Magnetometer Based on Optoelectronic Microwave Oscillator

This miniature instrument could also function as an atomic clock.

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A proposed instrument, intended mainly for use as a magnetometer, would include an optoelectronic oscillator (OEO) stabilized by an atomic cell that could play the role of a magnetically tunable microwave filter. The microwave frequency would vary with the magnetic field in the cell, thereby providing an indication of the magnetic field. The proposed magnetometer would offer a combination of high accuracy and high sensitivity, characterized by flux densities of less than a picotesla. In comparison with prior magnetometers, the proposed magnetometer could, in principle, be constructed as a compact, lightweight instrument: It could fit into a package of about 10 by 10 by 10 cm and would have a mass <0.5 kg.

As described in several prior NASA Tech Briefs articles, an OEO is a hybrid of photonic and electronic components that generates highly spectrally pure microwave radiation, and optical radiation modulated by the microwave radiation, through direct conversion between laser light and microwave radiation in an optoelectronic feedback loop. As used here, “atomic cell” signifies a cell containing a vapor, the constituent atoms of which can be made to undergo transitions between quantum states, denoted hyperfine levels, when excited by light in a suitable wavelength range. The laser light must be in this range. The energy difference between the hyperfine levels defines the microwave frequency.

In the proposed instrument (see figure), light from a laser would be introduced into an electro-optical modulator (EOM). Amplitude-modulated light from the exit port of the EOM would pass through a fiber-optic splitter having two output branches. The light in one branch would be sent through an atomic cell to a photodiode. The light in the other branch would constitute the microwave-modulated optical output. Part of the light leaving the atomic cell could also be used to stabilize the laser at a frequency in the vicinity of the desired hyperfine or other quantum transition. The microwave signal from the output of the photodiode would be amplified (if necessary, as explained below) and fed back into the EOM. This system would oscillate if the amplification in the closed loop exceeded the linear absorption of the loop. The microwave amplifier may be unnecessary to sustain stable oscillations, depending on the power of the laser radiation at the photodetector and on particular features of the modulator and optical delay line.

As described in the preceding paragraph, the proposed instrument could function as either an atomic clock or a magnetometer: If the instrument were designed to lock the microwave oscillation to a clock transition (a suitable hyperfine or other quantum transition characterized by a frequency that does not vary measurably with applied fields), then the instrument would function as an atomic clock. If, on the other hand, the instrument were designed to utilize a transition having a frequency that varies with an applied magnetic field, then the...
microwave oscillation frequency would serve as an indication of the magnetic flux density along the direction of the light beam. It may be possible to design the instrument to lock the oscillation frequency to either transition, in which case the same instrument could be used as either an atomic clock or a magnetometer.

The design of the EOM would be a key element of the overall design, affecting the size, power demand, and performance of the proposed instrument. An EOM based on a crystalline whispering-gallery-mode (WGM) resonator could be suitable for this purpose. WGM resonators offer high resonance quality factors ($\geq 10^7$), along with sub-centimeter dimensions that are suitable for tight packaging. The choice of a crystalline WGM resonator would also reduce, relative to other resonators, the amount of power amplification needed in the feedback loop. The OEO could be powered by a semiconductor laser that uses only a few milliwatts of power. Most of the power would be dissipated in the amplifier, which would operate in a low-gain regime and, hence, would not impose a large power demand. It has been estimated the total power demand of the instrument would be less than 1 W.

This work was done by Lute Maleki, Dmitry Strekalov, and Andrey Matsko of Caltech for NASA’s Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-40958