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Mission Study of Up-link Laser Differential Absorption Sensing

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1. INTRODUCTION

Up-link Laser Differential Absorption Sensing: ULDAS, shown in Fig.1, is a new method to measure green house gas concentration with earth observation satellites. Although the measurement area is restricted in only small visible area of an optical ground station, ULDAS has outstanding features as followed:

- Faster: Easy to development, small size and small resource requirements to satellite system
- Better: High accuracy (CO_2 observation error of weighted column is <0.3% which corresponds to 1ppm error of atmospheric concentration)
- Cheaper: Simple system, small number of parts and no special parts

The flight segment of the ULDAS is able to be loaded on a marginal resource of green house effect observation satellites, such as Japanese GOSAT-series. In this paper, the feasibility study of the mission concept and field experiments are reported.

2. BASIC PRINCIPLE

Laser differential absorption sensing uses two laser beams as probes. They have slightly different wavelengths, λon and λoff as shown in Fig.2.

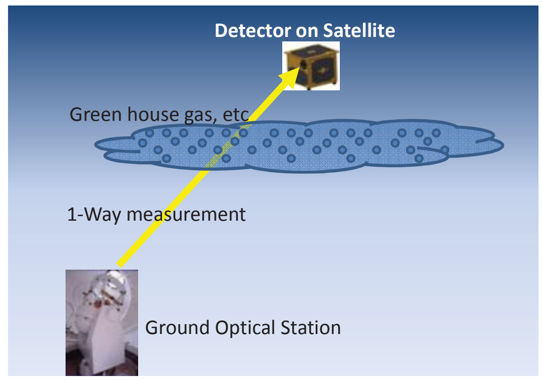

Fig.1 ULDAS image

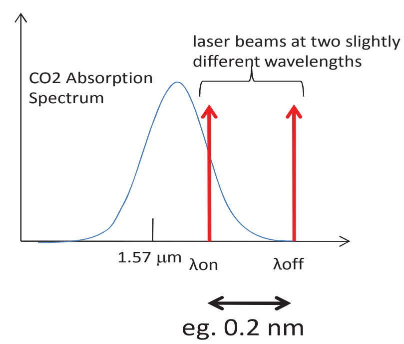

Fig.2 λon and λoff

We considered two methods to discriminate the probe beams. One method utilizes pulse lasers for the probe beams and discrimination between λon

Table 1 Trading off in laser sensing

Name	DIAL	-	-	ULDAS
Optical path (S: Satellite, G: Ground)	2way		1way	
	S→S	G→S→G	S→G	G→S
Observable Area	Global	Visible area from ground station		
On-board resource	Very big	Very small	Middle class	Small
Scale of Ground Station	Not needed	Very big	Big	Middle class
Cost	Very big	So-so	Nice	Nice
Total Score	Good	So-so	So-so	Good

and λoff is made in time domain, as shown in Fig.3 (Pulse type light source). The receiver identifies λon and λoff signals using pulse timing information.
In the other method, amplitude modulated (AM) CW beams are utilized as probes, and they are discriminated by difference between modulation frequencies as shown in Fig.4 (AM-CW type light source). The ground station has one type of the light sources. And in both cases, the equipment of ground station is consisted of shelf products.

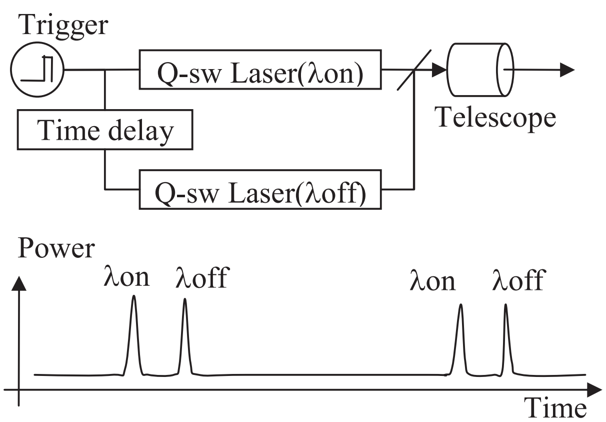

Fig.3 Pulse type ULDAS light source

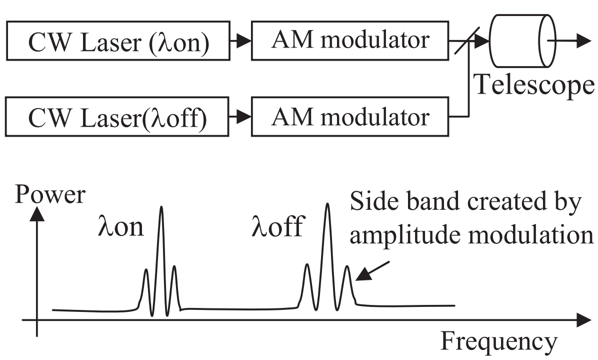

Fig.4 AM-CW type ULDAS light source

3. SYSTEM STUDY

Fig. 5 shows a schematic diagram of ULDAS onboard sensor. The sensor is consists of optics, electronics of analog circuits and a controller. The sensor is applicable to the both type of light sources (pulse type and AM-CW type). The required space, weight and power resource for satellite system are estimated to be small, as below:

- Optical system
  - Type: Telecentric optical system
  - Mass: < 1 kg
  - Size: ϕ40x150 mm
  - Effective optical diameter: ϕ3 mm
  - FOV: +/- 5 deg.
- Analog circuit & Controller:
  - Mass : < 2 kg
  - Size : 80x120x180 mm
  - Power : < 10 W

Since the required resources are small, the ULDAS onboard sensor can be equipped on earth-observation satellites as piggy back payload.

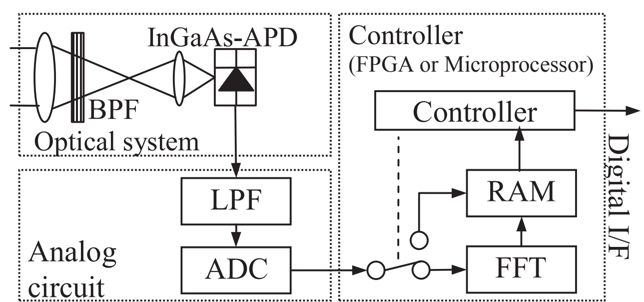

Fig.5 Schematic diagram of ULDAS onboard sensor

Fig.6-1 ULDAS flight segment (BBM, Optical aperture side view)

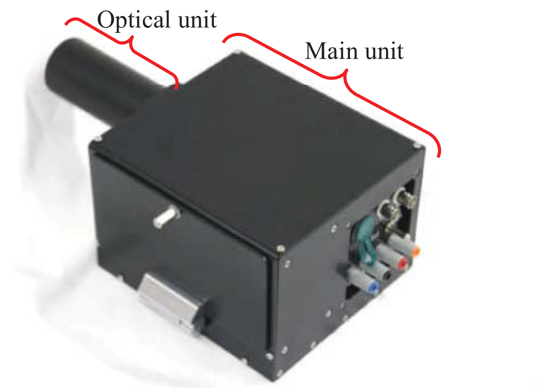

Fig.6-2 ULDAS flight segment
(BBM, terminal board side view)

4. PROTOTYPING

The developed breadboard model (BBM) of ULDAS onboard sensor is shown in Fig.6. The architecture is the same as shown in Fig.5. This BBM consists of two units, i.e. the main unit and the optical unit. The size of main unit is 175.9x185.2x116.5 mm^3 and the size of optical unit is ϕ48.0x106.8 mm^3. The total weight is 3.2kg. We plan field experiments to demonstrate CO_2 observation with long optical path such as 10~20km with AM-CW type light source.

5. ESTIMATED ACCURACY OF OBSERVATION

Accuracy of observation with ULDAS is estimated under the following conditions:

- Satellite
  - ➢ Altitude: 660km
  - ➢ Attitude: Nadia pointing
- ULDAS flight segment
  - ➢ Band width(optical filter): 3.3nm
  - ➢ Optical transmission: 50%
  - ➢ Field of view(FOV): +/-5deg.
  - ➢ Integration time: 4s
  - ➢ NF at front end: 2.2dB
  - ➢ Band width(FFT channel): 30Hz
- Laser output from ground station
  - ➢ Type: AM-CW
  - ➢ Power: 10W(par one beam)
  - ➢ Spread angle: 0.06deg.
- Atmosphere transmission
  - ➢ λon: 36%
  - ➢ λoff: 99%

In the worst case, the ground station is edge of FOV of ULDAS onboard sensor, the maximum distance between satellite and ground station is 662.2km. In this case, the beam diameter from ground station is estimated to be approx ϕ690m at the position of the satellite. Received signal power fluxes are approx 34pW for λon and 92pW for λoff, respectively. On the other hands, background light power (~5nW) causes 0.4fW shot noise per one channel of FFT (30Hz band width). SNRs including background shot noise, signal shot noise, thermal noise and quantization noise, are estimated to approx. 640 for λon and 4700 for λoff in four seconds integration time. Weather parameter: $\sqrt{(\partial N_{CO_2}/\partial T)^2 + (\partial N_{CO_2}/\partial P)^2 + (\partial N_{CO_2}/\partial U)^2}$ and wavelength parameter: $\sqrt{(\partial N_{CO_2}/\partial \lambda)^2}$ are estimated to approx 0.08% and 0.12% based on assumptions as follows:

- ➢ Temperature: $T < 2\ K_{RMS}$
- ➢ Atmospheric pressure: $P < 1\ hPa_{RMS}$
- ➢ Humidity: $U < 10\ \%_{RMS}$
- ➢ Stability of signal light frequency:
  $\Delta\nu < 300\ kHz_{RMS}$

As a result, the observation accuracy of weighted column CO_2 is estimated to be approx 0.16%, which corresponds to 0.6ppm error of atmospheric concentration.

6. GROUND STATION DESIGN

The portability of the ULDAS ground station in the field is important to spread observable area. As a result, two functions are required for ground station systems.

Star calibration function: The ground station must calibrate its attitude using fixed stars to satisfy required setting accuracy of less than 0.03 degree, which is too strict to point a target satellite without self calibration.

Scanning and detecting function: Beam scanning and acquisition/tracking functions to point the target satellite are required to the ground station. Because, the beam diameter of approx. ϕ690m is relatively small in comparison to the accuracy of simple determination of satellite position such as using two line elements (TLE). Even if, there is high accuracy information of the target satellite position, such information is not always available for the field observation. Spiral scan method was studied to search the target satellite. Onboard LDs and corner cube reflectors can considered to recognize that probe beams of ground station capture the target satellite.

7. CONCLUSION

Small and simple onboard green house gas observation system, ULDAS, has been studied. The feasibility of the onboard system and optical link were shown. The concept study of ground station system is also performed. Star calibration function and Scanning/detecting functions are required for the ground station system. The BBM of onboard system has been developed for field experiments.

In the future, drift of BBM output data and stray light tolerability will be estimated to show that ULDAS is able to work in orbit.

8. REFERENCE

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