Construction of an All-Fiber-Optic Michelson Interferometer

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Introduction

A Michelson interferometer using fiber-optic cable poses unique technical challenges. The principle problem is that when laser light is made to split into two separate paths through single mode cable, and then are re-united at a coupler, the co-travelling beams emerging at the detector are no longer capable of interfering with one another. This is entirely different than the situation with the fiber-optic Sagnac interferometer, where the co-travelling beams can go for kilometers through single mode cable and still interfere perfectly.

This problem arises because of two issues – one is the coherence length of the laser compared to the length of the optical paths, but second, and more important, is the issue of maintaining the state of polarization of the separate beams in the fiber. An optical beam travelling in a single mode fiber will undergo random changes in birefringence induced by stress, temperature changes, or vibration. The end result is that the returning beams in the Michelson interferometer won't maintain their original state of polarization, making interference impossible. There are two strategies that can be used to get around this problem. One is to use polarization-maintaining fiber throughout the optical system. Due to the high cost of PM fiber, this strategy is often unattractive. An easier approach is to use what is called a Faraday rotator mirror (FRM) to reflect the light back at the end of each interferometer arm. The FRM serves as a phase conjugate mirror by creating a phase delay of 90 degrees. This feature allows the mirror and the return path to automatically compensate for any birefringence induced in the beam during the first half of its travel down the arm. Although FRM's can be quite expensive from some of the optical suppliers such as Thorlabs and Edmund Optics, lower cost FRM's of suitable quality can be purchased from Chinese optical supply companies.

The coherence length issue can be dealt with by selecting an appropriate laser source. In this project we chose a distributed feedback (DFB) infrared laser diode as our optical source. DFB lasers generally have a narrow line width (typically 10⁻⁴ nm) and thereby have a coherence length of several meters. This is significantly improved over a Fabry-Perot type laser which typically has a coherence length on the order of a few cm. The DFB laser has the drawback of temperature dependent frequency response, which can cause fringe drift over time when the temperature is not constant.

Fig. 1: A Faraday Rotator Mirror:



Construction and Materials Used:

A diagram of the fiber optic Michelson interferometer is shown below. It consisted of only a few parts. On the left side of the SM 2X2 coupler was mounted a 1 mW 1310 nm DFB laser with an FC connector, the other port on the left was a FC mounted PIN diode detector. On the right ports we had two Faraday Rotator mirrors, each with a SM cable length of 1M. Since the 2X2 coupler also had cable lengths of 1 m on each side, the total arm length for each side was 2 m to the mirror.

Fig. 2:



While one mirror was affixed to the mounting platform, the other was bonded to an electromechanical actuator to stretch the fiber by a fraction of a wavelength at a low pre-defined frequency. The purpose of this was to oscillate the phase position of one of the returning beams with respect to the other, thereby generating a fringe shift at the oscillation frequency. The completed fiber optic Michelson interferometer is shown below.



Fig. 3: The experimental setup

The interferometer was tested as follows – the power supply was turned on and supplied about 1.2V to the DFB laser module. The electromechanical actuator was started by applying around a 25-40 Hz signal to it (signal amplitude was 4-30V). The signal height of the triangle wave generator was adjusted to control how many wavelengths of distance the actuator would move based on what was viewed on the oscilloscope. Briefly, if the actuator stretches the length of one arm by $\frac{1}{2}$ a wavelength, then the phase at the output should go from in phase to out of phase, assuming the beams are phase aligned to begin with. This should generate an output signal with the same period as the input triangle wave. If the actuator moves by one wavelength, then the phase should shift by two periods for every period of the triangle wave.

Some examples of what this output looks like are shown below. The triangle wave signal was started at around 25VAC as shown on channel 2 of fig. 4A. The output from the PIN diode (after amplification and filtering) was at about 2x the frequency of the drive signal. This would then suggest that the actuator is stretching the control arm of the interferometer by around 1.3um per stroke.



Fig. 4A Two fringe periods per triangle wave period. Conditions: 33Hz drive, 25VAC.

In our second example, shown in figure 4B, the triangle wave generator is set at around 15VAC as shown on channel 2 in the figure. The output from the PIN diode is at about the same frequency, suggesting that we are stretching the control arm by around 0.65 um per stroke.



Fig. 4B One fringe period per triangle wave period. Conditions: 40 Hz, 15VAC.

It seems pretty clear then that we have succeeded in getting interference of the two beams at the detector using single mode fiber optic paths and Faraday Rotator mirrors. So this strategy works and is considerably less expensive than the PM fiber method.

Further Improvements to the Interferometer - Wireless data transmission

For my purposes, I wanted to use this interferometer to replicate two well-known experiments testing Special Relativity – namely the Kennedy-Thorndike experiment of 1932 and the Shamir and Fox experiment of 1969. Since both of these experiments require rotating the interferometer to various positions, the wires connecting the device to the electronics as shown in Fig. 2 become an impediment to rotating it freely. In order to do this, it was necessary to use some form of wireless data logging to get the data out of the PIN diode and into a computer for analysis. I ended up constructing my own battery powered data logger using a PIC16F777 microcontroller. This device is a little too complicated to describe in detail – briefly, it used the A/D inputs from the microcontroller to log data from two ports – each port can sample at up to 300x per second, and this data is sent in real time out to a two wire port. I used a simple amplifier on the input of one port to amplify the weak signal from the PIN diode up to the 0-3.7V level readable by the A/D.



Figure 5: Custom Data-logger under construction

In order to get the two wire ASCII data output to communicate with my computer, I had to implement a MAX232 chip on the output to interface with a serial Bluetooth module. The circuit used for the MA232 is shown <u>here</u>. For the serial Bluetooth adapter, I used the USconverters UCBT232B, and paired it with a low cost Bluetooth dongle on my host computer. To receive the ASCII data, I used Putty as the terminal program operating at 230,400 baud. The data flow is initiated at the data logger using a menu switch, the data then flows into the Putty.log file. Once complete, this file is converted into a .csv file which can be easily opened in Excel.

This strategy eliminated the data output wire from the interferometer. The triangle wave input was eliminated in this second version, since the experiment calls for rapid rotation on a platform and this in and of itself will generate an actuating signal simply due to the rotational motion. These actuating signals are either:

- a) vibration induced actuations (artifacts) or
- b) Fringe shifts of interest which are orientation dependent , which may or may not be present.

The completed interferometer on its rotating platform with the wireless data logger mounted is shown in Figure 6:





The purpose of the light source and photocell is so that the data on channel 2 monitors the rotation of the platform. A blip is created in the channel 2 data every time the photocell rotates past the light source. In this way the data received on channel 1 can be correlated with the data received on channel 2, which is essentially the cardinal direction data.

An example of data received wirelessly from the interferometer while it was rotated at around 40-60 RPM is shown below in Figure 7. The sine wave output from the interferometer (blue) is a rotational stress in the fiber optic cable that amounts to around 0.2 of a fringe and has a period of once per rotation. The red output marks when one arm of the interferometer passes west as the device rotates clockwise. Based on the known height of the stress signal, the noise floor is at around $1/60^{\text{th}}$ of a fringe. Based on the length of our interferometer arms and the resolution

possible, this puts our interferometer at a comparable resolution to the one used in the original Kennedy-Thorndike experiment.



Figure 7:

Similar to the Kennedy-Thorndike experiment, we observed no additional signals, such as those expected for certain ether theories (such as Miller, or ether theories predating Lorentz's exact theorem of corresponding states) which would call for a signal with a period of ½ the rotation period. However, this result is consistent with the predictions of Lorentz ether theory (1904) or special relativity (1905). A theoretical discussion of this outcome with simulations is available <u>here</u>. This result is also distinct from the positive result claimed for a somewhat similar Michelson interferometer built by <u>Cahill</u> in 2007. Further, because this interferometer uses arms with a refractive index of 1.47, the result is consistent with the outcome of the Shamir and Fox experiment of 1969.

Conclusions

I believe we have shown that it is possible to construct a fiber optic Michelson interferometer using single mode cable that is capable of detecting quite small fringe shifts, on the order of 1/60th of a fringe. The use of low cost Faraday rotator mirrors is an effective way to achieve this result without going to all polarization-maintaining fiber.