The J-Series Modulator:
A Versatile FTIR Spectrometer System Element

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Introduction

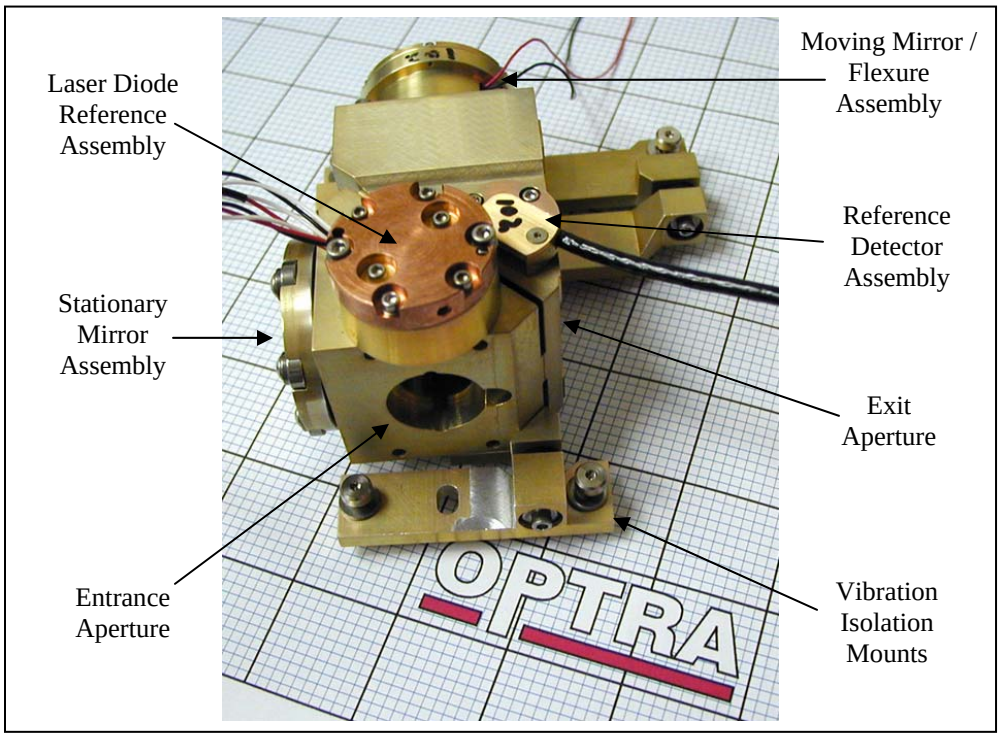
Technology developed under a series of SBIR (Small Business Innovation Research) programs has been incorporated by OPTRA into a ruggedized Michelson interferometer modulator. This standardized design (designated as the J-Series modulator) retains sufficient versatility to serve as a baseline element in many custom applications; yet it is appropriately described as a commercial off-the-shelf (COTS) item. The purpose of this paper is to describe how the J-Series modulator, in an essentially unmodified form, can become part of a number of specialty applications of Fourier transform infra-red (FTIR).

The J-Series Modulator

The J-Series modulator is based on a classical Michelson configuration with 15-mm diameter mirrors. The moving mirror is supported with flexures utilizing constrained layer damping for vibration and resonance management. The moving mirror position is monitored with a laser based spatial fringe reference system providing absolute (not relative) mirror location during the scan. Retardation rates up to 5 cm/sec are available including a step scan capability. Up to 2 cm^{-1} resolution is provided over any spectral region from 400 to 4000 cm^{-1}. With high duty cycle, 72, 16 cm^{-1} resolution interferograms/second may be obtained. Figure 1 depicts the J-

Series Modulator. The dimensions (without vibration mounts) are roughly 3.75×2.25x2.25 inches with a weight of approximately three pounds.

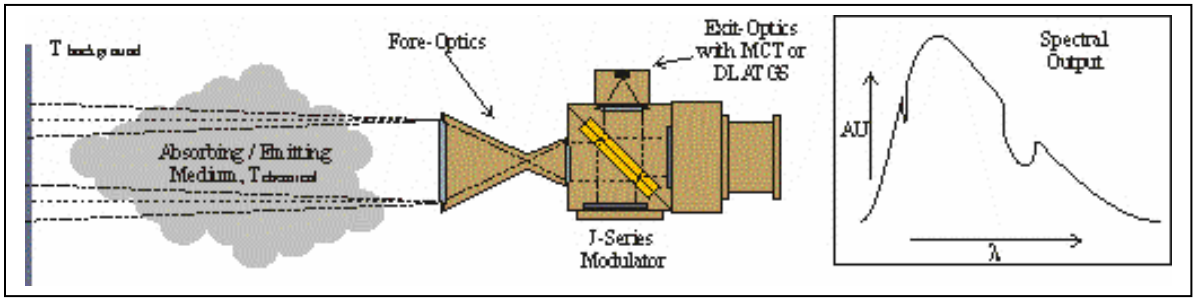
Figure 1: J-Series Modulator



Passive Standoff Detection

Passive standoff chemical detection requires a temperature contrast between the chemical of interest and the background against which it is being observed (figure 2).

Figure 2: J-Series in Passive Configuration



The sensitivity of the detection (in concentration pathlength units [mg/m^2]) is proportional to this contrast according to

$$CL_{min} \propto -\frac{1}{\alpha(\sigma)} \cdot \ln\left(\frac{1}{SNR(\sigma)}\right) \quad (1)$$

where

$$SNR(\sigma) = \frac{N(\sigma, T_{chemical}) - N(\sigma, T_{background})}{NESR(\sigma)} \quad (2)$$

NESR is the noise equivalent spectral radiance of the spectrometer, determined by system factors including the detector characteristics, throughput of the system, spectral resolution, and observation time.

The configuration of the J-Series for passive detection includes simple fore-optics, such as a refractive or reflective telescope, and an exit optics assembly composed of an exit lens, field lens, and detector. While usually configured with cooled detectors, concentration levels, expected temperature differences, and permitted observation times may allow use of uncooled detectors for this application. Cooled detectors (at ~15x the cost of uncooled detectors) offer ~35x more sensitivity than uncooled detectors; uncooled detectors, in general, offer a broader spectral coverage. This type of system usually provides detection and discrimination but not quantification. Likely applications for this passive configuration include detection of chemical agent attacks in military and civilian venues, fugitive leak detection near industrial sites, etc.

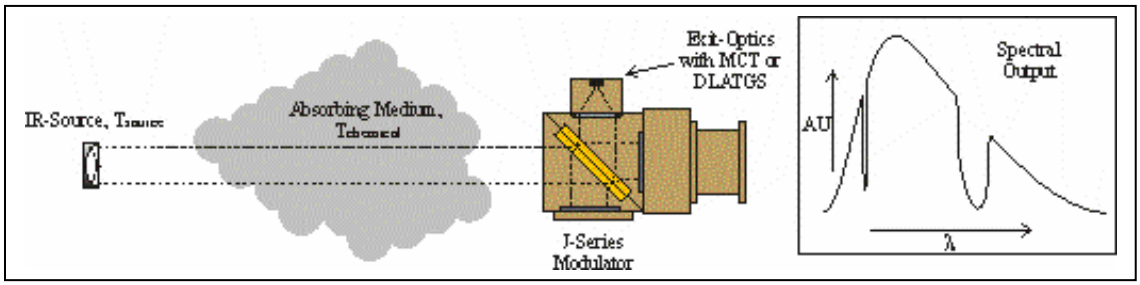
JSLSCAD (A Passive Standoff Detection Application)

The first major success of the J-Series modulator has been as an element of the FTIR spectrometer incorporated into the JSLSCAD [i] system. During the conduct of this program, rigorous testing demonstrated the ability of the modulator to endure extremes in temperature, shock, and vibration. OPTRA has fabricated 65 units that are in various stages of additional testing by the user community. The JSLSCAD in its present configuration employs a two-axis scanner for examination of a large field of regard and a mechanically cooled mercury cadmium telluride (MCT) detector.

Active Standoff Detection

Standoff detection sensitivity can be improved by the use of an active source to create a larger temperature difference than might otherwise be unavailable. In figure 3, an infrared source is placed at some distance from the J-Series modulator location. Careful control of experimental parameters allows for quantification with this arrangement.

Figure 3: J-Series in Active Configuration



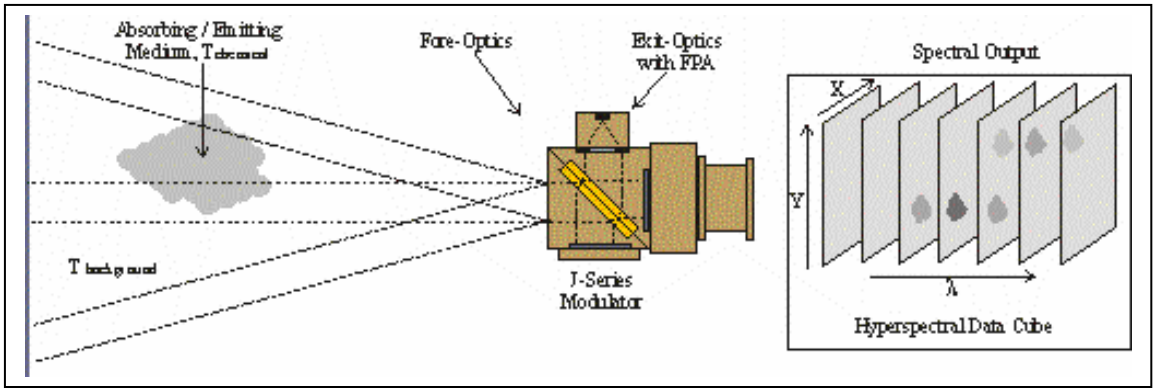
The path between the source and spectrometer may be left open or it may be a highly controlled path as in a long path cell. The modulator hardware will adopt the same geometry as for the passive case, employing a either cooled or uncooled detector, depending on the sensitivity needs. Fore-optics may or may not be necessary, depending on the open-path length to the source. Equation 1 still applies, only now the background radiation becomes that of the source. Alternative configurations where the source and modulator are co-located may offer more convenience and more control of the measurement.

The active configuration is appropriate for monitoring enclosed spaces such as in building monitoring in cases of ‘sick building’ syndrome or general surveillance of air quality due to enclosed industrial processes or even purposeful attack through the building ventilating system. Within this same scenario, as the spectral library of biological agents grows, this configuration may lend itself to the same level of protection against biological attacks of buildings. Other applications include in-stream process monitoring and on-road vehicle emissions monitoring.

Hyperspectral Imaging

Hyperspectral imaging simultaneously provides both two-dimensional spatial and one-dimensional spectral information (figure 4).

Figure 4: J-Series in Hyperspectral Configuration



For this configuration, the fore optics and exit optics create an image of the scene on a detector array. Each pixel of the FPA records a spatially-independent interferogram as the mirror scans through its stroke. Again, depending on the sensitivity needs of the application, this FPA may be an inexpensive uncooled or a more sensitive cooled array. In either case, the J-Series spatial fringe-based reference allows for two unique modes of operation. With the high position resolution, the modulator can be step scanned, simplifying processing, as all pixels are read at the same optical path difference for each interferogram point. Possibly more interesting, however, the J-Series modulator can be held in a staring mode at zero optical path difference. In this location the system produces a broadband image (integrated over all wavelengths in the passband) virtually no different than the IR FPA without the modulator. In other words, the J-Series in its hyperspectral configuration is *both* an IR camera and an imaging spectrometer.

This IR-staring capability is very attractive form a processing standpoint; the operator may locate a temperature contrast first and then switch into spectral mode to identify the chemical. Candidate applications for this configuration include industrial fugitive leak detection, chemical agent detection, and other industrial monitoring applications.

Summary

Within this paper, a modulator has been described which forms the basis of an all-in-one FTIR spectrometer system that is configurable for passive, active, and imaging operation by simply reconfiguring fore- and exit-optics assemblies. In all of the configurations, this system is rugged, portable, and relatively inexpensive by comparison to presently commercially available analytical gas detection equipment. The J-Series will offer considerable utility for a number of applications.

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[i] JSLSCAD: Joint Services Lightweight Standoff Chemical Agent Detector. This item is designed to detect and classify chemical warfare agents from a variety of mobile platforms and stationary installations. OPTRA participated in this program as a subcontractor to Intellitec, DeLand FL. See www.intellitec.com/samples/jslscad.html