputs remained the same. The sensor output ratio varied less than 1% over the full testing range (up to 50% of the total power loss), which indicated that the implemented multimode fiber-based SCIIB system had an excellent self-calibration capability to compensate the fiber loss variation.

3.3. Single-Mode Fiber-Based SCIIB System

Single-mode fibers have no intermodal dispersion and very low optical attenuation to the transmitted light. The typical attenuation of single-mode fiber is about 0.3dB/km at the wavelength of 1300nm and 0.2dB/km at the wavelength of 1550nm. Therefore, light can be transmitted inside the single-mode fiber for a very long distance. However, due to the small core diameter of single-mode fibers, it is relatively difficult to couple the light efficiently from optical sources into the fiber. Also, the low-noise detection of the light at 1300nm or 1550nm requires expensive InGaAs photodetectors. Therefore, the cost of single-mode fiber-based sensor systems is much higher compared to those made by multimode fibers. The single-mode fiber-based SCIIB sensor system is mainly designed for long distance applications, typically longer than one kilometer from the actual sensing region to the signal processing unit.

The schematic of the single-mode SCIIB sensor system is shown in Figure 3-5, and the photograph of the system is shown in Figure 3-6. The single-mode SCIIB system is designed to operate at the central wavelength of 1310 nm and to use single-mode fiber to transmit optical signals between the sensor probe and the signal-processing unit.

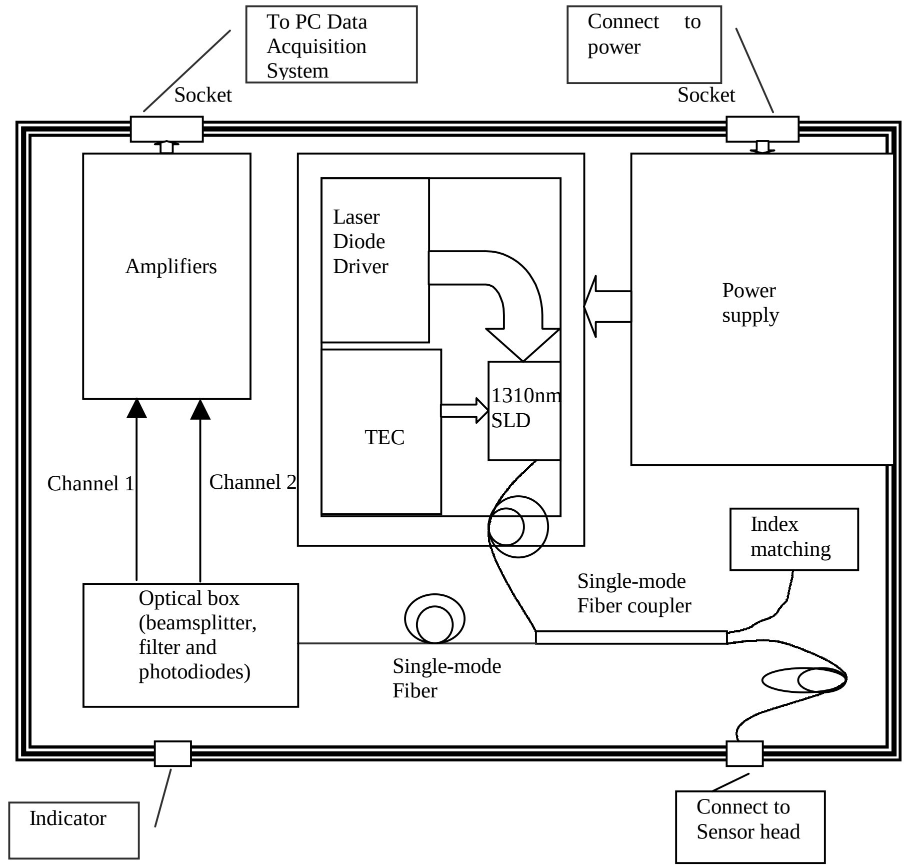

Figure 3-5. Schematic of the single-mode SCIIB sensor system

Figure 3-6. Photograph of the developed single-mode SCIIB sensor system

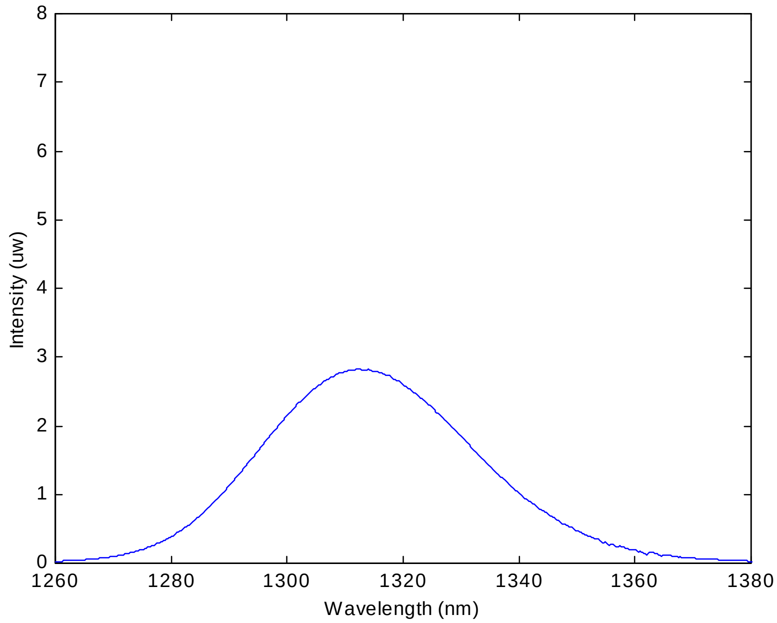

Figure 3-7. Optical spectrum of the SLED source

The source used for the single-mode fiber-based SCIIB system is a high power superluminescent light emitting diode (SLED) provided by Anritsu Corp. (AS3B281FX), with the central wavelength of 1312 nm, the spectral width of 41.5 nm, and the output power of 1.21mW into a 9/125μm pigtailed single-mode fiber. Figure 3-7 shows the source spectrum measured by an Ando Optical Spectrum Analyzer (OSA).

A polarization insensitive beam splitter with a splitting ratio of 50:50 at the wavelength of 1310nm is used to split the light signal from the sensor head into two channels. In one channel, the light passes an optical neutral density filter (its function will be discussed in Chapter 5) and is detected by a large effective area InGaAs photo-detector and amplified to offer the reference signal. The light in the other channel passes through an optical bandpass filter with its central wavelength at 1310 nm and the FWHM spectral width of 10 nm. Because the spectral width of this channel is much narrower, an interferometric signal as the function of the sensor cavity length can thus be obtained after the photo-detection. Similar to the multimode fiber-based system, the two channels' outputs are sampled and converted to digital signals and input to a host computer where the ratio and linearization can be performed easily.

3.4 Electronic Circuits and Software

The receiving electronics for the photodetectors are very simple, consisting basically of a transimpedance amplifier to convert the photocurrent from the photodetector to a voltage output. The schematic of the circuit is shown in Figure 3-8. The central unit is a low noise FET operational amplifier (AD795) manufactured by the Analog Device Corp. The circuit is designed to have a voltage-current gain of 10^7 V/A and the 3dB bandwidth can be calculated as:

$$f_{3dB} = \frac{1}{2\pi R_1 C_1} = 15.92\,(\text{Hz}) \qquad (3\text{-}1)$$

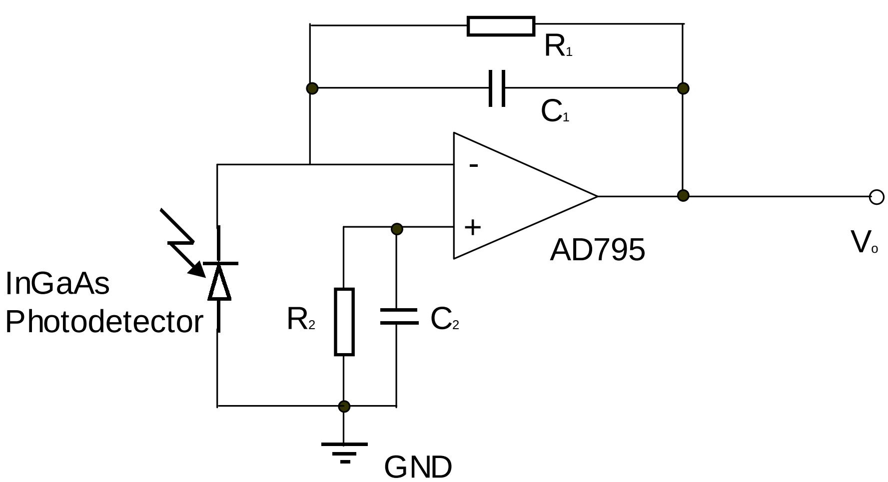

Figure 3-8. Schematic of the receiving electronic circuit

($R_1 = R_2 = 10$ MΩ, $C_1 = C_2 = 1000$ pF)

SCIIB signal processing requires a ratio function to compensate the unwanted optical power fluctuation. In the system implementation, the ratio of the two channels is performed digitally through the host computer. A 23-bit data acquisition system purchased from Lawson Labs Inc. was used in the system to convert the analog output from the SCIIB two channels to digital data. Computer programs were also written to interface the A/D system so that two channels were sampled alternately. A scanning window filter was designed in the software to further filter the high frequency noise. After the dark current correction, the ratio of the two channels data was mapped to pressure output through the prestored calibration curve.