Strain Sensing using Optical Phase Interrogation Technique with Polymer Optical Fiber

Description

This technical note is intended to give integrators an introduction to the optical phase interrogation (OPI) technology and a basic understanding of how a sensing solution can be used together with polymer optical fiber (POF).

Principle

If we couple a modulated signal into a POF and subject the POF to strain, the signal will experience a phase shift (Figure 1). The amount of phase shift scales linearly with the amount of strain (Figure 3).

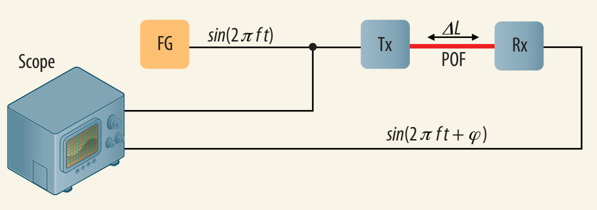


Figure 1. Signal phase shift due to POF elongation

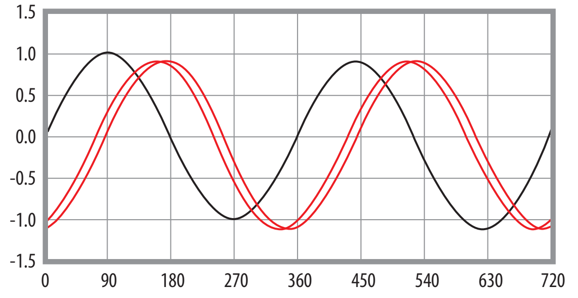


Figure 2. Measuring phase shift with phase comparator

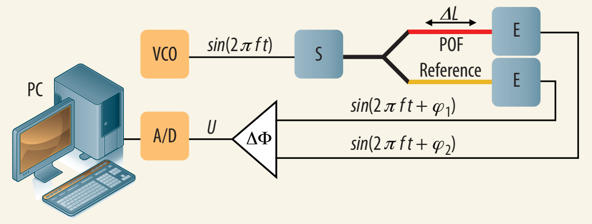


Figure 3. Degree of phase shift depending on strain

By splitting the modulated signal into a measuring fiber subjected to strain and a reference fiber not subjected to strain and subsequently comparing the 2 signals over a phase comparator, we can determine the amount of strain the sensing POF is experiencing.

The optimal workpoint is at 90° phase difference between the reference and sensing fiber where the phase comparator is working in a linear region. (Figure 4)

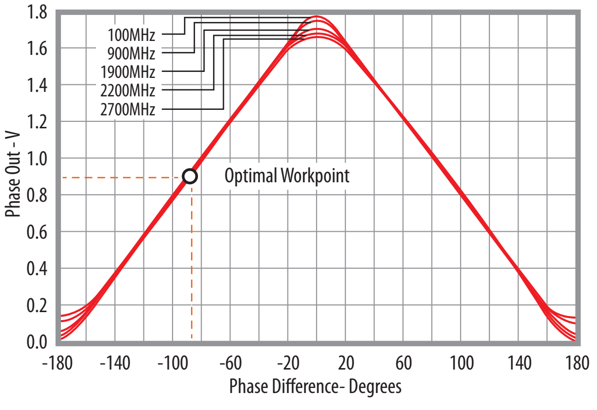
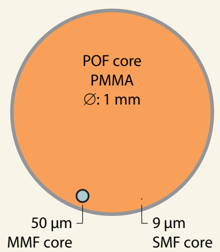


Figure 4. Working point of the phase comparator

POF Characteristics

Made out of polymer, POF offers a comparably high elasticity. Most POF can be stretched more than 5% and remain within the elastic range (Figure 6).

This translates into a wide potential dynamic range of the technology. The large dimension of the fiber makes it easy to handle (Figure 5). POF is used in a variety of industrial and automotive applications where it has proven its robustness. In addition to its robust characteristics, POF also offers complete EMI/ EMC immunity.



Parameters:

- approx. 100 dB/km
- 100 m distance
- -40/+85˚C
- 5...20 mm bending

Figure 5. Dimension of POF compared to glass optical fibers

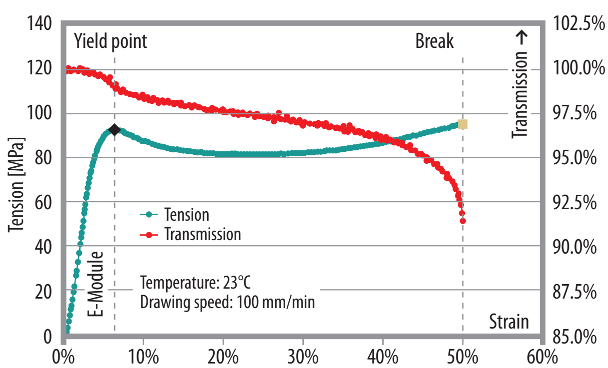


Figure 6. Fiber attenuation (transmission) vs strain

As can be seen in figure 7, the elastical properties of POF remains over a considerable temperature range.

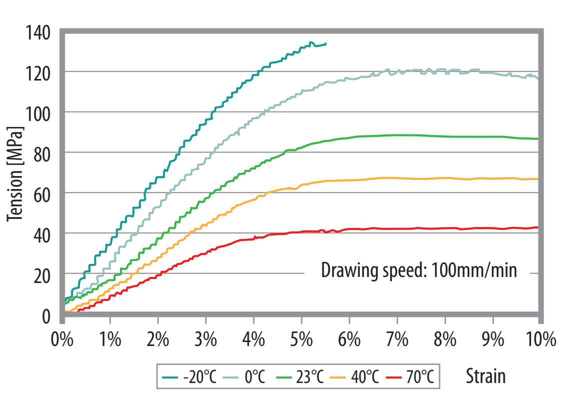


Figure 7. Elastical range remains considerable over a wide temperature range.

Resolution

The resolution and sensitivity of the measurement is dependent on the modulation frequency and the length of the sensing fiber. By changing the modulation frequency or the length of the fiber, sensitivity and resolution can be tailored to the application specifications.

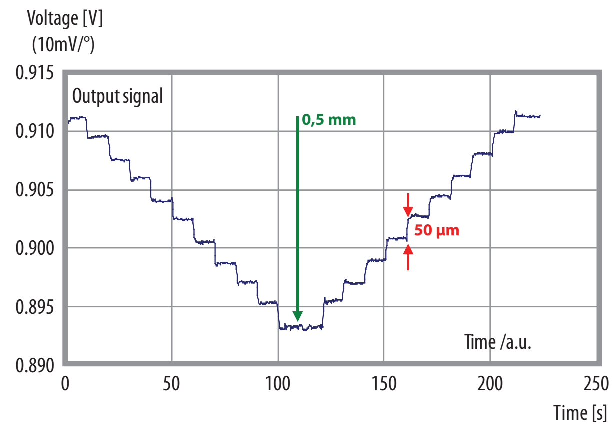


Figure 8. Resolution for a signal modulated @ 2200 MHz; 1m of length

Dynamics

In order to get the widest possible dynamic range, the working point is adapted and calibrated to a strain state that corresponds to the neutral line in figure 9.

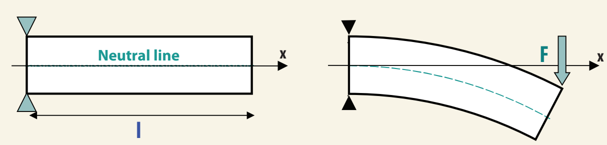


Figure 9. Measurand (beam) subjected to a downward force

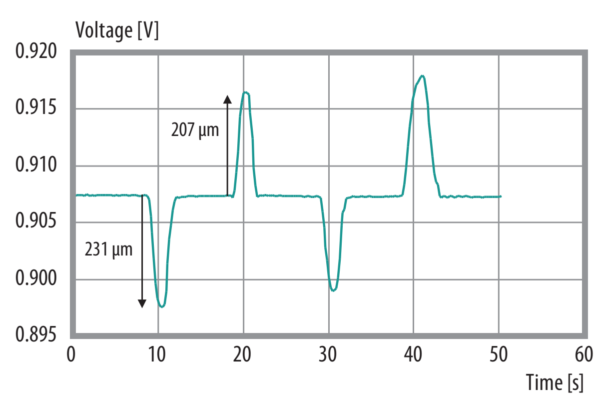


Figure 10. Tensile and compressive strain captured around the neutral line and optimal working point

POF Sensing Applied

A measurement system to instrument strain consists of an interrogator unit coupled to the sensing POF (figure 11). The POF is divided into two functional components; the transmission component which is responsible for transmitting the signal back and forth and the sensing component which couples POF mechanically to the measurand and detects the strain.

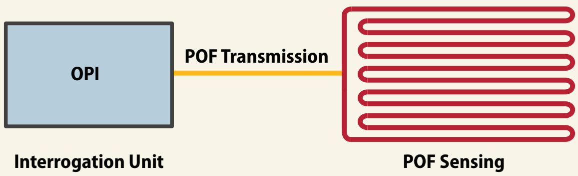


Figure 11. Measurement setup

In the sensing section shown in picture 12, the sections responsible for transferring strain are those aligned with the direction of the strain. By varying the length of this section and multiplying the number of sensing fiber paths, the sensitivity and resolution of the measurement can be optimized to the specific application.

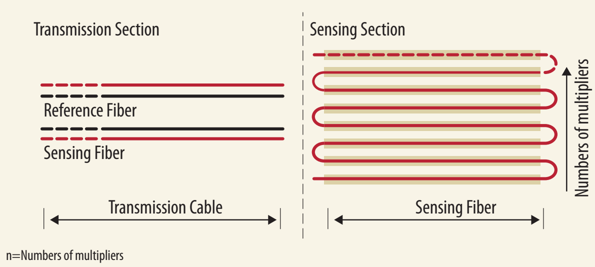


Figure12. Transmission and sensing sections

As can be seen in figure 13, the sensitivity can be refined by altering the the complete length of the sensing fiber.

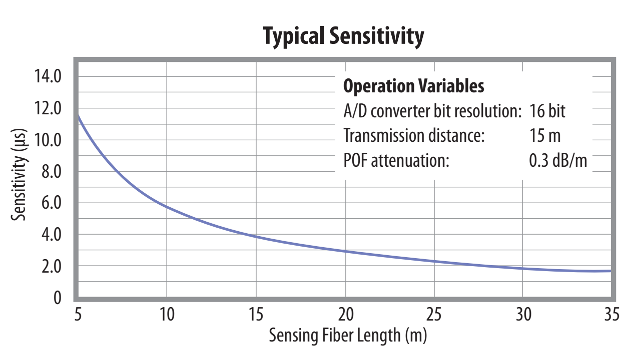


Figure 13. Sensitivity vs sensing fiber length

The system is restricted by a limited power budget so that the total length of fiber (Transmission Length + Sensing Length) for the given hardware specification remains constant.

The sensing fiber length will affect the sensitivity of the system setup. Integrators will be restricted by border conditions such as transmission length.

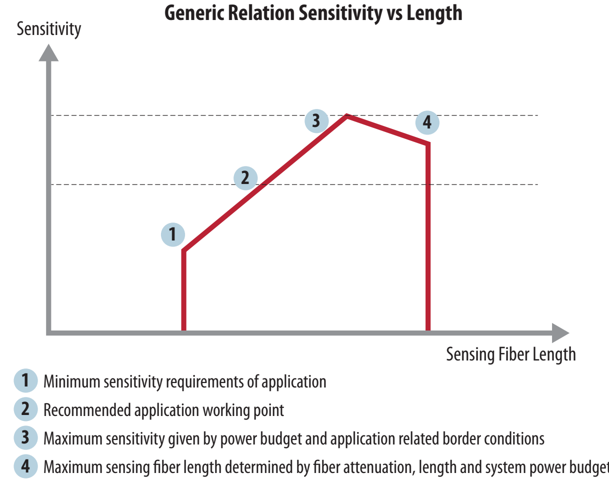


Figure 14. Sensitivity vs sensing fiber length and application conditions

Temperature Compensation

By incorporating the reference fiber in a bridge like configuration in the measurement sensor pad, we can achieve an intrisic temperature compensation of the measurement. Reference and Sensing POF will see the same temperature. For the transmission length lead fiber (between interrogator and sensor pad) the reference and sensing fiber runs together in a single cable which compensates for mechanical and temperature induced effects. Figure 15 shows a possible layout to achieve temperature compensation. Other configurations are possible where the reference is maintained floating or in an alternative pattern configuration.

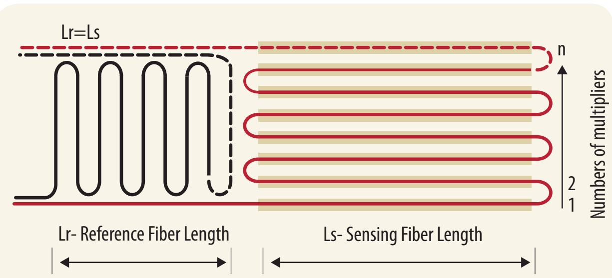


Figure 15. Example of a temperature compensated meander design

Figure 16. shows the working principle of the intrinsic temperature compensation put up to test. By positioning the reference fiber together with the sensing fiber we are able to cancel the influence of temperature over a very large temperature range of -20 to 80°C.

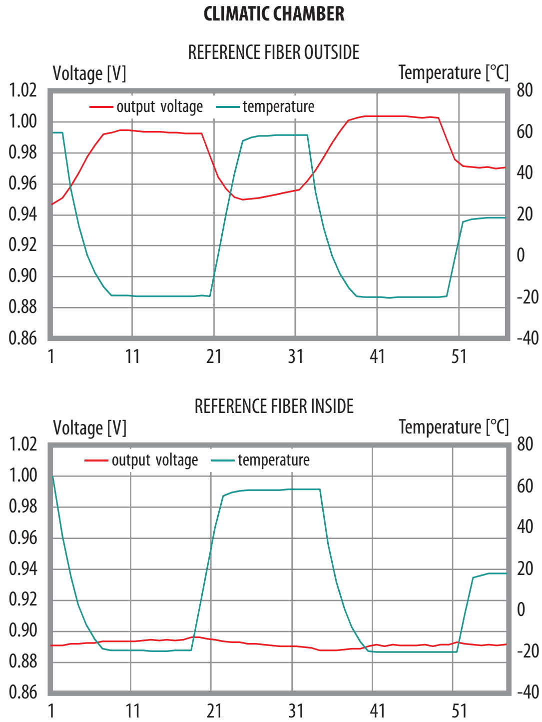


Figure 16. Intrinsic temperature compensation

Summary

Optical phase interrogation with POF offers an easy to handle and integrate optical strain sensing solution. The robustness and flexibility of POF are advantages that are evident in rough environments or applications. The optical phase interrogation principle enables temperature compensated strain measurement solutions for a wide range of applications.

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