Chapter 3: System Overview

As discussed in the previous chapter, an EFPI can be used to measure a number of different parameters as long as the external parameter produces a change in the gap length of the sensor. The sensor geometry of the EFPI can be modified accordingly to obtain maximum sensitivity to the measurand. The following sections describe the design and fabrication of an EFPI-based sensor system used to measure ultra-low-level, DC magnetic flux densities.

3.1 Principle of Operation

The optical fiber based magnetic field measuring system uses a modified EFPI geometry for the measurement of ultra-low-level fields. The dynamic range of the system is 100 nT to 40,000 nT (1 mG to 0.4 G) with a resolution of 100 nT. The upper limit of the dynamic range corresponds to the magnetic field level on the surface of the earth. The system is primarily designed for space based applications, typically on-board weather satellites. As can be seen from the measurement requirements on the system, sensitivity as well as resolution are of utmost importance. Hence in addition to increasing the sensor response to external magnetic fields, it is necessary to maintain the noise level in the system to a minimum. Various methods developed to increase the signal to noise ratio (SNR) of the system will be briefly described in the subsequent sections. Figure 3.1 shows the schematic of the modified EFPI-based magnetic field sensor. As can be seen from the figure, the single axis sensor consists of two modified EFPIs which are in quadrature with each other. A single mode fiber carries light at a wavelength of 1320 nm to and from the EFPI sensor cavity. The reference reflection takes place at the first glass-air interface. About 4% of the incident light is reflected back as reference reflection. The sensing fiber in the EFPI in this case, is replaced by a magnetostrictive filament. The sensing reflection takes place at this metal-air interface. Reflected reference and sensing waves interfere in the single mode fiber to yield a fringe pattern at the output. Figure 3.2 shows the overall system arrangement for a single axis field measuring system.

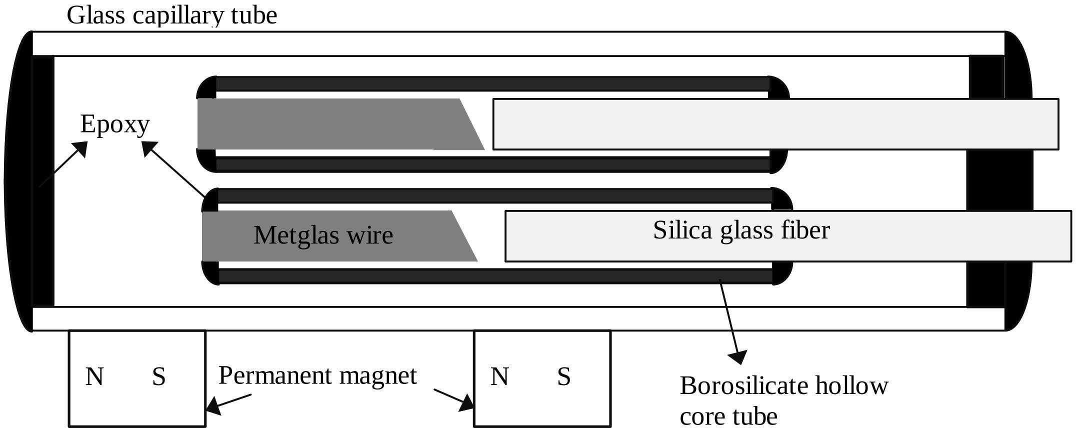

Figure 3.1 Schematic of single-axis, passively temperature compensated sensor.

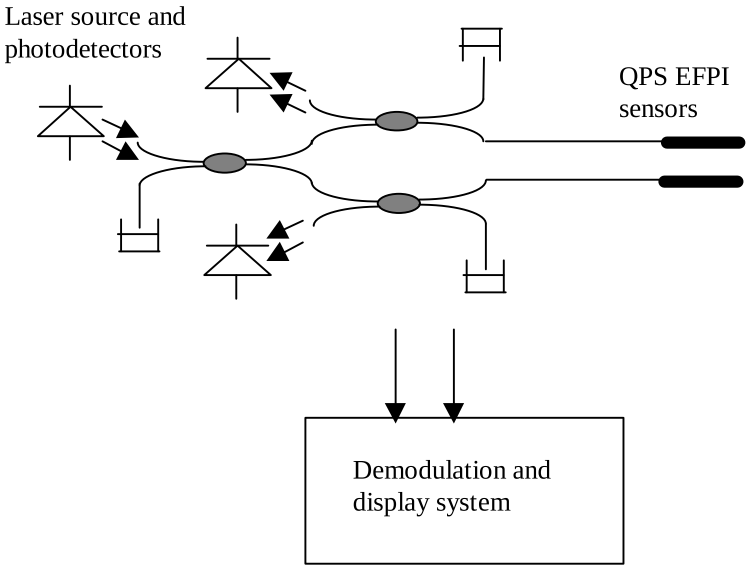

Figure 3.2 Overall system arrangement for a single axis system.

In order to increase sensitivity, it is necessary to select a material with high magnetostrictive coefficient as the sensing element. Metglas exhibits a sensitivity of almost 5 ppm/G in the range of interest if properly biased in the region of maximum sensitivity. Thus a 5 cm long filament of metglas can produce a gap length change of 0.25 nm in the presence of a 100 nT external magnetic field. For a source wavelength of 1320 nm, this is almost 0.075% of the peak to peak value of the fringe pattern if the sensor is operated at the quadrature point. This displacement, though extremely small, is measurable. Hence metglas is an ideal candidate for this particular application.. The composition of the glassy metal filament used in the above schematic is $Fe_{77.5}B_{7.5}Si_{15}$. As can be seen from the figure, a pair of permanent magnets are used to bias the metglas filament to its region of maximum sensitivity.

Since the signal output, particularly at the lower end of the dynamic range, is small, it is pertinent to keep any inherent noise to its minimum level. Laser source fluctuation, temperature variation, mechanical vibration and thermal noise in the associated electronic circuitry are the major sources of noise in the system.

In order to keep the source fluctuations to its minimum, the laser diode is driven by a stable current source and the temperature maintained by a thermo electric cooler (TEC). In addition, the output from the sensor is normalized using the signal from the laser source. As can be seen from Figure 3.1, the metglas filament is polished at an angle to the vertical axis. The polished endface reduces the amount of light reflected from the polished end thus making it comparable to the reference reflection. As a result, the fringe visibility of the output signal is greatly increased without increasing the gap length. Thus any fluctuation in the signal output due to variation in its DC level is minimized and hence there is an increase in the SNR of the system.

Gap length change due to temperature variation in the sensor is passively compensated by making use of the difference in coefficients of thermal expansion (CTE) of the materials used in the fabrication of the sensor [13]. Although complete passive temperature compensation using this scheme is practically impossible, 98% compensation has been achieved in the above system.

The sensors are then packaged so as to shield them from external temperature variation as well as mechanical vibration. Thermal noise in the system is reduced by shielding the electronic circuitry from EMI and using low-noise components.

3.2 Optical Components of the System

The magnetic field measuring system, essentially consists of three main sub-systems as shown in Figure 3.2. The Laser diode, the couplers and the photodetectors make up the optical sub-system. The preamplifiers and the signal demodulation circuitry form the sub-system that performs the electronic signal processing and the sensors themselves with their packaging form the sensor head. Figure 3.3 shows the schematic of the optical sub-system using a single laser diode as the source. As can be seen from the figure, a total of six channels are required for a complete vector field measurement. An extra channel is provided as backup. Another scheme using three different laser diodes for the three axes is also possible. Although this design is more reliable due to inherent redundancy, it requires separate TECs, current drivers and source normalizations. The couplers used in the system are 2x2, 3 dB couplers. Assuming a 0.1 dB loss at each fusion spliced point, the total loss seen by each channel is 12.5 dB. Thus a little less than 1/16 of the laser diode output power finally reaches the sensors. At maximum fringe visibility, about 8% of this light is reflected back to the last 3 dB coupler and only half of that actually reaches the PIN photodetector. These factors have to be taken into consideration while designing the preamplifier circuitry. Thus to increase the SNR of the system, it is necessary to maximize the output power of the laser diode. Figure 3.4 shows the block diagram of the temperature controlled, constant power, laser diode system.

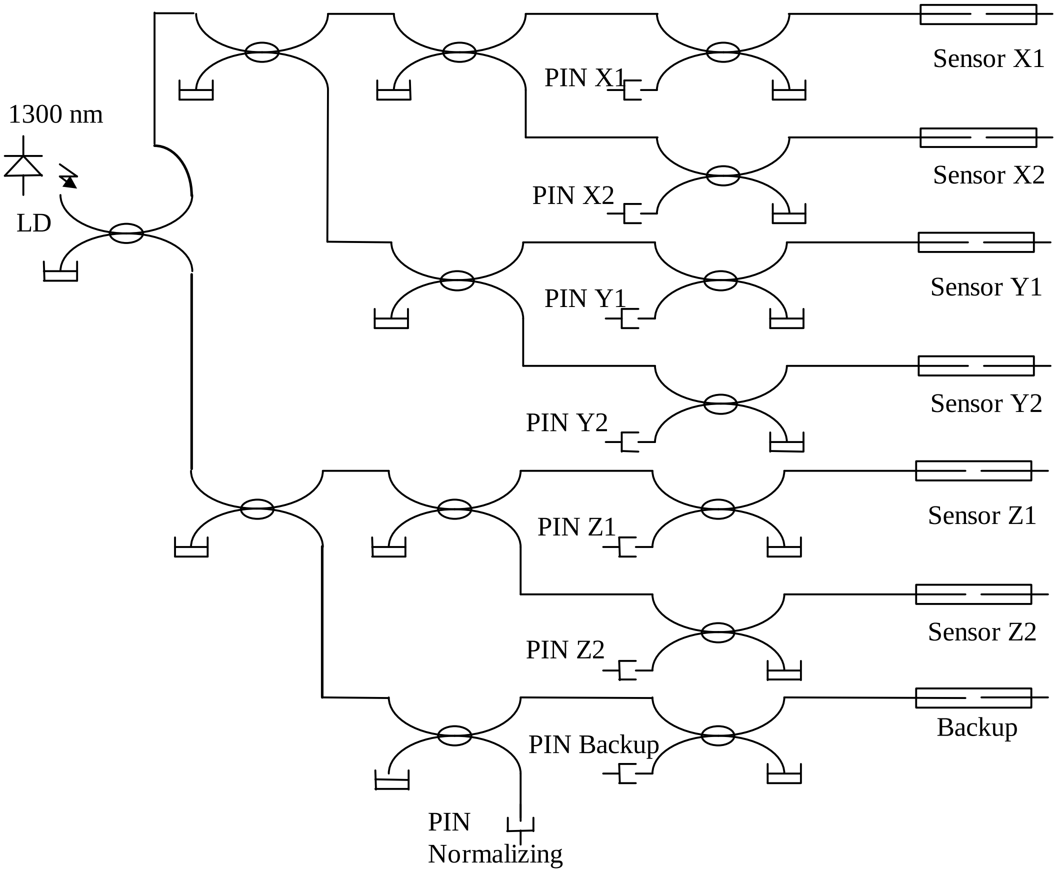

Figure 3.3 Optical sub-system using a single laser diode.

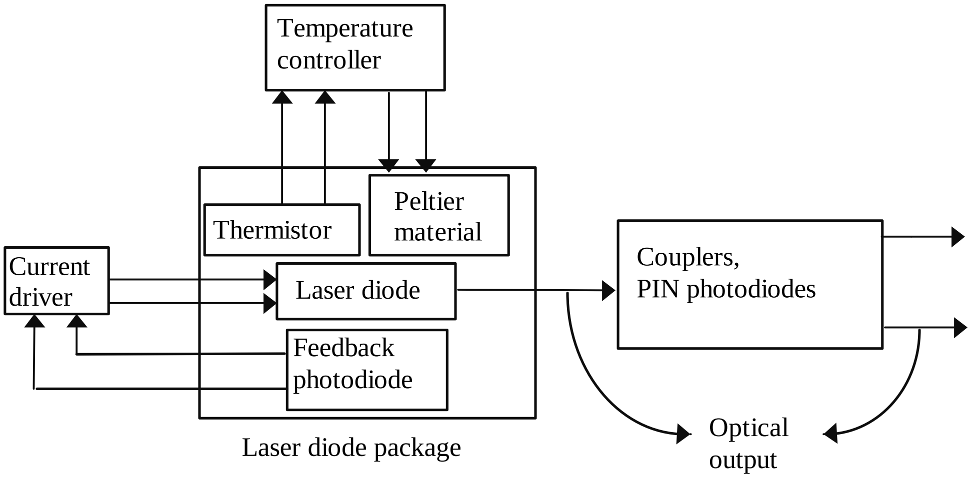

Figure 3.4 Block diagram of laser diode assembly.

3.3 Electronic Components of the System

The output signal from the sensor head is in optical form. Accurate phase information can only be obtained by electronically signal processing this signal. Opto-electronic conversion, processing of this signal and display of the results are the tasks performed by the electronic sub-system. Figure 3.5 shows the various electronic components of the magnetic field measuring system.

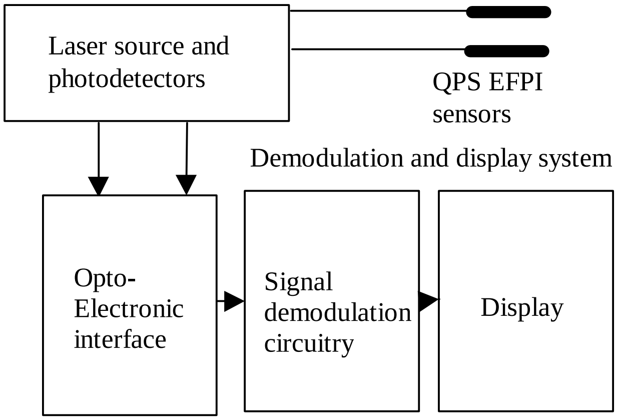

Figure 3.5 Electronic components of the system.

The opto-electronic interface circuitry is basically a transimpedance amplifier which converts the current output of the PIN photodiode into voltage. The PIN photocurrent is a linear function of incident optical power. Typical photodiode responsivity is about 0.9 A/W. The two most important requirements of the pre-amplifier circuitry are low input bias current and low current noise. The output of the current to voltage converter is then passed on to the demodulation circuitry through a voltage follower, which prevents the subsequent stages from loading the transimpedance amplifier.

Once the sensor output is converted into electrical form, quadrature phase shift (QPS) demodulation scheme is employed to obtain information about the phase from the signal. This technique, as described in the previous section, uses two sensors which are in quadrature with each other. As will be described in the next section, the electrical output from each sensor is differentiated, squared, added and its square root obtained, to yield a signal linearly proportional to the phase change induced by the external magnetic field. This signal is then appropriately scaled to display the magnitude of a one-directional magnetic field. Three such sensor systems are multiplexed to measure a vector magnetic field. The output is displayed on a LCD panel, in spherical coordinate system units.