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LIFT A FUTURE ATMOSPHERIC CHEMISTRY SENSOR

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ABSTRACT

Natural and anthropogenic trace constituents play an important role for the ozone budget and climate as well as in other problems of the environment. In order to prevent the dramatic impact of any climate change, exchange processes between the stratosphere and troposphere as well as the distribution and deposition of tropospheric trace constituents are investigated.

The Limb Infrared Fourier Transform spectrometer (LIFT) will globally provide calibrated spectra of the atmosphere as a function of the tangent altitude.

LIFT field of view will be 30 km × 30 km. The resolution is 30 km in azimuth corresponding to the full field of view, and 2 km in elevation, obtained by using a matrix of 15×15 detectors. The instrument will cover the spectral domain 5.7-14.7 µm through 2 different bands respectively 13.0-9.5 µm, 9.5-5.7 µm.

With a spectral resolution of 0.1 cm^{-1}, LIFT is a high class Fourier Transform Spectrometer compliant with the challenging constraints of limb viewing and spaceborne implementation.

1. INTRODUCTION

Natural and anthropogenic trace constituents play an important role for the ozone budget and climate as well as in other problems of the environment. Atmospheric trace aerosol distribution plays an important role in key evolutions of the Earth atmosphere, such as stratospheric ozone depletion and greenhouse effects. In order to monitor those changes and to try to prevent their dramatic impact, exchange processes between the stratosphere and troposphere as well as the distribution and deposition of tropospheric trace constituents are investigated. Usually, all these atmospheric processes are studied by means of expensive field measurement campaigns and a three dimensional numerical model of the middle atmosphere. In order to monitor those changes at a global scale, satellite measurements have proved to be an efficient manner to monitor data at global scale, which makes sense for global effects.

The Future Atmospheric Chemistry Sensors instruments will collect essential global information, about the aerosol concentration to be used to retrieve atmospheric chemical reaction properties, on a global scale.

LIFT is a Fourier Transform Spectrometer which supply observations of species with regard to eight specific questions centred on climate-chemistry inter-actions and the role of anthropogenic emissions.

The key targets for a thermal emission, infra-red instrument were identified to be:

1. Temperature in the stratosphere and (cloud free) upper troposphere.

2. C_2H_2, C_2H_6, acetone and PAN in the (cloud free) upper troposphere.

3. HNO_3, H_2O, and O_3 in the upper troposphere, lower stratosphere and above.

4. CH_4, N_2O, CFCs, HCFCs in the lower stratosphere and above.

5. NO_2, N_2O_5, and $ClONO_2$ in the mid-stratosphere;

6. Aerosol in the lower stratosphere and upper troposphere in cloud free conditions.

7. Cirrus in the UT and PSCs in the lower stratosphere.

The objective of the mission is to globally provide calibrated spectra of the atmosphere as a function of the tangent altitude. The users will subsequently retrieve altitude profiles of the target species form the spectra provided through the ground segment.

2. MISSION

The initial mission of this instrument is to provide information complementary to IASI Fourier Transform Spectrometer (FTS) onboard of Metop satellite. The orbit configuration of the LIFT spacecraft will be the same as Metop, i.e. a sun-synchronous orbit at an altitude of 819.8 km with a local time at descending node of 9H30. The instrument will be pointing towards the limb in the opposite direction of the spacecraft velocity vector and under Metop.

The footprint of the instrument field-of-regard inside the limb is a square area of 30 km in azimuth and 15x2 km in elevation. Viewed from a target distance of 3368 km, it corresponds to a square IFOV of 8.91 x 8.91 mrad or 0.510°. The along track coverage is 100 km resulting into a total observation time about 15 s. As required by the scientific objectives, this time must be divided into 5 or more interferograms letting about 3 s for each interferogram. Also, it is required that the global duty cycle of the instrument should be higher than 90 %. Finally, the spectral range of the instrument is from 5.7 to 13 µm which is quite classical for an interferometer and the expected resolution is 0.1 cm^{-1}.

Another instrument, the Limb Cloud Imager is co-boresighted with the LIFT. This instrument allows quality control of the retrieved radiance from LIFT by determining the presence of clouds inside its field-of-view. The LCI instrument consists of a SWIR camera with a resolution in the limb of 200 m in vertical and 3000 m in horizontal at 1.02-1.06 µm and a TIR camera with a resolution of 600 m in vertical and 9000 m in horizontal at 11.77-12.27 µm.

3. LIFT INSTRUMENT DESCRIPTION

3.1 BLOCK DIAGRAM OF THE LIFT CONCEPT

The LIFT instrument is composed (Fig. 1) of

- One pointing mirror able to point the scene as well as towards two calibration sources :
- One plate black body at 290 K made of small emissive corner cubes
- One afocal telescope with 2 mirrors and a magnification factor of 4.15. A field lens is also placed on the intermediary image.
- The interferometer itself is a double pendulum system with corner cube retro-reflectors. The beam splitter and the compensator are in ZnSe. The OPD is ± 5 cm. The incidence angle is 45° in order to reduce the size of the system. A laser diode at 1.55 µm and its detector are used for spectroscopy calibration.
- Secondary optics is constituted of 2 mirrors (one plane and one parabolic) and are still outside of the cold box.
- Inside of the cold box recurrent from IASI (passive cooler at 95 K) are place the 2 matrix of 15 x 15 detectors of 175 µm pitch. In the cold box is also included the beamsplitter and focusing optics.
- The horizontal pixels are binned to reach the required resolution of 30 km.
- The electronics is composed of three units : APU, ICPU and MHCU. The data rate of the instrument is estimated to be 507 kbps.

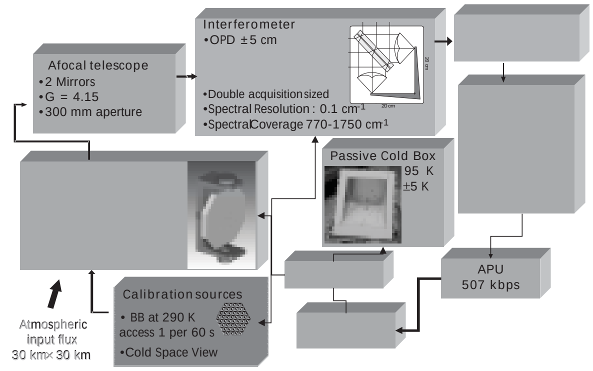

Fig. 1. Block Diagram of the LIFT interferometer

The following section describes in more details each of the LIFT sub-systems.

3.2 SUBSYSTEMS DESCRIPTION

The selected design of this instrument results from several trade-offs performed in parallel during the definition phase. The compliance with the observation requirements as well as the verification of the radiometric performances have been the main drivers of this trade-off, however the reduction of the costs of the instrument has been another parameter considered in this selection.

To be compliant with the asymmetric FOV two solutions have been envisaged. First, the most straightforward solution compliant with the 2 x 30 km field of view includes a scan mirror able to reach one after one the 15 position of the elevation field of view, an anamorphic telescope to generate a square field of view at the interferometer level and a single detector. The main advantage of this configuration is the simplicity of the detection chain, however the time allocated for the acquisition of one interferogram is reduced to less than 0.2 s which could be an issue for the radiometric performances. Moreover, the design and implementation of the anamorphic telescope could have induced some difficulty.

The second solution, selected for the current design of LIFT, is far less complex from an optical design point of view but it requires a more complex detector assembly. The detector is now a matrix of 15 x 15 pixels, each of them covering a 2 x 2 km square field of view. At the instrument level, the total field of view is considered as a square of 30 x 30 km, leading to a more regular telescope, while the time for each interferogram acquisition is close to 3 s.

In order to meet the noise and radiometric performance requirements, the diameter of the entrance pupil is fixed at 300 mm. This pupil is located on the pointing mirror to minimise its size and allow fast motion and good pointing accuracy. The Pointing Mirror Assembly - PMA - orients the instrument FOV towards either the limb, the deep space or the internal calibration blackbody.

A two-mirror afocal input telescope with a magnification factor of 4.15 is located between the pointing mirror and the interferometer. The exit pupil of the telescope is located on the apex of the retro-reflector by means of a field lens located on the intermediate image. This lens allows us to place the retro-reflector as far as we need for mechanical constraints. The intermediate image can be used to place a field stop to minimise stray-light

The core of the instrument is composed of a double-pendulum, cube-corner interferometer as shown in Fig. 2. The scanning mechanism is highly inspired from the ACE-FTS interferometer on-board Scisat-1 designed and manufactured by ABB. The advantage of this approach is to provide a mechanical-to-optical-path-difference factor of 4. This configuration is also less sensitive to vibration induced shear due to the fact that the interferometric mirrors are permanently aligned at each end of the balanced scanning arm. The LIFT interferometer offers an optical path difference coverage of ± 5 cm, corresponding to spectral sampling of 0.1 cm^{-1}, while the corner-cubes mechanical displacement is only ± 1.25 cm. The entrance pupil diameter along with the magnification factor of the telescope define a pupil size of 7.15 cm inside the interferometer. State-of-the art retro-reflectors developed for the IASI program are re-used in the LIFT design. The angle of incidence on the beamsplitter is 45° like in the ACE-FTS instrument. This angle of incidence may give rise to slightly higher polarisation effects but it considerably reduces the overall dimensions of the subsystem.

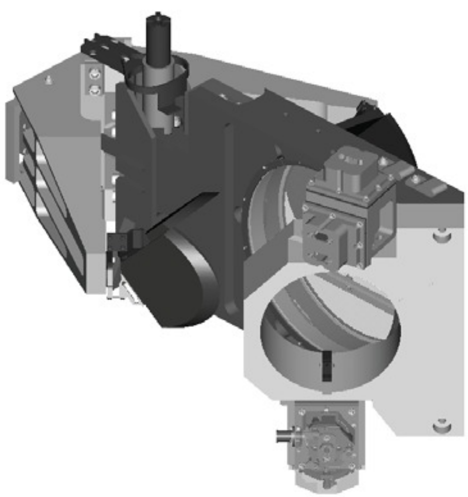

Fig. 2. Core of the interferometer

At the output of the interferometer, the spectral separation is done with a single dichroïc located after a parabolic focusing mirror. Focusing optics is implemented in each spectral channel and the F/# at the detector is 0.97.

The detection chain is composed of two arrays of detectors covering the LIFT spectral bands and working at 95K in a passive cooler. Two MCT photovoltaic detectors have been chosen to cover the spectral range (channel A from 4.7 µm to 9.5 µm, channel B from 9.5 to 13 µm). Each focal plane consists in 15 x15 pixels (to cover the 30km x 30km field of view). The pixel size is 0.175 mm leading to a total active area equal to 2.625x2.625mm².

The selection of the focal plane cooler system is based on improved performances of the MCT detectors with lower temperatures but also on the increase in costs and complexity of the active system compared to a passive solution. Moreover, LIFT being on the same orbit than IASI on Metop, the experience gained on IASI could be fully applied. Since using a recurrent system from IASI significantly reduces the development costs of LIFT, the passive concept is preferred. This sub-system uses a 3-staged radiator and a Cold Box (Fig. 3). The Cold Box structure contains the cold optics and the detectors. The radiator position & orientation are such that it avoids any IR radiance input from the Earth and from the rest of the spacecraft - platform and payload instrument. The Sunshield is designed to keep the radiator free from sun illumination. As it is exposed to Earth radiation, it is given a specific curved profile that prevents any reflected light to reach the cold radiator. This cold box is located on the [+X_S] side of the spacecraft.

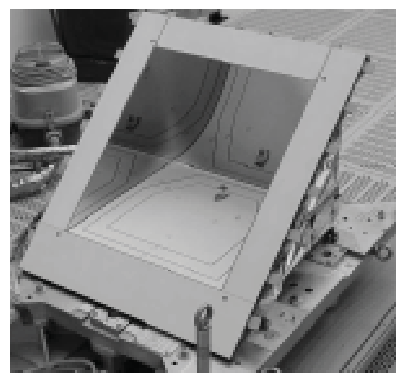

Fig. 3. Cold box compact layout

The last aspect of the instrument to be considered is the calibration target. In order to measure the gain and the offset, a two-point calibration is the minimum needed. For the cold calibration, deep space from 90 to 120 km is used. For the hot calibration, the concept is much more complex. Due to the large dimensions of the pupil (300 mm), a classical black body cavity cannot be envisaged since these devices offer acceptable performances when their length-to-aperture ratio is higher than one. Weight and envelop constraints avoid the use of such a large cavity. On the other hand, using a smaller source would require a dedicated afocal telescope between the black body and the pointing mirror, also inducing constraining implementation requirements. Therefore, a passive plate blackbody with a corner-cube pattern and a specular coating is the selected approach. Such plate blackbody could have a diameter of about 300 mm (Fig. 4) which covers the entire entrance pupil.

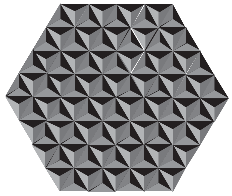

Fig. 4. **Plate blackbody**

3.3 TIMELINE

The requirement for 90 % global coverage must be adapted to the calibration need. One calibration each 30s is enough for the deep space view (stability of the instrument) while detector drift can be calibrated less often (each 80 s in IASI)

The calibration sequence is different, depending of the pointed calibration source. According to the pointing mirror specification the Deep Space depointing is 300 ms and 400 ms are use to point back at the scene. The spectrometer last rotation is performed in the same time. For the limb view, the depointing time is 700 ms and the pointing back is 1000 ms. This depointing is more time demanding as the required angle is greater than for the deep space view. Table 1 summarises the times needed for the re-orientation of the pointing mirror.

From Position	To Position	Number of degree	Time before acquisition [msec]	Comment
Limb view	Deep space view	1°	**300**	No need to have a stable position
Deep space view	Limb view	1°	**400**	Wait for a stable position
Limb view	Blackbody view	16°	**700**	No need to have a stable position
Blackbody view	Limb view	16°	**1000**	Wait for a stable position

Table 1 : Mirror Pointing Constraints

The acquisition of the interferograms during calibration is made at 1/10 of the nominal resolution. Two interferograms are acquired for a total of 646.2 ms including 75 ms for the direction change of the interferometer scanning mechanism between these two acquisitions (see Fig. 5)

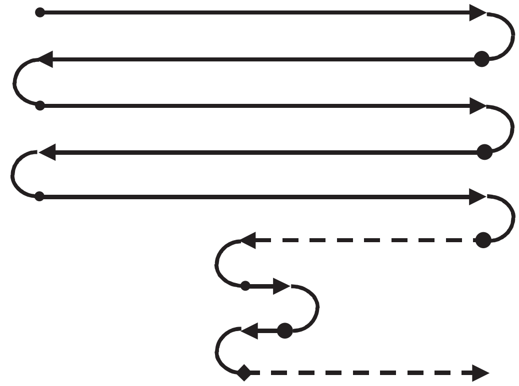

Fig. 5 :Interferogram mechanism movement during acquisition and calibration

The following timeline (Table 2) is proposed as the baseline for the LIFT instrument. The scene acquisition takes 2.856 s, this acquisition is repeated 5 time to cover the 100 km of along track sampling interval. Between two acquisitions, the scanning mechanism of the spectrometer must change direction. This turn around motion is estimated to be shorter than 75 ms and must be repeated 4 times, the corresponding cumulated time is therefore 300 ms. The time between two calibrations is about 30 to 33 s between two deep space views and 66 s between two BB views. This sequence is sufficient to insure the right performances of the FTS. This time sequence is compliant with the requirement of 0.9 duty cycle.

OPERATION	DURATION (ms)	Cumulative time (ms)
Scene acquisition	14280	14280
Spectrometer mechanism rotation	300	14580
Pointing Mirror forward	300	14880
Space view acquisition	646,2	15526,2
Pointing Mirror backward	400	15926,2
Scene acquisition	14280	30206,2
FTS Mirror rotation	375	30581,2
Scene acquisition	14280	44861,2
Spectrometer mechanism rotation	300	45161,2
Pointing Mirror forward	300	45461,2
Space view acquisition	646,2	46107,4
Pointing Mirror backward	400	46507,4
Scene acquisition	14280	60787,4
Spectrometer mechanism rotation	300	61087,4
Pointing Mirror forward	700	61787,4
BB view acquisition	646,2	62433,6
Pointing Mirror backward	1000	63433,6
Total time		63433,6
Calibration operations		5039
Scene acquisitions	57120	
Ratio acquisition/total	0,900	

Table 2 : Timeline for the LIFT instrument

4. LIFT PERFORMANCES

4.1 NESR PERFORMANCES

The principal source of noise in the total NESR is the noise from the detector and its associated electronics. Fig. 6 shows that the NESR requirement is obtained within the spectral the band B where the detectivity is higher at 95K.

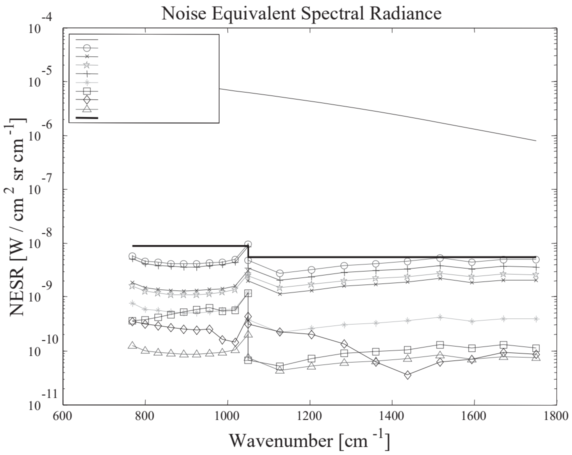

Fig. 6 : NESR performance with F_number of 0.97

These NESR values are obtained after a combination of the signals collected from the 15 horizontal pixels (corresponding to the horizontal resolution requirement) and a summation of 5 interferograms (corresponding to the along track resolution of 100 km). This latest summation is made on ground in order to discard cloud contaminated measurements.

In term of SNR (Fig. 7), SNR is greater than specifications with a maximum SNR equal to 2620 at $\sigma = 1080\ cm^{-1}$.

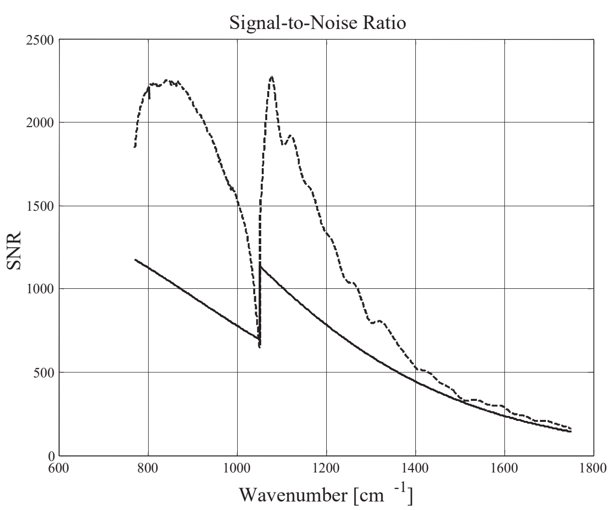

Fig. 7: SNR for a F_number of 0.97

4.2 ILS CALCULATION

As described in Section 3, the detector is a 15 by 15 focal plane array. The pixel divergence inside the interferometer is square. The input afocal telescope maps the instrument instantaneous FOV to a pixel divergence of 2.46 mrad inside the interferometer. This divergence for the most off-axis pixel is small enough so that the resolving power of the FTS is preserved (Fig 8). The next picture gives the calculated ILS at $1750\ cm^{-1}$ for a divergence inside the interferometer that maximises the modulated signal at MPD.

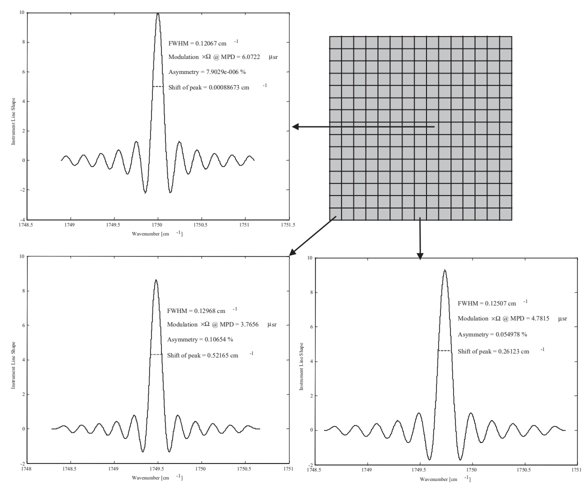

Fig. 8 : Instrument line shapes for a square 15 by 15 focal plane array at $1750\ cm^{-1}$

Finally, for the corner pixel (worst case) of a this square focal plane array, the ILS FWHM is about $0.13\ cm^{-1}$ and the asymmetry of the secondary lobes is about 0.11%.

4.3 OVERALL MECHANICAL LAYOUT AND BUDGETS

As shown in Fig. 9, the instrument is sandwiched between its optical bench and the platform. The mounting of the instrument uses three fixation feet. The overall dimensions of the instrument are 2000 mm x 1630 mm x 1077 mm taking into account the input baffle but not the electronics boxes to be placed on the spacecraft. The overall mass is estimated to be smaller than 196 kg, the electrical consumption is less than 235 W and the data rate, 507 kbps.

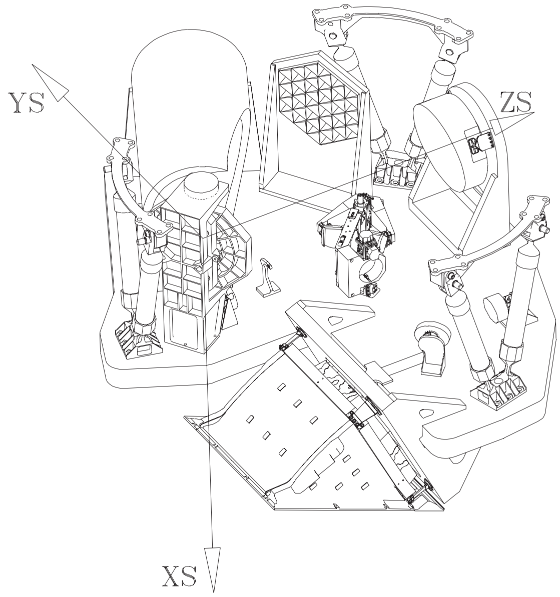

Fig. 9 : overall mechanical layout of the LIFT instrument

5. CONCLUSION

The innovative design of the LIFT instrument takes advantage of the combined experience of Alcatel and ABB in space borne Fourier Transform Spectrometer. The challenging requirements are met through new promising concepts such as plate black body or matrix detectors as well as proven space qualified concepts like passive cold box or double pendulum interferometer. The LIFT instrument appears well adapted to the challenges of the space atmospheric chemistry measurements.

6. ACKNOWLEDGEMENTS

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