Atmospheric environment monitoring system based on an earth-to-satellite Hadamard transform laser long-path absorption spectrometer: a proposal

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Recently, the need for accurate measurements of trace gases in the global troposphere and stratosphere has increased so that we might study the impact of human activities on the atmospheric environment. This letter describes a new monitoring system for trace gases in the global atmosphere. The measurement principal is based on laser long-path absorption between a ground-based laser station and a satellite-borne detector in a stationary orbit. The Hadamard transform method[1] is utilized to make simultaneous measurements from multiple stations. Although the concept of long-path absorption measurement between earth and satellite is not new,[2] using the Hadamard transform makes the system very flexible as described below.

Figure 1 shows the concept of the Hadamard transform laser long-path absorption spectrometer system HALLPASS. The system is similar to the Hadamard transform active long-path absorption spectrometer described in our previous paper.[3] Each ground-based station emits a pulse train coded by a Hadamard code specifically assigned to each station, while a satellite-borne spectrometer with a wide field of view simultaneously receives the laser light from the ground stations. The spectrometer has many bands consisting of multiple channels of appropriate spectral bandwidths. Every signal detected in each channel is converted to digital data for each laser pulse and is transmitted to the ground-based central station by microwave. The set of received signals is decoded by a fast computer. The central station sends the timing signals for laser pulse modulation and the decoded signals to each laser station.

The advantage of using the Hadamard transform is that each ground station virtually occupies its own detector in a stationary orbit, which means each station can make its own observation independently. Another advantage is that one can make any kind of measurement, such as absorption measurement with wavelength scanning and differential absorption measurement. The satellite-borne multichannel spectrometer is used simply as a bandpass filter; the spectral resolution is determined by lasers. If a station simultaneously needs more than two wavelengths within a single channel of the spectrometer, different Hadamard codes are used to distinguish the signals for each wavelength.

The SNR of the light detection was crudely evaluated for the HALLPASS with specifications as listed in Table I. Here we consider two typical cases, one a visible laser source and the other the IR. The S-N ratio for a single set of measurements by station i is written as

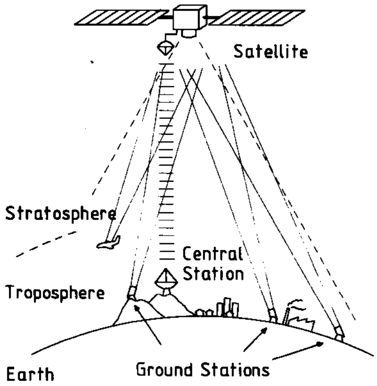

Fig. 1. Conception of the HALLPASS.

Table I. Specification of the HALLPASS used for the Evaluation

Satellite-borne multichannel spectrometer	Aperture of receiving telescope	0.28 m^2
	Field of view	14 mrad (500 × 500 km)
	Spectral bandwidth of a channel	<10 nm
	Bandwidth of signal processor	10 MHz
Ground station	Laser output energy	0.2 mJ/pulse (500 nm)
		10 μJ/pulse (10 μm)
	Pulse width	100 ns
	Pulse repetition rate	5 kHz
	Beam divergence of transmitter	0.05 mrad
	Efficiency of detection	0.1
	Number of stations	512

$$\frac{S}{N}=\frac{MI_i}{\left[(1/\xi)M\sum_j I_j+2M\theta^2+2M(1/\xi)B\right]^{1/2}}, \qquad (1)$$

where I_i represents the signal intensity from the laser station i, ξ is the conversion factor from power to the number of photoelectrons, B is the intensity of background radiation, θ

represents the noise equivalent power of the detector, and M is the number of stations.

The background radiation intensities from the earth surface at 500-nm and 10-μm wavelengths are estimated at 1.2×10^{-4} and 5×10^{-8} W m^{-2} nm^{-1}, respectively, at its maximum. On the other hand, the received peak power of the laser light from a ground station is 8×10^{-4} W m^{-2} for 500 nm and 4×10^{-5} W m^{-2} for 10 μm. In the IR region the detector noise power may be comparable to the background radiation; however, the received laser power is much larger than the detector noise power.

Equation (1) and the parameters described above give the S-N ratio of the light detection of 1×10^3 for a single set of data (0.2-s measurement) for both wavelengths, when all ground stations are in operation. Thus an S-N ratio of 10^4 can be achieved for 15-s measurement. In the HALLPASS, the S-N ratio depends on the number of operating ground stations in the photon noise dominant case as seen in Eq. (1). The S-N ratio will be improved by a factor $(M/K)^{1/2}$, when only K stations among M stations are in operation.

Since the HALLPASS requires lasers with only intermediate power, tunable light sources based on a cw-pumped Q-switched YAG laser and a CO_2 laser, for example, are the candidate. The ghost signal caused by the nonlinearity of the detector may raise a problem in the Hadamard transform method. However, the effect of the ghost can be corrected by data processing[4] and suppressed below the random noise level.

The HALLPASS is effective not only for measuring trace gases in the troposphere and stratosphere but also for regional or local pollution monitoring; the latter can be achieved when the ground stations are suitably distributed. The earth-to-satellite long-path absorption method in stratospheric measurements has the disadvantage that the measurements might be disturbed by absorption in the troposphere. However, the high S-N ratio of the HALLPASS can separate the effect of the absorption in the troposphere from the received signal, if the absorption in the troposphere is fully investigated with very high accuracy. Results of a great many previous studies on long-path absorption measurement are useful for selecting wavelengths suitable for each species.

Research in many fields, especially quantitative absorption spectroscopy and to develop tunable IR lasers, will be necessary to achieve the HALLPASS. Realization of such a system will be useful for atmospheric environment studies.

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