

Measuring a Fiber-Optic Delay Line Using a Mode-Locked Laser

Fractional error is no more than about 3×10^{-6} .

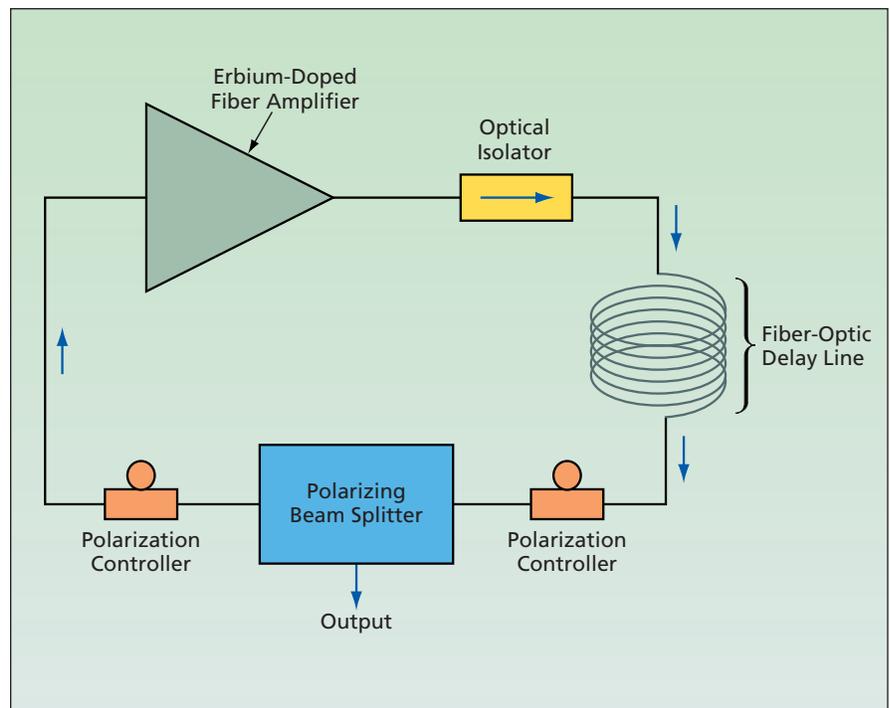
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The figure schematically depicts a laboratory setup for determining the optical length of a fiber-optic delay line at a precision greater than that obtainable by use of optical time-domain reflectometry or of mechanical measurement of length during the delay-line-winding process. In this setup, the delay line becomes part of the resonant optical cavity that governs the frequency of oscillation of a mode-locked laser. The length can then be determined from frequency-domain measurements, as described below.

The laboratory setup is basically an all-fiber ring laser in which the delay line constitutes part of the ring. Another part of the ring — the laser gain medium — is an erbium-doped fiber amplifier pumped by a diode laser at a wavelength of 980 nm. The loop also includes an optical isolator, two polarization controllers, and a polarizing beam splitter. The optical isolator enforces unidirectional lasing. The polarizing beam splitter allows light in only one polarization mode to pass through the ring; light in the orthogonal polarization mode is rejected from the ring and utilized as a diagnostic output, which is fed to an optical spectrum analyzer and a photodetector. The photodetector output is fed to a radio-frequency spectrum analyzer and an oscilloscope. The fiber ring laser can generate continuous-wave radiation in non-mode-locked operation or ultra-short optical pulses in mode-locked operation.

The mode-locked operation exhibited by this ring is said to be passive in the sense that no electro-optical modulator or other active optical component is used to achieve it. Passive mode locking is achieved by exploiting optical nonlinearity of passive components in such a manner as to obtain ultra-short optical pulses. In this setup, the particular nonlinear optical property exploited to achieve passive mode locking is nonlinear polarization rotation.

This or any ring laser can support oscillation in multiple modes as long as sufficient gain is present to overcome losses in the ring. When mode locking is achieved, oscillation occurs in all the



An All-Fiber Ring Laser is configured alternately with and without the fiber-optic delay line as part of the ring. The length of the fiber-optic delay line is calculated from the FSRs of the laser in mode-locked operation in the two configurations.

modes having the same phase and same polarization. The frequency interval between modes, often denoted the free spectral range (FSR), is given by c/nL , where c is the speed of light in vacuum, n is the effective index of refraction of the fiber, and L is the total length of optical path around the ring. Therefore, the length of the fiber-optic delay line, as part of the length around the ring, can be calculated from the FSRs measured with and without the delay line incorporated into the ring. For this purpose, the FSR measurements are made by use of the optical and radio-frequency spectrum analyzers.

In experimentation on a 10-km-long fiber-optic delay line, it was found that this setup made it possible to measure the length to within a fractional error of about 3×10^{-6} , corresponding to a length error of 3 cm. In contrast, measurements by optical time-domain reflectometry and mechanical measurement were found to be much less

precise: For optical time-domain reflectometry, the fractional error was found no less than 10^{-4} (corresponding to a length error of 1 m) and for mechanical measurement, the fractional error was found to be about 10^{-2} (corresponding to a length error of 100 m).

This work was done by Meirong Tu, Michael R. McKee, Kyung S. Pak, and Nan Yu of Caltech for NASA's Jet Propulsion Laboratory.

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