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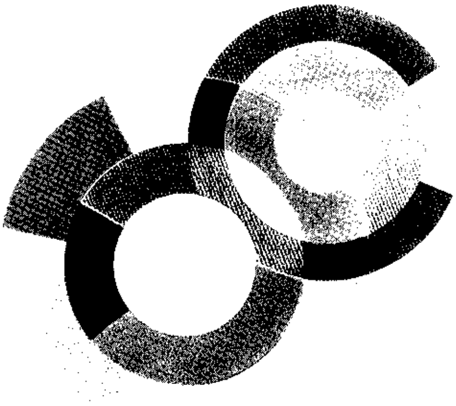

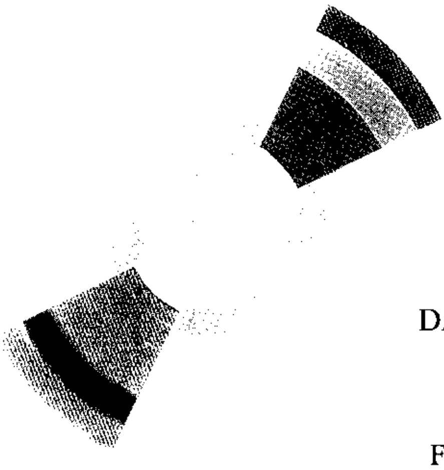

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DEVELOPMENT OF A HIGHLY TRANSPARENT FLUORESCENT OPTICAL SENSOR FOR TRANSVERSE POSITIONING OF MULTIPLE ELEMENTS WITH RESPECT TO A REFERENCE LASER BEAM

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Development of a highly Transparent Fluorescent Optical Sensor for Transverse Positioning of Multiple Elements with respect to a Reference Laser Beam

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ABSTRACT

A new type of highly transparent (95%) two dimensional position sensor has been developed which allows the accurate positioning (below 10 μm r.m.s.) of successive elements to which each sensor is attached, transversally to a laser beam used as a reference straight line. The present useful area of the sensor is about 15x15 mm^2, and can be further increased.

Keywords: alignment, transparent sensor, position sensor, fluorescent light, pigtail laser, photodiode

1. INTRODUCTION

An optical sensor has been developed[1] for the alignment of the muon chambers of the ATLAS[2] experiment (a). The momentum measurement in the ATLAS muon spectrometer aims at a precision of the order of 10% for muons of momentum 1 TeV by a sagitta measurement using triplets of precision chambers with a mean inter chamber distance of 5 meters. The target degree of accuracy for the precision chamber alignment is such that the alignment contribution to the final sagitta measurement error stays below the intrinsic chamber measurement error which contributes at a level of 50 μm.

That is why the alignment system should provide a positioning of triplets of muon chambers (b), with a resolution below 20 μm in translation and below 50 μrad in rotation. These resolutions are required for translation and rotation ranges of ±15 mm and ±5 mrad respectively. Therefore the optical sensor useful area should be typically 30x30 mm^2 combined with a transparency above 90% to allow at least 6 successive sensors to be aligned.

Finally, the accelerator environment imposes that the system tolerate high particle fluence and dose rates.

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(a) ATLAS is an LHC (Large Hadron Collider) experiment, located at CERN (European Laboratory for Particle Physics), CH - 1211 Geneva 23, Switzerland.

(b) Due to the particular chamber geometry in the end-cap ATLAS spectrometer, at some positions, up to four chambers must be aligned.

2. PRINCIPLE

A Saclay Transparent Position Sensor (SATRAPS) is made of a square neodymium (1%) doped glass plate, 40 mm to the side and 3 mm thick. The plate faces are flat and parallel (wedge angle <10 µrad). They are optically polished with a precision of 0.5 µm (λ/2) over a 30x30 mm^2 area. The neodymium is very homogeneous in the glass (at a 10^{-6} level). Fluorescent light, with a wavelength of about 1060 nm (see Fig. 1 and 2) produced by a continuous (or pulsed, see section 7) 10 mW laser beam (λ = 680 nm) crossing the plate, is detected using 16 silicon photodiodes (3x10.52 mm^2 each) glued all around the plate (4 photodiodes on each side).

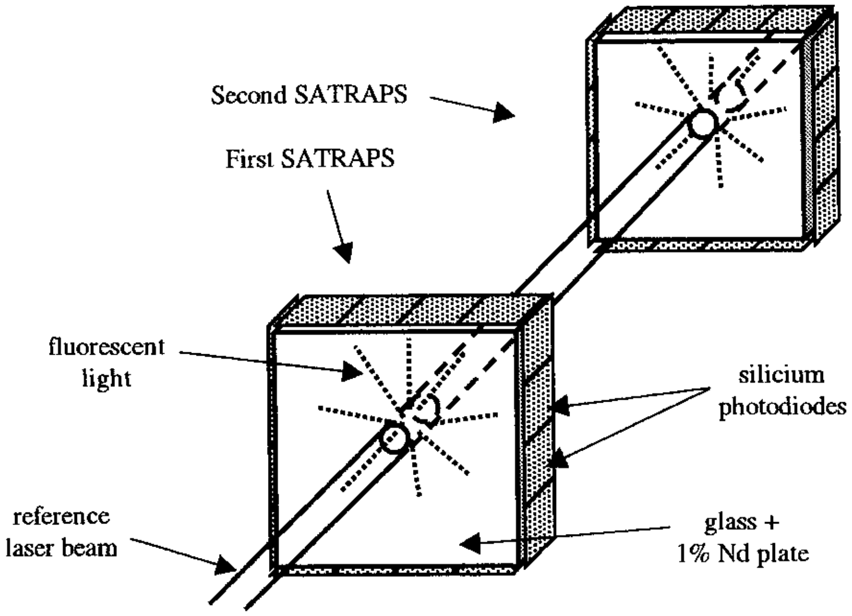

Figure 1. Two SATRAPS lightened by the reference laser beam. An optic glue connects the photodiodes to the glass plate. Due to the high transparency of each sensor (> 95%) one can put other SATRAPS (another one in this example) along the same reference laser beam.

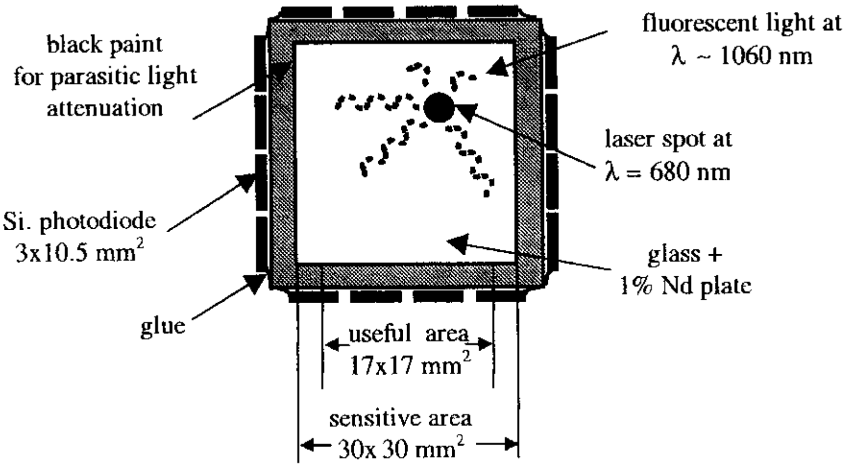

Figure 2. Sketch of a SATRAPS (front view): principle of light re-emission and detection.

The optical barycentre is determined by the relative amount of light seen by each photodiode (see Section 5). Since only 16 photodiodes are combined for the barycenter analysis, a measurement precision of at least 12 bits is required.

3. ELECTRONICS

The electronics used to read the photodiode current is within a grounded box connected to a PC (Fig. 3). The electronic box is very close to the detector in order to minimise noise affecting the low current intensity (typically 1 µAmp). It contains two cards with the following functions:

a high gain trans-impedance amplifier for current to voltage transformation,
a low pass filter for high frequency noise suppression,
a low noise gain stage for converter input adjustment,
a 16 to 1 channel multiplexer (MUX).

The PC is equipped with an I/O card providing:

the multiplexer command for the 16 channels,
the multiplexer output signal conversion through a 16 bit A/D converter.

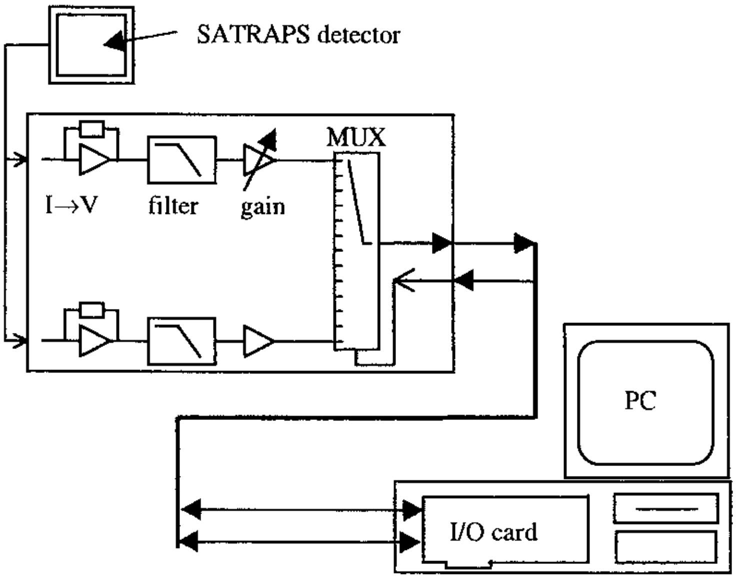

Figure 3. Electronics readout chain of the photodiodes.

The acquisition takes ~0.5 sec and this delay is dominated by the dialog between the electronics box and the PC I/O card. Finally a software program is used for signal treatment and the data formatting.

4. EXPERIMENTAL SET-UP

In order to evaluate the SATRAPS laser spot positioning precision, we have used the following set-up. A fixed diode laser beam of 1 mm diameter is focused on a SATRAPS, 30 cm away. It can be displaced in a plane transverse to the beam thanks to two micro-metric stages (±1 µm precision) perpendicular to each other (±25 µrad). There are two other SATRAPS in this set-up (see Fig. 4). They are fixed and are used to correct possible time dependent beam pointing variations.

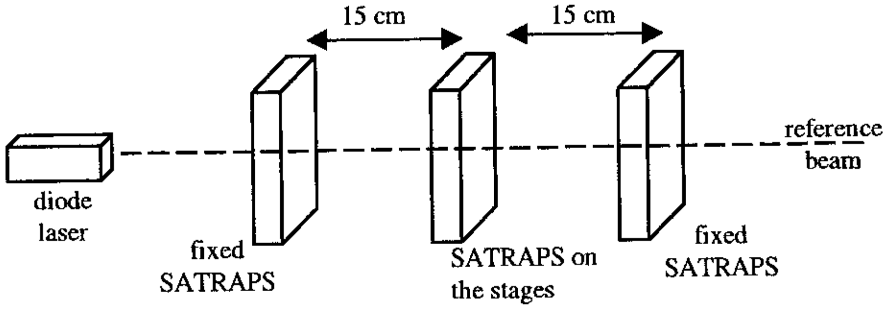

Figure 4. Experimental set-up.

5. FINDING THE LASER SPOT POSITION

To determine an unknown laser spot position characterised by the 16 photodiode voltages, a calibration is needed. It is obtained via a reference grid. This grid is built using the illumination of the SATRAPS, by the diode laser, at different precise positions obtain from the micro-metric stages. At each position the 16 photodiode voltages are read out and recorded. The grid has an area of 25x25 mm^2 with a 1 mm step (625 points).

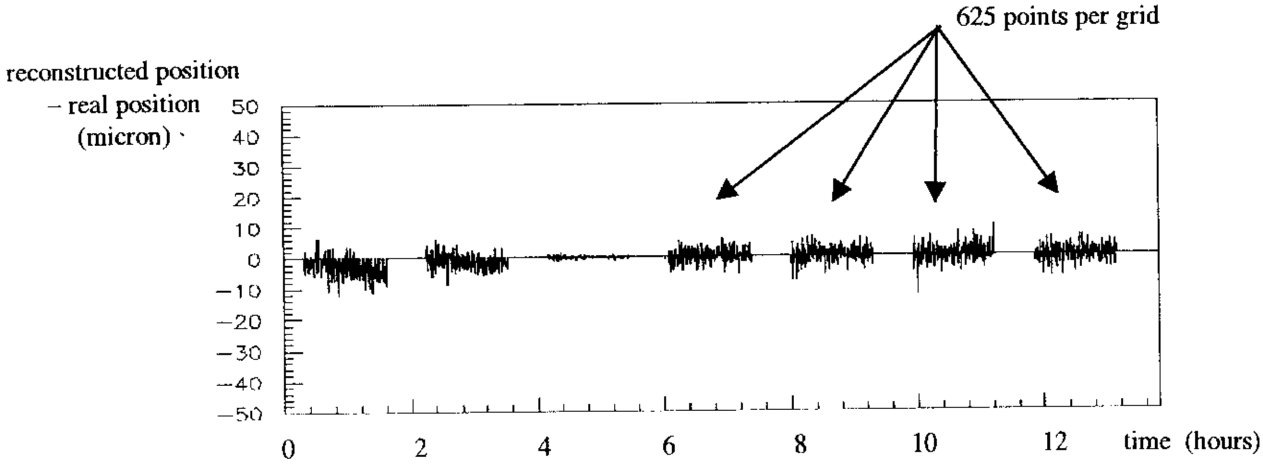

Figure 5. Resolution as a function of time for 7 successive grids after a 2D B-Spline (see text) has been performed on the *third* grid. Each grid has 625 reconstructed points (it took ~2 hours to be recorded) and is randomly displaced with respect to the *third* grid. Thus, each spot position on grid number 1, 2, 4, 5, 6 and 7 can be considered as unknown spot positions with respect to the calibrated grid (number *3*).
The deviation of the spot (of grid 1 and 2) with time can be mainly explained by laser pointing variations (not corrected in this plot) coming from room temperature variations (~1 degree).

Both horizontal and vertical spot positions are then parameterised each by a polynomial function with 16 parameters. Using these 32 parameters, an unknown spot position can be reconstructed with a 50 μm r.m.s. precision over the entire sensitive area.

A 2-D B-Spline[3] is performed on each of the 16 photodiode outputs obtained for the 625 grid positions. Then, interpolated points can be used in turn to perform two new more precise 16 parameters fits (for the horizontal and vertical directions). The resolution is around 10 μm r.m.s. (see Fig. 5).

The two other fixed SATRAPS allow for the correction of laser beam pointing instability (after recording a calibration grid for each of them). After these corrections we found the final resolution on the sensor position with respect to the laser beam to be 5 μm r.m.s..

6. SYSTEMATIC STUDIES

We have simulated the sensitivity of the resolution to the difference in spot diameter between the calibration position and the measurement position. Indeed a large spot size may induce a different fluorescent light distributions on the photodiodes as compared to a small spot size, thus degrading the final resolution. A Monte-Carlo study has been performed in order to understand this effect. It should not increase the resolution by more than 10 μm.

Fig. 6 shows the resolution, for experimental data, when using a laser beam diameter ≤1 mm for the fit of the 16 parameters (after the spline, see previous section) and then applying these parameters to find the spot position for a different laser beam diameter (~ 4 mm). The resolution is ~ 10 μm r.m.s..

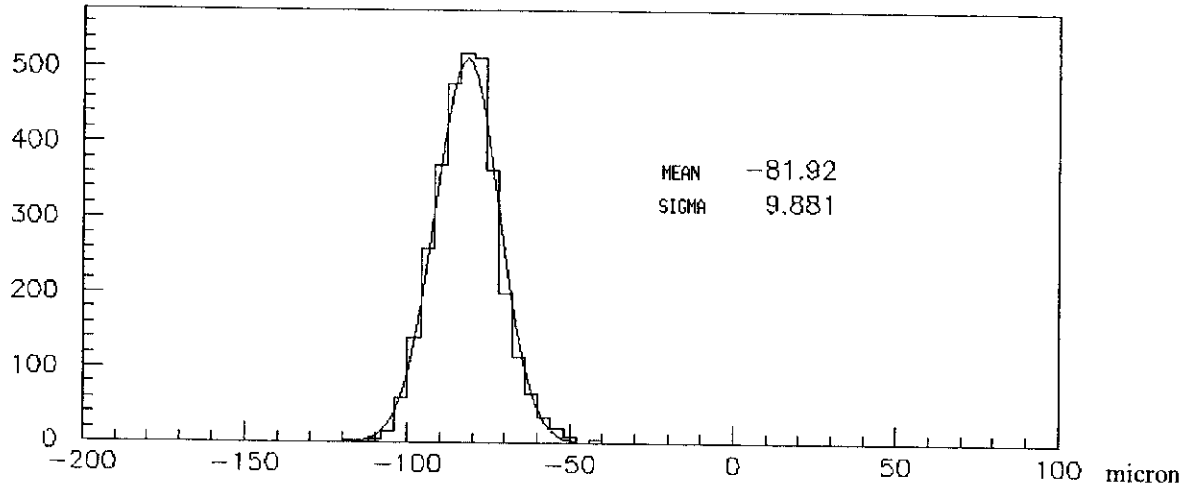

Figure 6: Resolution, for a reference grid using a beam diameter ≤1 mm for the calibration position, for ~3000 unknown positions using a beam diameter ~ 4 mm. The mean value (equivalent to an offset in the sensor position) is none zero since no absolute position has been performed.

In addition, it is important to have a laser spot coming from a pig-tail laser diode in order to avoid diffuse light all over the plate area even at distances up to 15 m encountered in ATLAS.

7. PROSPECTS

7.1 Electronics

Some improvement could be made by shortening the data acquisition time in order to eliminate the laser intensity instability which could be at the 1% level. It may introduce a systematic shift in the spot centre reconstruction.

The distance between the electronics box and the PC conversion card does not allow fast switching of the photodiode current conversion channels. Also the digital signals made by the I/O board for the acquisition sequence are too slow. Finally, in a system where a large number of detectors have to be measured at the same time, the previous prototype electronics has to be modified.

Considering these aspects new electronics has been designed (Fig. 7). It is located close to the detector and is divided into two boards. The first one performs the 16 photodiode currents conversion, the channel multiplexer and the 16 bit A/D converter. A "Sample and Hold" circuit has been added in front of the multiplexer to avoid laser beam instability problems.

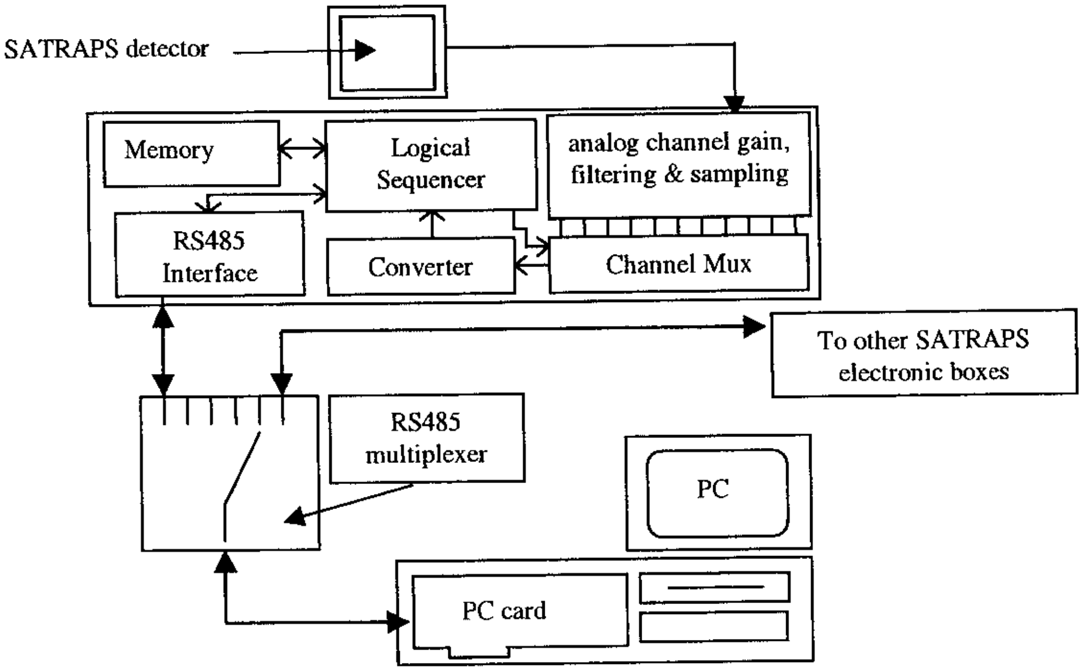

Figure 7: The future electronic logic.

The second board contains:

i) the logical sequencer, generating digital signals for channel multiplexing and conversion;
ii) the logical signals for the 16 bit data storage;
iii) the command signals and the data transmission from and to the PC (using a RS-485 protocol).

These two VME size board are placed in a EMI/EMC box which also contains two power supplies.

The RS-485 command line and data transfer signals coming from at least five electronic boxes can be multiplexed within a third board located near the acquisition PC. The expected data acquisition time for one SATRAPS should be less than 1 msec.

7.2 Laser

We plan to use a pulsed laser so the electronics, describe in section 7.1, should be synchronised to the laser. Under these conditions a typical event will consist of at least two measurements (of the 16 photodiodes):

i) one measurement in-between two laser pulses in order to measure the electronics offset and the light background;
ii) one measurement laser on.

A third step may also be useful in-between two laser pulses in order to check the 15 relative electronic gains (see next section 7.3).

7.3 Relative gain control

One can also control (and improve) the stability with time by performing a relative gain measurement of the 16 electronics channels. Indeed, at a 12 bit precision level, the characteristic of some electronic components may vary according to the working temperature, creating a differential gain variation between the 16 channels.

To calibrate the 15 differential gains with respect to one channel (call photodiode number 1 in the following), one can proceed as follows: a LED[a] light the sensor through an optical fibre optically glued, therefore fixed, on one corner[b] of the doped glass (Fig. 8). In-between to laser pulses and after the offset measurement, we switch on the LED and we record the 16 photodiode currents $c_{i=1,16}$ (another identical system may be added on the opposite corner in order to have enough light on all photodiode with respect to the reference channel –1–, see Fig. 8. In that case we switch on successively these two LEDs because the relative light from each LED may not be stable at a 12 bit level). The light from the LED should be constant during the record of one event but not necessary identical for all events since the optical fibre is fixed in position.

The comparison of the ratio $R^{i,j} = (c_i/c_1)^j$ obtained for event number (j) and $R^{i,k} = (c_i/c_1)^k$ for event number (k), gives for each channel (i) a correction factor $R^{i,j}/R^{i,k}$ which allows to control the relative gain of the 16 channels at a 12 bit precision level (with two LEDs, we take for each channel, the correction factor calculated with the highest current).

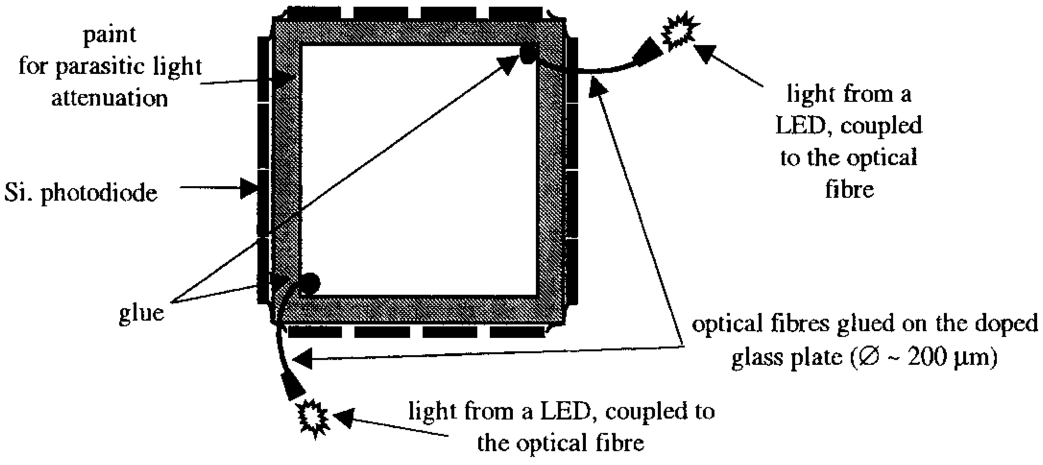

Figure 8: Measurement of the relative electronic gain with the help of two LEDs, each optically coupled to the doped glass plate through an optical fibre (of course the calibration grid should be done with the two optical fibres in position, see section 5).

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[a] The spectral emission of the LED is not necessary centred on the laser wavelength. Indeed, light absorption and thus fluorescent light emission from neodymium is more efficient at wavelength around 580 nm or 740 nm for example.

[b] In this way, the useful area is not affected.

8. CONCLUSIONS

We have developed a new type of highly transparent 2D position sensor. For a stable spot size, from a diode laser beam, the typical resolution on a useful area of about 15x15 mm^2 is 10 μm (r.m.s.) using only 16 photodiodes. The size of the doped glass plate of the SATRAPS and thus the useful area could be doubled keeping a constant photodiode number without degradation of the resolution.

By coupling two SATRAPS on a rigid mechanical support one can built a telescope[1] allowing for measurements of translation and rotation.

Also, a method to calibrate the photodiode relative gain has been described in order to maintain a 12 bit resolution over long time period. An absolute positioning with respect to an external mechanical reference and the radiation hardness have not been tested yet.

9. ACKNOWLEDGEMENTS

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10. REFERENCES

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