Fiber Laser, Michaelson Interferometer, and Coherence Length

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December 2007

Lasers and Waveguides

This experiment illustrates the analogy between RF and optical components.

The fiber laser has a wavelength of 1550 nm, corresponding to a frequency of 193.5 THz (193,500 GHz). This is about one-half the frequency of visible light.

Many optical fiber components have direct electrical analogues:

- Fiber waveguide (coaxial line or waveguide)
- Directional couplers
- Mirrors (shorted coaxial lines)
- Circulators
- Filters
- Amplifiers
- Square-law detectors (photodiodes)

Laser Coherence Length

Fiber lasers produce a THz frequency with a finite bandwidth, which depends on the nature and construction of the laser itself, as well as the physics of the oscillation mechanism. The bandwidth of the signal determines its **coherence length**, which is the difference in path length that a laser signal can interfere with itself.

If a laser has a small coherence length, then the interference of a sample of the laser with a time-delayed sample of the same laser light is not stable in time.

Fiber lasers can have coherence length of many ten's of kilometers, corresponding to a very narrow line.

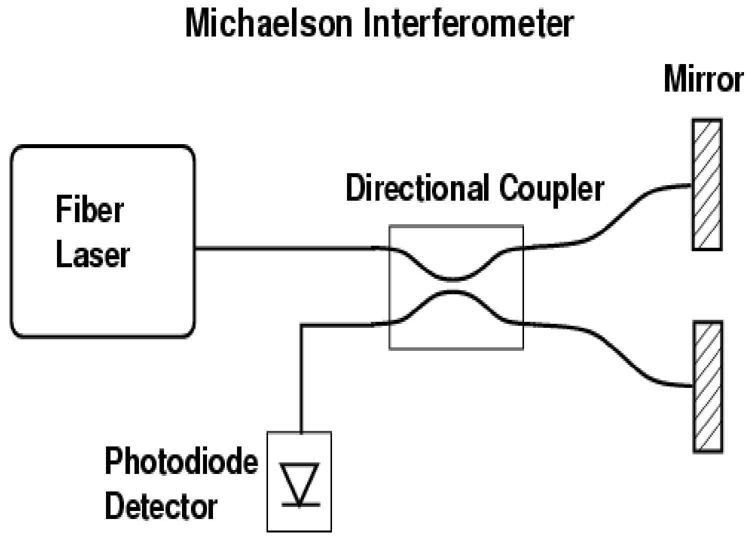
$$L_{coherence} = \frac{\lambda}{n} \frac{\lambda}{\Delta \lambda}$$

where *n* is the index of refraction of the fiber, typically 1.5. For a 10 km coherence length of a 1550 nm laser, the relative line width is 10^{-10}, corresponding to a frequency spread of less than 200 kHz. Linewidths much smaller than this are common.

Interferometers

The most common way to measure the coherence length (or linewidth) of a laser is with an interferometer. The simplest interferometer that can produce zero length difference between its two paths is the **Michaelson interferometer**.

The light from the laser is split into two paths in the **directional coupler**. Each travels to a **mirror** and is reflected. The two light paths are recombined in the splitter and travel to the **photodiode detector**. (The light also goes back to the laser, which includes an optical isolator, which absorbs the light and prevents it from interacting with the laser.)



As long as the difference in optical path between the two mirrors is less than the coherence length of the laser, an interference pattern exists and is detected by the photodiode.

The photodiode is a good square-law detector. The output voltage is proportional to the input optical power over a wide range (usually wider than RF diode detectors).

When the light returning from the mirrors is in phase, the optical voltages add, for a power power *four times* that of a single leg in the interferometer.

Optical Fibers

The output of the laser is launched into a single-mode fiber, which has a core diameter of 9 microns. The core has a higher index of refraction from the surrounding glass, producing a waveguide of small enough dimension to support only a single mode.

The polarization of the light may be changed due to bending and nonuniformity of the fiber. The interferometer requires that the polarizations of the two interfering light signals be aligned.

To insure that the light returning from both arms of the interferometer will interfere, the mirrors, Faraday rotator mirrors introduce a 90 degree rotation of the reflected light, so any change of the polarization of the light along the fiber is "unwound" as it returns along the same fiber.

When both return beams are added in the optical splitter, the relative polarization of the two light signals is preserved and interference can occur. Without such mirrors, special polarization controllers must be used to align the field vectors of the interfering rays.

The directional coupler consists of two single-mode fibers in very close proximity, in direct analogy to a 3-dB RF hybrid, that splits an oncoming ray into two outputs of equal amplitude. The forward-to-reverse directivity of optical splitters far exceeds that of their RF counterparts, 60 dB being typical.

DFB Fiber Laser

The laser provided is a 1 mW DFB (distributed feedback) fiber laser with a 1550 nm output wavelength.

The output spectrum of this laser may consist of a single mode with a coherence length of a few hundred meters, or it may oscillate at several frequencies, spaced GigaHertz apart, depending on the adjustment of the output power and the temperature of the laser cavity. When the laser multimodes, the coherence length is very short.

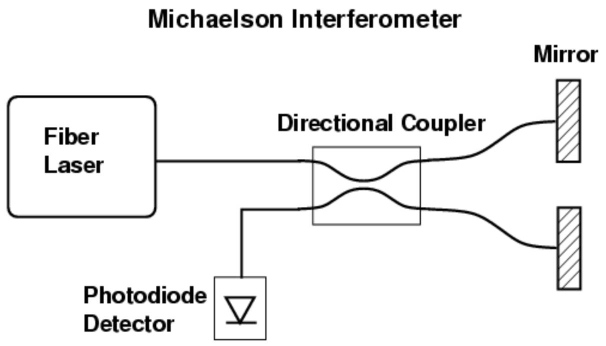
Problem: if the laser oscillates at two frequencies 1 GHz apart, what is the coherence length?

The temperature of the laser is set by a front-panel control. The laser will jump between single- and multi-mode operation for small changes in the temperature set point.

The laser is safe to use in an uncontrolled environment as the 1550 nm wavelength is absorbed in the eye before the retina, and the beam from a single-mode fiber is highly divergent. Just don't look directly into the fiber at short distance.

Fiber Laser Experiment

IMPORTANT: The fiber and connectors are very delicate and easily broken. Be sure that no bending stress is placed on the fiber, particularly around the connectors. Don't let the connector dangle on the end of a fiber. Pick up the fiber and connectors carefully.



Connect the output of the laser to the optical splitter, the mirrors and the photodiode. Connect the photodiode to the input of an oscilloscope with a 10,000 ohm resistive load. A fiber cleaner is provided to clean the ends of the fiber before inserting into the fiber connector. A specially treated card is provided that lights up in the visible when illuminated by the 1550 nm wavelength may be used to check the presence of light.

The photodiode has an internal battery that runs down fast. Be sure to turn the photodiode off when not using it.

With equal lengths to both mirrors, random temperature fluctuations will cause some fringes to pass across the photodiode. Put your hand on the fiber going to one of the mirrors and note the rapid increase in fringes. As the fiber cools, the fringes will go more slowly.

Measure the photodiode voltage with one leg of the interferometer disconnected, and then the other. The amplitudes should be reasonably balanced. What is the peak fringe voltage with both mirrors connected?

Fiber Laser Experiment

Add a 2 meter length of fiber to one of the legs of the interferometer.   If the laser is multimoding, no fringes will be present.

Adjust the laser temperature and note when it single- and multimodes. (It takes a few seconds for the internal temperature to catch up with the front-panel control.)

Could you detect single and multimode operation when the two interferometer legs were equal?