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SPATIALIZED LASER SOURCE
FREQUENCY LOCKED ONTO A MOLECULAR LINE

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ABSTRACT - For IASI spectrometer, CSO Mesure developed a high frequency stabilized laser source used as a reference to sample the measurement interferogram. Semi-conductor laser diode and fibered optical components have been used to achieve a compact and spatialized frequency reference.

1- INTRODUCTION

The work presented here has been supported by CNES in the frame of IASI project. IASI instrument mission will be to provide with improved infared soundings of the temperature and moisture profiles in the troposphere and the lower stratosphere as well as some of the chemical components playing a key role in the tropospheric chemistry.
The heart of the instrument is a Michelson interferometer working within the [3.6-15.5 µm] wavelength range. As any interferometric spectrometer, this instrument requires a reference interferogram to sample the measurement interferogram.
CSO developed the laser source of this reference interferometer.

2 - CONCEPT OF IASI LASER SOURCE:

2-1- TECHNICAL REQUIREMENTS:

The laser source has to provide the IASI interferometer with a laser beam fulfilling the two following main requirements:

a)- Very high frequency stability ($\Delta\nu / \nu > 1\ 10^{-7}$)
b)- Optical compatibility with interferometer

Moreover the device has to be able to stand the space environment for the 5 years of IASI mission and to keep the same frequency emission value within 2.10^{-7}during this period of time.

This paper describes how the developed device achieved the requirement a).

2-2- CONCEPTS FOR FREQUENCY STABILISATION:

2-2-1-The choice of source:

The achievement of long term (several years) high stability laser frequency has already been reached by developments led in the field of atomic clocks.

The first studies in laser frequency stabilisation used gas laser such as He-Ne. Then, thanks to the development of telecommunications, new type of solid-state laser, laser diodes, became good candidates for being used as stable optical oscillators. This compact technology is more compatible with spatial requirements than glass tubes filled with gas.
But, as a matter of fact, the frequency of a laser diode driven at constant current and temperature shows a slow drift versus time which value can not be predicted from one diode to another. To achieve an absolute stability of 2.10^{-7} over the full duration of the mission, the use of atomic or molecular absorption line as frequency reference is mandatory.

There is a wide choice of usable spectral absorption lines. Nevertheless, the selected material has to present absorption lines matching with the disposability of commercial laser frequencies. The selected line itself has to be strong enough to deal with a compact device (small absorption cell) and spectrally recognisable from its neighbourings. Its width has to be related to the aimed stability.

A preliminary work made by the Laboratoire de l'Horloge Atomique (Orsay, France) showed that $^{13}C_2H_2$ gas was a very good candidate for frequency locking of telecommunication standard laser diode emitting at 1.55 µm.([1]).

2-2-2- Stabilisation principle:

Once the working line is chosen, the laser diode has to be electronically driven in such a way that its emitted frequency reaches the reference line and remains locked on it with an accuracy of 1.10-7.
As the temperature of the laser has a strong effect onto emitted frequency, this parameter can be used to set the emission in the vicinity of absorption line . The fine lock-in of the frequency has to be done by its dynamic tracking around the top of the line.

The most reliable concept for locking a laser onto a spectral reference is to modulate the frequency of the laser around the aimed value. This can be done easily by modulating the laser current: the frequency modulation can then be chosen from a few hertz up to several gigahertz.
The guideline for choosing the modulation frequency and depth is their influence onto the spectral shape of the laser (a too big widening of the laser line can destroy the visibility of the final interferogram) and the availability of high frequency operating components compatible with a spatial use

The frequency modulation of the IASI laser source is 350 MHz. In this configuration, phases and amplitudes of lateral bands generated by the modulation and standing at 350 MHz on both sides of the optical carrier frequency, are exactly opposite when the optical frequency is set at the maximum of absorption line. An error signal, proportional to the first derivative of absorption line can then be generated through a phase discriminator.

. 3-IASI LASER SOURCE DESIGN:

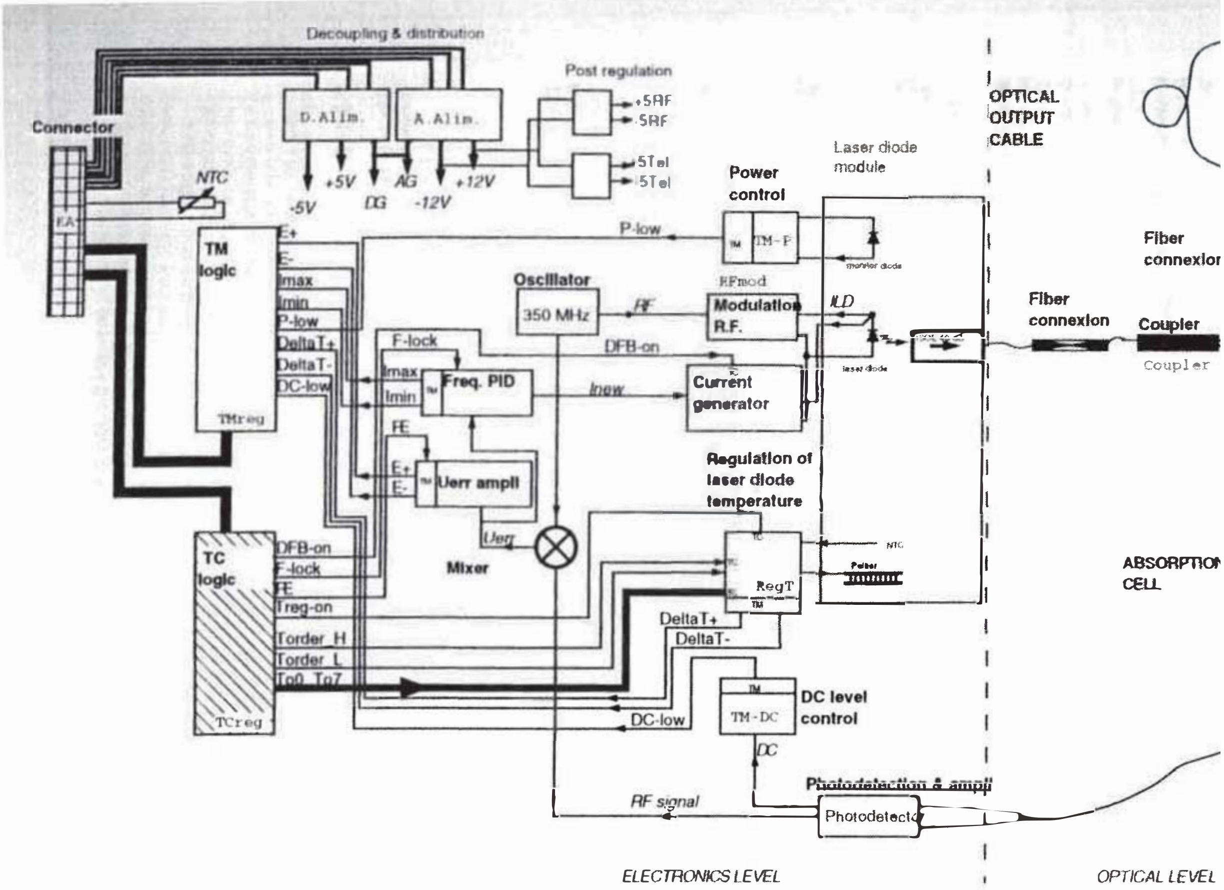
3-1- Functional breakdown:

The laser unit is a two stage box: the lower stage holds optical components and the upper stage the electronic board.
Laser module and photo detector module, as optoelectronical components, belong to both stages: they are soldered onto the printed board and connected via optical fibers to optical stage.

The functional breakdown of the laser unit is shown in "Fig.1".

3-2- Optical level:

The optical stage of laser unit contains:


Decoupling & distribution
Post regulation
Connector
D.Alim.
A.Alim.
+5RF
-5RF
+5Tel
-5Tel
NTC
EA
-5V
+5V
DG
AG
-12V
+12V
TM
logic
TMreg
E+
E-
Imax
Imin
P-low
DeltaT+
DeltaT-
DC-low
Laser diode
module
Power
control
TM-P
monitor diode
OPTICAL
OUTPUT
CABLE
Fiber
connexion
Oscillator
350 MHz
RF
RFmod
Modulation
R.F.
ILD
laser diode
Fiber
connexion
Coupler
Coupler
F-lock
DFB-on
Imax
Imin
Freq. PID
Inew
Current
generator
FE
E+
E-
Uerr ampli
Regulation of
laser diode
temperature
TC
logic
TCreg
DFB-on
F-lock
FE
Treg-on
Torder_H
Torder_L
Tp0_Tp7
Uerr
Mixer
RegT
NTC
Peltier
ABSORPTION
CELL
DeltaT+
DeltaT-
TM
TM-DC
DC level
control
DC-low
DC
Photodetection & ampli
RF signal
Photodetector
ELECTRONICS LEVEL
OPTICAL LEVEL

- a laser diode module: provides the optical source of the device
- a 1X2 coupler: splits the optical emission into two arms. One is delivering the optical output of the laser source; the other is used to realise the frequency servo-control.
-an acetylene cell: provides the LAU with an internal frequency reference
- a photodetection module: detects the optical signal transmitted through the cell and converts it into electrical signal.
-an external optical cable: ensure the optical connection between the laser unit and the collimator
- a collimator: shapes the beam going out of optical cable to a parallel beam.
- two type of fiber assemblies: connection between fibers by fusion splicing and ending of optical fibers by ceramic ferules.

3-2-1- Laser module:

We use as optical source a laser module containing inside the same package the following components:

- a Distributed Feedback laser diode
- a Peltier thermocooler
- a thermistor
- an optical isolator (-45 dB)
- a " pig-tail " output on monomode optical fiber

The selected laser module can be frequency tuned to the right acetylene absorption line by driving the laser current and temperature.
The tunability of the laser is:

$$\Delta\nu / \Delta T = 11 \ \text{GHz / K}$$

$$\Delta\nu / \Delta i = 0.9 \ \text{GHz / mA}$$

Its spectral drift is lower than +/- 12 Ghz ($\Delta\nu/\nu = +/- 6.\ 10^{-8}$) on the full duration of the mission.

In order to achieve a high stability of $\Delta\nu/\nu = 10^{-7}$, the laser diode resonator needs to be optically isolated from part of the light which may come back from downstream components. Tests proved that not less than 45 dB of isolation rate is mandatory.
The coupler splits the light coming from the laser with the following ratio:

- 40% are put into the servo control loop, to the acetylene cell
- 60% are sent to the optical output of LAU

Coupler is made by monomode fused fiber technology. It has been chosen for its low sensitivity to input polarization state (less than 0.1 dB in insertion losses can be generated by change in polarization) and specified for a directivity (reflection coming from dead arm) better than -50dB.

3-2-3- acetylene cell:

The acetylene cell is made by using glass-metal technology in order to ensure a high reliability of the device.
A 80 mm length titan tube with both sides ended by sapphire windows is filled under a 20 mbar pressure of $^{13}C_2H_2$ acetylene gas.
The light coming out from the 40% arm of the coupler is collimated by plano-convex lens and crosses the cell before being coupled inside photodetector input fiber thanks to a second plano-convex lens.

We chose isotopic $^{13}C_2H_2$ acetylene because of the adequation between the frequency position of its lines and commercially available laser diodes. Absorption lines are strong , fully separated from each other and have simple shapes.

We lock the laser onto the strongest one, set at $\lambda = 1537.7$ nm. For an internal cell pressure of 20 mbar of acetylene, the absorption depth is **78 %** (T = 20°C) and the line width is **650 Mhz**.

3-2-4- Photodetection module

The photodetection module contains .in the same package:
- a InGaAs photodiode, working in the range of 1.55 µm
- an integrated electronic stage for amplification of the photosignal
- a fiber pig-tail

The photodetector module sends to the upper electronics stage an amplified picture of optical signal behind the cell.

3-3- Internal electrical design of the LAU:

The electronical stage of LAU ensures the following functions:
- modulation/démodulation of the laser frequency
- Laser current regulation
- laser temperature regulation
- decoupling, distribution and post-regulation of external power supply
- TM / TC logic

3-3-1-Modulation and demodulation of laser frequency:

The servo-control loop needs a modulation of laser frequency around the aimed working point.
The full modulation/demodulation sub-system contains:
- an oscillator
- a modulator
- a detection line
- a mixer

The value of frequency modulation is set to half the value of absorption line width : **350 Mhz**.
The 350 Mhz used oscillator has two outputs: a low level one used to modulate the laser frequency with a small depth (**10%** of the total optical power is transferred into modulation bands), and high level one used as frequency reference for demodulation.

The photodectector and its amplification chain detects a 350 Mhz signal coming from the beating of the two spectral modulation bands with the carrier. When the frequency of the laser crosses the absorption line, the two lateral bands n0-Fmod and n0-Fmod are absorbed with a different value versus the relative position between absorption line and average frequency of the laser.
The phase of this compound 350 Mhz signal is proportional to the first derivative of absorption line .

The phase detection is ensured by mixing, the frequency reference delivered by the high level output of the oscillator with the amplified photodetector signal. The delay of the signal coming from the optical loop is tuned thanks to an ajustable delay line.
The tracking range represented by the amplitude of the error signal is about 700 MHz.

3-3-2- Laser current regulation:

The value of the laser current is set by a reference bridge. This working point can be slightly adjusted by the frequency servo-control loop in the range of +/- 5 mA in order to lock the laser frequency to the zero of the servo-control error signal.

The laser current modulation block contains:
- a -5V regulator and a current generator
- a resistor reference bridge
- a protection kit for the laser diode (protection against inverted current, over range current, etc..)

3-3-3-laser temperature regulation:

The value of laser temperature is set from outside the LAU by a digital TC.
The LAU temperature control contains:

- a 12 bit digital / analog converter for the temperature setting point
- a measurement bridge of the thermistor enclosed inside the laser module
- a power and integrating amplifiers to drive the Peltier thermocooler
- a watching circuit for the regulation

The thermistance enclosed inside the laser package is measured and compared to the set temperature point. Then the Peltier thermocooler is driven in order to make the thermistance reach the right value (a working point close to the top of absorption line, inside the current servo-control tracking range). The Peltier thermocooler can, in this configuration, ensure a **thermal regulation of the laser from +10°C to +30°C** when the external thermal environment is somewhere between +10°C and +30°C.

3-3-4- Telecomands and telemeasures:

The control of the LAU requires the following functions:

- find the frequency position of the wanted absorption line
- in locked mode, correction of temperature setting point in case of drift of the laser wavelength requiring a fine control of current over +/- 2.5 mA (full current range available for servo-control is +/- 5mA).
- watching of control parameters
- interface with upper control.

TM and TC are ensured thanks to two 16 bit synchronous serial interfaces of AS16-CS16 type. Parallel 16 bit registers are associated to serial interfaces to record the commands and the telemeasures.

The telecommands are:

- 1: power on/off the laser diode
- 2: lock/unlock the frequency servo-control
- 3: reset the detection of E^+ and E^- (thresholds set on the error signal allowing it to be clearly identified as generated by the crossing of absorption line)
- 4: power on/off the thermal regulation (allowed only if the LAU temperature is in the operational +10/+30°C range)
- 5: DAC converter control and temperature loading

The telemeasures are:

- 1: state of E^+ and E^- thresholds
- 2: alarm for the current exceeding its nominal driving range
- 3: alarm for a too low value of laser diode optical power (reading of rear facet monitor diode)
- 4: alarm for a too low value of photodetector optical signal
- 5: alarm for over 6 cK between temperature set point and temperature measurement

4- PERFORMANCES AND BUDGETS

Performances and budgets of laser unit have been measured onto a full representative breadboard.

Optical output power	900 µW < Popt < 1600 µW
Nominal wavelength	1537.65663 nm
Short term wavelength stability (few minutes)	$+/- 3.\ 10^{-10}$
Long term wavelength stability (2000 hours)	$+/- 6.10^{-8}$
Laser spectral width	< 15 MHz
Power consumption	< 5.5 W
Mass	2 kg

Long term measurements have been made thanks to a high accuracy lambdameter, specially developed for IASI laser source in a frame of co-operation between CSO Mesure and Institut Nationnal de Metrologie. Basic principle of the instrument is a double Michelson interferometer allowing to compare the wavelength to an unknown laser to those of a frequency stabilized one, connected with International Standards.
A clever associated fringe counting proceeding allows to achieve a reproducibility of frequency measurement of few 10^{-8} [2].

5- CONCLUSIONS:

The phase B development led onto IASI laser source proved the feasibility of a high frequency stabilized optical source compatible with spatial requirements.
This device show the benefits spatial applications can get From using new optoelectronical components developed for telecommunications, has laser module, coupler and monomode optical fibers: reliability; low consumption and low mass.

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