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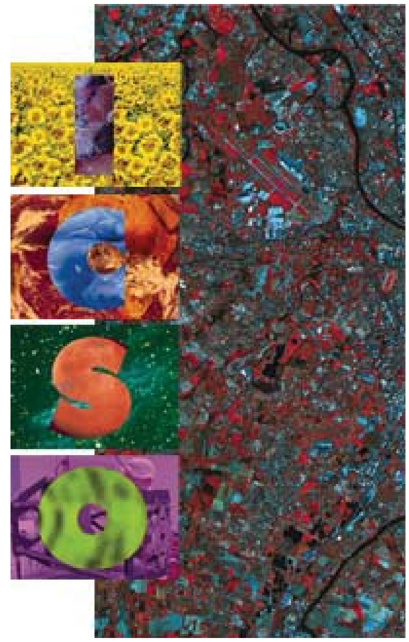

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SPATIALIZED INTERFEROMETER IN INTEGRATED OPTICS

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1 – INTRODUCTION

This project, realized as part of a CNES/CSO Mesure contract, concerns the study and the industrial realization of a sensor aimed at the relative position control of space telescope mirrors.

That for, we have to measure three degrees of freedom, which requires the use of three measuring heads.

The main idea is to develop, for each head, a Michelson interferometer in a compact chip compatible with a space use.

The interferometric function is performed by integrated optics made by ion exchange on a glass substrate. Its principle has been previously validated [Lang 95].

This technology allows us to have an optical circuit of small size compared with a bulk optics device, without optical misalignment (alignment being done by the mask design itself).

Expected performances are the following:

- measuring range : 0 to 3 m
- resolution: 0.1 µm
- accuracy: 0.2 µm
- maximal displacement speed: 150 mm/s

2 – PRINCIPLE

2.1 – General synoptic of the system

The system is composed of the following elements (Fig.1):

- a laser source,
- three measuring heads,
- an electronic unit,
- a user interface, which is a dedicated PC software.

The laser source is a DFB diode emitting at 1.55 µm. This wavelength allows us to use telecom components (diodes, fibers, couplers…). The source is regulated in current and temperature and frequency stabilized on a molecular absorption line. Flying models are under production at CSO Mesure for the IASI project [Pujol 97].

The electronic unit includes the global power supply and the fringe counting system.The current and temperature regulations of the source are driven by a portable PC.

Optical source and electronic treatment are routed by optical fibre and electrical cable.

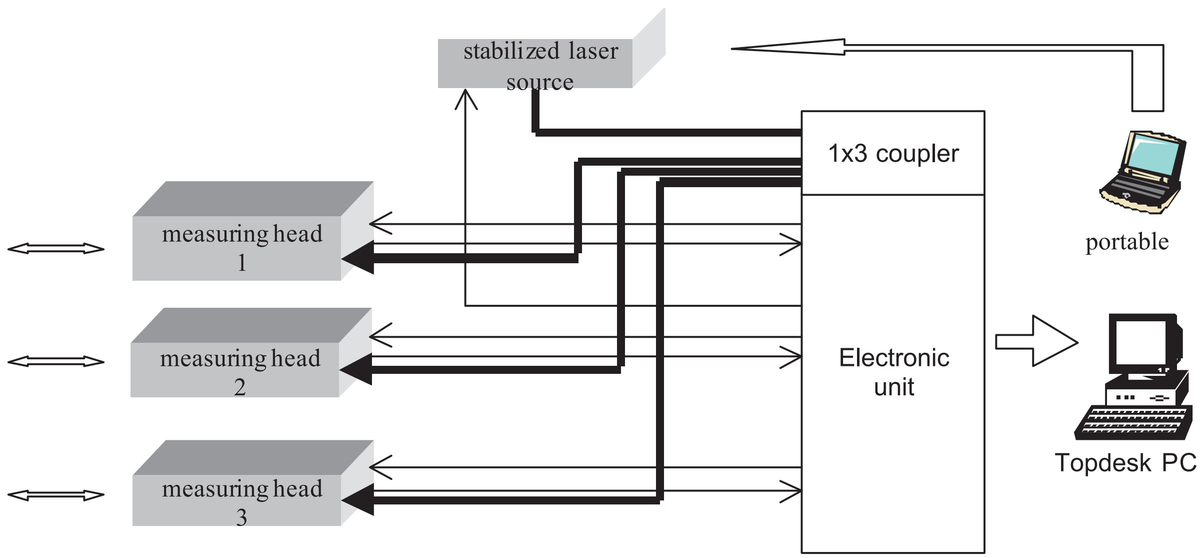

Fig.1 : Synoptic of the system

2.2 – Measuring head principle

For each measuring head, the general principle used squares with a Michelson interferometer operation.

The beam is injected into the optical circuit of the head and then divided into two beams: the reference one and the measuring one.

The measuring beam propagates in the air or the vacuum and is reflected on the corner cube, associated with the object of which we want to measure the displacement along the beam propagation axis.

The measuring beam coming back is injected in the optical circuit and overlaps with the reference beam with the tilt half-angle γ (Fig.2).

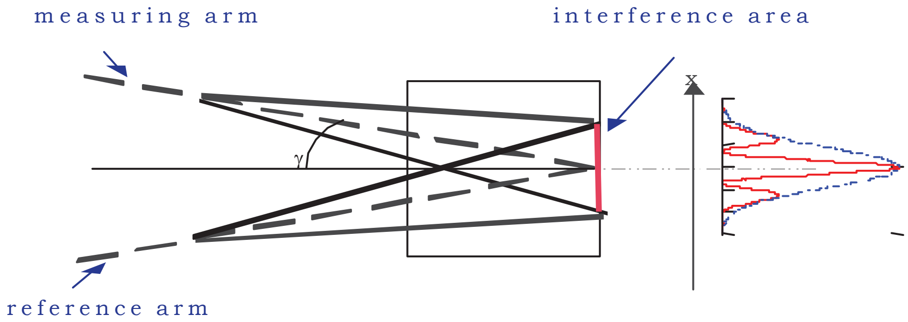

Fig.2 : interference area

At the beam overlapping area level, the optical intensity is done by:

$$I(x,\varphi) = I_0 \cdot \exp\left(\frac{-2\cdot x^2}{\sigma_1^{\,2}}\right)\cdot\left(1+\cos\left(\phi+2\pi\cdot\frac{x}{ii}\right)\right) \tag{2.1}$$

with $I_0 \cdot \exp\left(\frac{-2\cdot x^2}{\sigma_1^{\,2}}\right)$ the gaussian envelope expression,

ϕ: phase shift due to the corner cube position,

$$\phi = \frac{2\pi}{\lambda}\cdot 2\cdot n\cdot \Delta \tag{2.2}$$

$2\pi\cdot\frac{x}{ii}$: phase shift due to beam tilt with ii the interference fringe spacing,

$$ii = \frac{\lambda}{2\cdot n_{eff}\cdot \sin\gamma} \tag{2.3}$$

λ: wavelength;

2.n.Δ: optical phase difference, n refractive index of the propagation medium (air or vacuum) and Δ the corner cube position with respect to the sensor,

n_{eff} : refractive index of the overlapping medium,

γ: tilt half-angle.

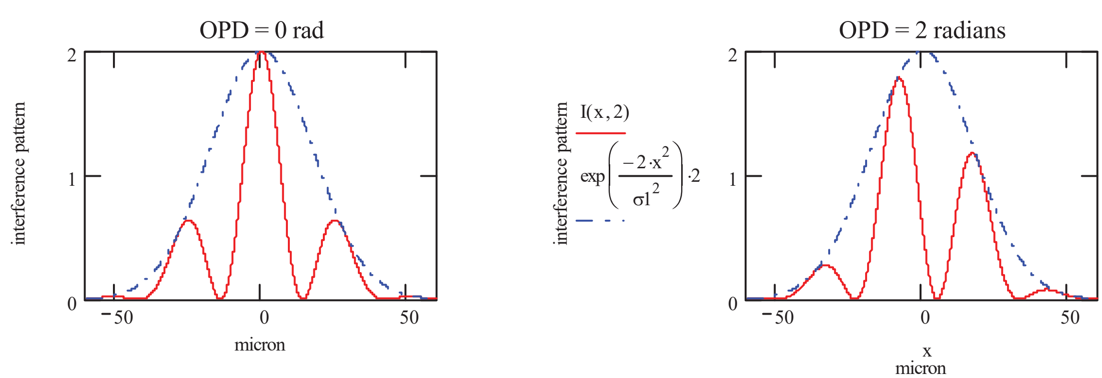

Fig.3 : Fringes moving with the object displacement

The result is an interference pattern moving when the corner cube moves along the measuring axis (Fig.3).

Four signals taken from the interference pattern allow the object displacement measurement.

Two other ones are taken respectively from the measuring and the reference arms (photometry outputs). They enable us to control the optical power injected into the measuring head by the stabilized laser source and the optical power received in the measuring arm.

2.3 Optical circuit

The interferometric circuit made in integrated optics on glass is the following (Fig.4):

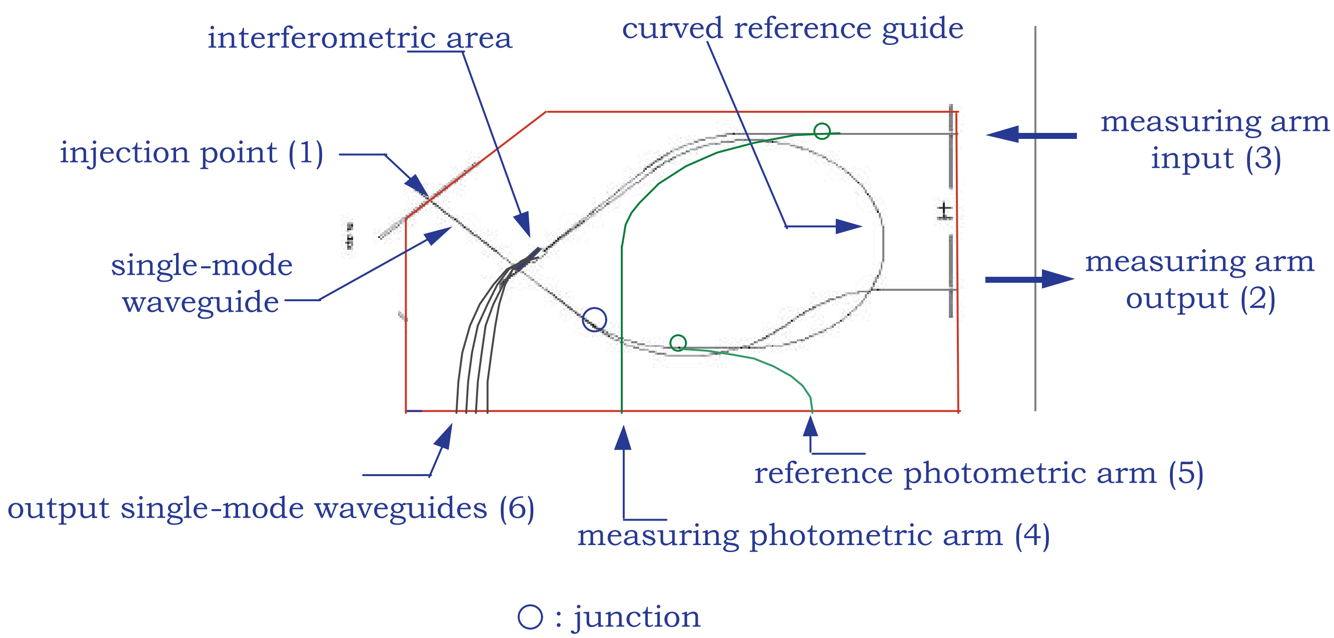

Fig.4 : Scheme of the optical circuit

The optical circuit includes:

- a straight input waveguide, in which we inject the optical beam coming from a single-mode fibre;
- a splitting junction, dividing this beam into two arms: the measuring one (straight) and the reference one (curved). This junction can be an asymmetric Y-junction or a directional coupler;
- a return straight waveguide, in which we collect the measuring beam coming back from the corner cube;
- a loop, allowing to drive the reference beam into an area where it interferes with the measuring beam. Losses of this curved guide depend on its curvature radius and represent the main criterion for the circuit dimensions;
- two tapers, each allowing the light coming from a single-mode straight waveguide to propagate and thus to provide a collimated beam;

- a planar waveguide, which is the interference area. Collimated beams from the tapered waveguides propagate freely in the horizontal direction (x axis) while remaining confined in the vertical direction (y axis). Both beams interfere at the output of the planar waveguide structure (called the overlapping plane);
- four single-mode guides set in the overlapping plane and used for the signal detection;
- two couplers, one on the measuring arm and the other on the reference arm, providing two photometry outputs.

In order to obtain a precise phase shift between detection signals, those waveguides are placed:

- symmetrically, compared with the gaussian interference pattern envelope. Then, we obtain, by appropriate combination of the four signals, the value and the direction of the corner cube displacement,
- with a spacing $d = \frac{3}{4} \cdot ii$ - ii fringe spacing done by equation (2.3) –in order to have $\frac{3\pi}{2}$ between two adjacent guides.

2.4 Measuring head

In order to favour sensor miniaturization, we have placed in the measuring head only the optical circuit, interference fringes detection (photodiodes), photometric outputs and their treatment (Fig.5):

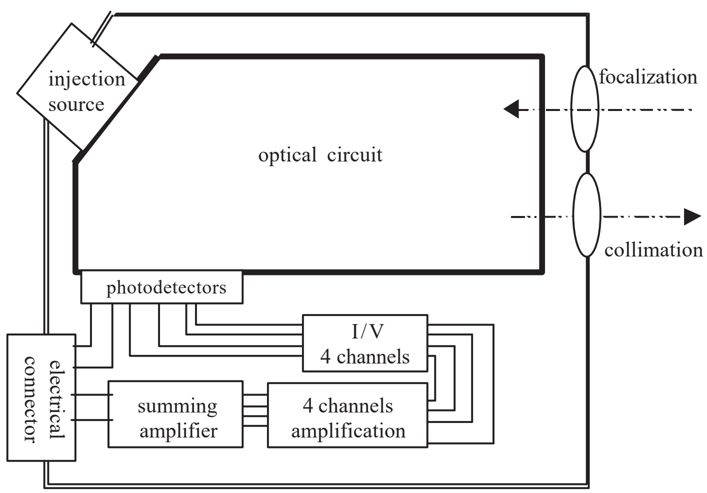

Fig.5 : scheme of a measuring head

At the output of the four photodiodes placed directly at the back of the guides, currents are changed into voltage signals and then amplified in order to have the same average amplitude and the same modulation depth. Those amplification coefficients are theoretically independent of the contrast and can be hold constant over the whole measuring range.

Two summing amplifiers provide the following signals :

$$V1(\phi) = channel1(\phi).coef - channel3(\phi)$$

$$V2(\phi) = channel2(\phi) - channel4(\phi).coef$$

Thus, the result is two quadrature phase shifted signals, with the same amplitude A and no offset. Those signals are called Sin and Cos.

2.5 Treatment in the electronic unit

The general principle used for the displacement measurement consists in generating a TTL signal for every sinusoidal signal positive part and in counting every front. The frequency of these TTL signals gives the resolution.

The use of quadrature phase shift signals allows value and direction displacement measurement with a $\lambda/8$ resolution, which corresponds to 200 nm.

So, in order to improve the resolution, at the electric cable output we create two other signals from Sin (or Cos) by adding and substracting a DC component proportional to $\cos(\pi/4)$.

After a logic treatment, the device can generate TTL signals which are injected into a 32 bits counter (because of the measurement number to carry out), enabling to achieve the required resolution of the displacement measurement ($\lambda/16$, i.e. 100 nm).

3 – PRELIMINARY RESULTS

3.1 – Optical circuit transmission results

Optical circuits have been realized by GeeO.

Transmission measurements are made after 5° faces polishing.

The obtained results are shown in the following table, indications in brackets being injection point and measuring point, as represented in *Fig.4*. Values are given in dB.

	Circuit n°1	Circuit n°2
measuring arm output (1-2)	-3.5	-4.1
measuring photometric arm (3-4)	-19.7	-17.7
reference photometric arm (1-5)	-41	-35.3
interferometric channels: reference arm only (1-6)		
V1	-27.6	-22.7
V2	-22.9	-17.3
V3	-22.8	-17
V4	-26.5	-21
interferometric channels: measuring arm only (3-6)		
V1	-15.9	-16.2
V2	-12	-11.2
V3	-11.9	-11.7
V4	-17.7	-16.9

Circuit n°1 is the first complete tested circuit and we notice that measuring and reference arms are not well balanced. Circuit n°2 (with a reajusted process) has a better ratio and less losses.

In theory, V1 and V4 (V2 and V3) should be equal. It seems that waveguides are not placed symmetrically according to gaussian beam profiles and that reference and measuring beams don't overlap exactly.

3.2 – Interferometric signal characterization

3.2.1 – Fringe spacing

The fringe spacing value ii done by equation (2.3) is determined by circuit design. In order to avoid coupling between waveguides, d must be larger than 21 µm and so ii larger than 28 µm. The value measured by GeeO is :

$$ii = 28.1 \pm 0.8\ \mu m$$

3.2.2 – Phase shift

	Circuit n°1
phase shift V1/V2	87.3 ±1.1 °
phase shift V2/V3	87.9 ± 1.3 °
phase shift V3/V4	91.3 ± 0.9 °

Measured phase shift values are in agreement with theoretical values.

3.2.3 – Peak-to-peak amplitude and offset.

Characterization of output beams in term of peak-to-peak amplitude and DC component enables us :

- to quantify maximum optical power at the output of the four guides and so to establish the circuit transmission,
- to determine the lack of balance between measuring and reference arms according to the corner cube distance (contrast influence study),
- to quantify amplitude and offset evolution between the fourth channels due to dissymetric phenomenon (cf §3.1).

This part is important to precisely define signal treatment electronics : channel gain determination, potential DC correction, potential phase shift correction.

4 – Following tests and conclusion

Other tests are presently under way. After that, prototypes will be manufactured and the whole system use will allow us to determine its functionnal characteristics.

A fourth measuring head will undergo space environment tests and this will validate the measuring heads convenience for required environment conditions (thermical, mecanical, in vacuum).

Radiation tests have shown that no evolution of straight waveguides transmission appears after 5 krad and 10 krad irradiation.

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