



## Automatic Locking of Laser Frequency to an Absorption Peak

Initial manual tuning is ordinarily not necessary.

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An electronic system adjusts the frequency of a tunable laser, eventually locking the frequency to a peak in the optical absorption spectrum of a gas (or of a Fabry-Perot cavity that has an absorption peak like that of a gas). This system was developed to enable precise locking of the frequency of a laser used in differential absorption LIDAR measurements of trace atmospheric gases. This system also has great commercial potential as a prototype of means for precise control of frequencies of lasers in future dense wavelength-division-multiplexing optical communications systems.

The operation of this system is completely automatic: Unlike in the operation of some prior laser-frequency-locking systems, there is ordinarily no need for a human operator to adjust the frequency manually to an initial value close enough to the peak to enable au-

tomatic locking to take over. Instead, this system also automatically performs the initial adjustment.

The system (see Figure 1) is based on a concept of (1) initially modulating the laser frequency to sweep it through a spectral range that includes the desired absorption peak, (2) determining the derivative of the absorption peak with respect to the laser frequency for use as an error signal, (3) identifying the desired frequency [at the very top (which is also the middle) of the peak] as the frequency where the derivative goes to zero, and (4) thereafter keeping the frequency within a locking range and adjusting the frequency as needed to keep the derivative (the error signal) as close as possible to zero.

More specifically, the system utilizes the fact that in addition to a zero crossing at the top of the absorption peak, the error

signal also closely approximates a straight line in the vicinity of the zero crossing (see Figure 2). This vicinity is the locking range because the linearity of the error signal in this range makes it useful as a source of feedback for a proportional + integral + derivative control scheme that constantly adjusts the frequency in an effort to drive the error to zero. When the laser frequency deviates from the mid-peak value but remains within the locking range, the magnitude and sign of the error signal indicate the amount of detuning and the control circuitry adjusts the frequency by what it estimates to be the negative of this amount in an effort to bring the error to zero.

Before the laser frequency can be locked as described above, it is necessary to find the locking range. For this purpose, the frequency is swept through a broad range that includes the locking range and, in ad-

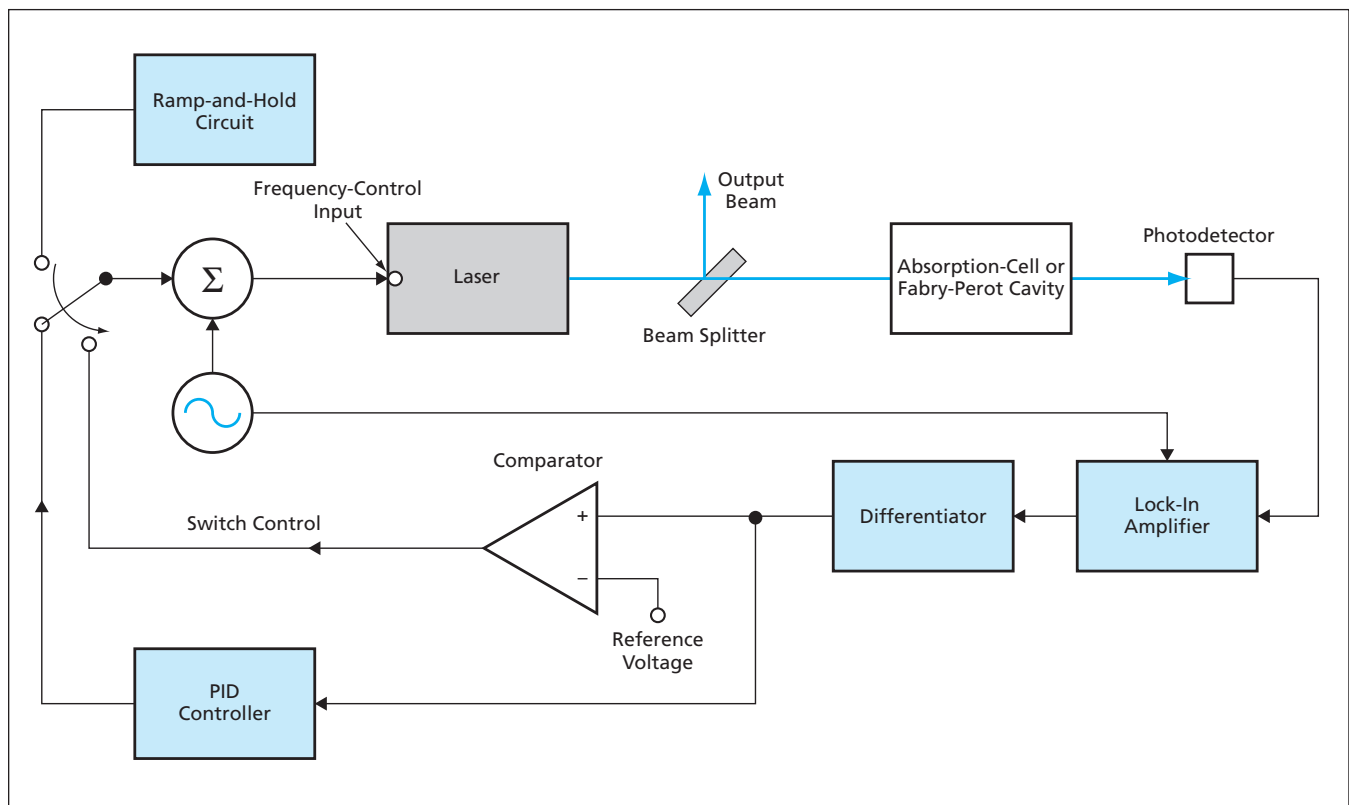


Figure 1. The **Automatic Frequency-Locking System** first sweeps the laser frequency through a wide range to find the locking range, then switches to a locking mode, in which it constantly adjusts the frequency to keep it at the middle of the locking range. (Note: PID is Proportional-Integral-Differential.)

dition to determining the error signal (the first derivative of absorption with respect to frequency), the system also determines the derivative of the error signal with respect to time. The system can readily identify the locking zone because the derivative of the error signal is positive and reaches its highest value in the locking zone and is negative just outside the locking zone. Once the laser frequency is inside the locking zone, the frequency sweep is halted and the frequency-stabilization circuitry that implements the locking scheme described above is activated. In a test, the system was demonstrated to be capable of maintaining the frequency of a diode laser at the middle of a 944-nm-wavelength water-vapor absorption peak, with an error of no more than 3 percent of the full width at half maximum of the peak.

*This work was done by Grady J. Koch of Langley Research Center. Further information is contained in a TSP (see page 1). LAR-16394-1*

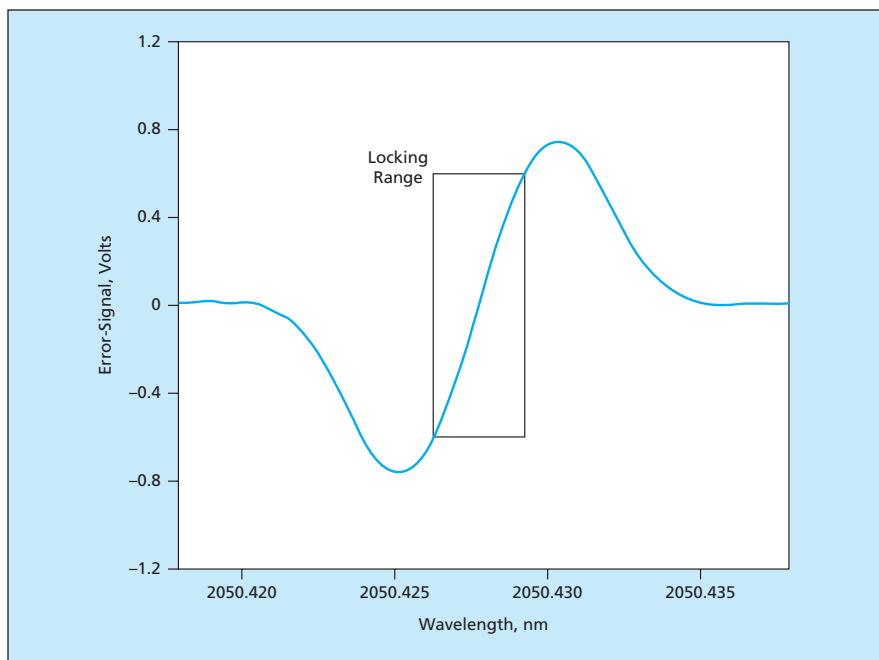


Figure 2. The Error Signal and its derivative are used in finding the locking range and then maintaining lock. This error signal was obtained in operation using a CO<sub>2</sub> absorption peak centered at a wavelength of 2,050.428 nm.

## Self-Passivating Lithium/Solid Electrolyte/Iodine Cells

Passivating lithium iodide films of optimum or nearly optimum thickness form spontaneously.

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Robust lithium/solid electrolyte/iodine electrochemical cells that offer significant advantages over commercial lithium/iodine cells have been developed. At room temperature, these cells can be discharged at current densities 10 to 30 times those of commercial lithium/iodine cells. Moreover, from room temperature up to 80 °C, the maximum discharge-current densities of these cells exceed those of all other solid-electrolyte-based cells.

A cell of this type includes a metallic lithium anode in contact with a commercial flexible solid electrolyte film that, in turn, is in contact with an iodine/graphite cathode. The solid electrolyte (the chemical composition of which has not been reported) offers the high ionic conductivity needed for high cell performance. However, the solid electrolyte exhibits an undesirable chemical reactivity to lithium that, if not mitigated, would render the solid electrolyte unsuitable for use in a lithium cell. In this cell, such mitigation is affected by the formation of a thin passivating layer of lithium iodide at the anode/electrolyte interface.

Test cells of this type were fabricated from iodine/graphite cathode pellets, free-standing solid-electrolyte films, and

lithium-foil anodes. The cathode mixtures were made by grinding together blends of nominally 10 weight percent graphite and 90 weight percent iodine. The cathode mixtures were then pressed into pellets at 36 kpsi (248 MPa) and inserted into coin-shaped stainless-steel cell cases that were coated with graphite paste to minimize corrosion. The solid-electrolyte film material was stamped to form circular pieces to fit in the coin cell cases, inserted in the cases, and pressed against the cathode pellets with polyethylene gaskets. Lithium-foil anodes were placed directly onto the electrolyte films. The layers described thus far were pressed and held together by stainless-steel shims, wave springs, and coin cell caps. The assembled cells were then crimped to form hermetic seals.

It was found that the solid electrolyte films became discolored within seconds after they were placed in contact with the cathodes — a result of facile diffusion of iodine through the solid electrolyte material (see figure). This is fortuitous for the following reasons:

- Upon reaching the anode side, the iodine reacts with lithium from the anode to form lithium iodide, which is known as both a solid electrolyte and an effec-

tive passivating-film material for solid electrolytes in contact with lithium.

- Heretofore, it has been necessary to vacuum-deposit LiI onto a solid electrolyte to form a passivating film. The vacuum-deposition process is expensive, time-consuming, and difficult. If the thickness of the deposited LiI film is  $\approx 1$  mm or more, the high electrical resistivity of LiI limits the cell discharge rates. If the film is too thin, it likely contains pinholes, which act as corrosion sites and thereby degrade cell performance.
- In the present case, the LiI is neither thick enough to introduce excessive electrical resistance nor too thin to prevent formation of pinholes: The formation of LiI film is self-limiting because iodine diffuses very slowly through LiI.

Commercial lithium/iodine cells are primary cells (that is, they are not rechargeable, as opposed to secondary cells, which are rechargeable). Thus far, lithium/solid-electrolyte/iodine cells have been demonstrated in primary form only. However, in principle, the present approach to passivation should be applicable to secondary cells also.

*This work was done by Ratnakumar Bugga, Jay Whitacre, Sekharipuram Narayanan, and*