Experiments with an Optical Seismometer

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Modern seismometers rely on electronic displacement transducers to sense the motion of an inertial mass suspended by a spring. Most advanced systems use force-feedback on the inertial mass to circumvent shortcomings of the spring and the displacement transducer.

Recent advances in optical fiber technology and digital signal processing offer an alternative. We have recently developed an optical fringe resolver to replace the electronic displacement transducer that could lead to a greatly improved seismometer. The use of optical fiber interferometry in place of electronics adds other important benefits, including immunity to noise pickup, simplification of remote deployment (in a borehole, for example), the elimination of a heat source in the seismometer—an important cause of noise in the best existing systems, and elimination of electrical connections between the seismometer and the recording system.

Our displacement transducer uses polarization splitting to create two fringe signal outputs from a Michelson interferometer. From these two signals, a digital signal processor computes the optical phase in real time, producing a wide dynamic range (many cm), linear, high-resolution displacement signal. In a measurement of the inherent noise floor of our displacement transducer, we found that the RMS noise in a 100 Hz bandwidth was approximately 5×10^{-12} m. This, when applied to a mass-spring suspension having a 5.4 s period and a Q of 7.4, will resolve the USGS ground noise model up to at least 15 Hz.

The use of optical fiber interferometry rather than traditional electronic displacement transducers affords significant advantages, including:

- A linear, high-resolution displacement detector — the proposed optical sensor includes the functionality of a digitizer providing about a 30-bit digital output;
- Absolute displacement measurement referenced to the wavelength of light;
- Bandwidth sufficient to resolve the USGS Low Noise Model from DC to > 15 Hz;
- Dynamic range sufficient to record the largest teleseisms and most regional and local earthquakes;
- Minimum electronics in package - only optical fiber connection to the seismometer, minimizing heat from electronics in the sensor package and noise pickup from connecting electrical cables;
- Smaller package — our design will be applicable to both vault and borehole installations and should be relatively easy to manufacture.

Because we are not relying on force-feed back, our new design is still subject to imperfections in the spring and damping components, which are not linear and may change characteristics with time. If we are to succeed without feedback, these problems must be addressed in other ways. This is currently the subject of our research.