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# New electro-optic sensor architecture for temperature measurements

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## I. INTRODUCTION

We show in this paper, the first results on the feasibility of a new electro-optic sensor architecture used for temperature measurements. This sensor is based on the birefringent variation of an optical material. This phenomena is well-known and often exploited for electric field measurements [1, 2] or temperature measurements [3]. All these sensors use the refractive index variation induced on a crystal placed into a polarimetric setup. Optical intensities variations due to temperature variation enable to determine the value of the temperature. Nevertheless, for most of the authors, the electronic part of these sensors is not the main interest, that why, we describe the optical part and focus on the electronic instrumentation of our sensor. This one is based on an electronic detector which remains its output directly proportionnal to the temperature variation [4]. The temperature value is obtained by a control of the static intensity at a specific operating point of the transmittance. The results show that this architecture offers a high linearity and has a short response time (50ms).

## II. SENSOR OPTICAL CONFIGURATION

Even if the sensor is used for temperature measurements, the optical configuration allows others applications such as electric field measurements or strain measurements. These applications depends only on the birefringent material (crystal) used for the probe (KTP for temperature or LiNbO<sub>3</sub> for electric field, for example). The optical part shown on figure 1 is based on the Sénarmont setup into which a electrooptic modulator is inserted between the quarter-wave plate and the optical fiber. The optical transmittance is :

$$T = T_0 \left[ 1 - \sin(\Gamma + \Gamma') \right] \quad (1)$$

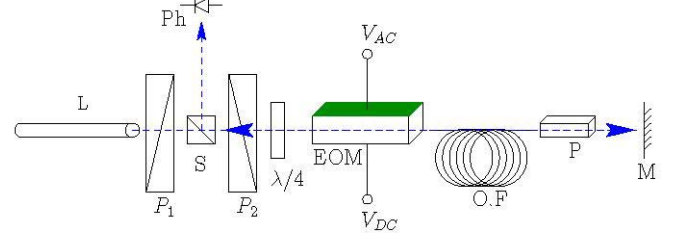


FIG. 1: Sensor optical configuration. L : laser, P<sub>1</sub> : polariser, SC : beam splitter, P<sub>2</sub> : analyser, λ/4 : quarter-wave plate, EOM : electro-optic modulator, O.F : optical fiber, S : probe, M : mirror, Ph : Photodiode + detector

where  $\Gamma$  is the phase retardation of the EOM, related to its bias voltage  $V_{DC}$  by  $\Gamma = \pi \frac{V_{DC}}{V_{\pi}}$  and  $\Gamma'$  is the phase retardation due to temperature variation on the probe crystal and related to the birefringence by :  $\Gamma' = 2 \cdot \pi \cdot L / \lambda \cdot \delta \Delta n$ . Where  $V_{\pi}$  is the half-wave voltage,  $\lambda$  the wavelength,  $L$  the optical path length and  $\delta \Delta n$  is the birefringence, linearly linked to the temperature [5].

On the EOM, the  $V_{DC}$  voltage sets the operating point on the transmittance and the  $V_{AC}$  voltage is used to modulate the intensity. The EOM is a lithium niobate crystal ( $L=40\text{mm}$ , Section =  $3 \times 3\text{mm}^2$ ).

According to the figure 2, representing the equation 1, when the  $V_{DC}$  voltage is chosen to have the operating point is at  $M'_0$ , the  $V_{AC}$  voltage create a amplitude modulated signal related to this  $V_{AC}$  voltage and with the same  $\omega_0$  pulsation than  $V_{AC}$  pulsation ( $\omega_0$  is the fundamental). On the opposite, at  $M_0$  point, the modulated signal has a double pulsation  $2\omega_0$  [6]. Between  $M_0$  and  $M'_0$  (at  $M''_0$  for exemple) the modulated signal is composed by two harmonics at  $\omega_0$  and  $2\omega_0$  pulsations.

## III. FULL SENSOR ARCHITECTURE

When a birefringent variation of the probe crystal occurs, induced by a temperature variation, the phase  $\Gamma'$  is shifted and thus modify the operating point. The return to the initial point can be done by an opposite variation of  $\Gamma$  with the same value. This compensation leads to a linear relationship between the temperature variation

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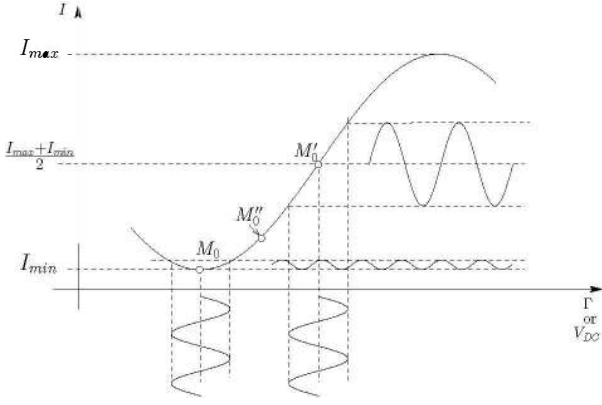


FIG. 2: Transmittance of the setup and associated operating points

and the EOM bias compensation voltage  $V_{DC}$  [7] :

$$dT = \alpha dV_{DC} \quad (2)$$

Where  $\alpha$  depends on the already defined parameters :  $\lambda$ ,  $\delta\Delta n$ ,  $L$  and  $V_\pi$ . Our goal is to control the system at  $M_0$  point to ensure an unsensitivity to the laser variation. To do that, we have chosen to control the system on the amplitude of  $\omega_0$  signal. As shown the figure 3, at  $M_0$  point,  $\omega_0$  signal amplitude is zero and intensities variations are linear for small variations of  $V_{DC}$ . We can also notice that the sign of this signal depends on relative position of the operating point and thus informs us about the variation sense of the temperature.

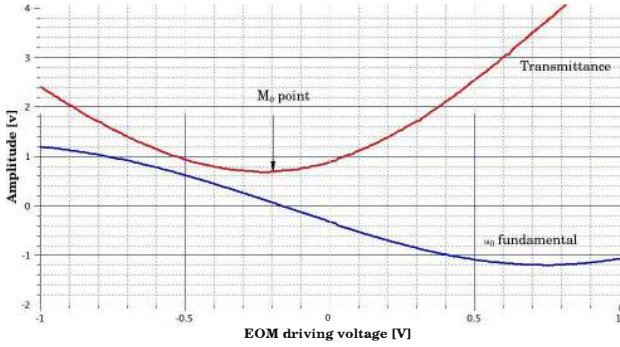


FIG. 3: Voltage amplitude of the fundamental at  $\omega_0$  according to  $V_{DC}$

The control is made by a feedback loop and a PID controller (see figure 4).

$V_{AC}$  sinusoidal voltage is the output of a stable low frequency oscillator associated to a transformer (52V - 20.7kHz). The DC voltage is generated by an high voltage PWM oscillator whose mean value ( $0 \rightarrow 740V_{PP}$ ) is proportional to the driving voltage ( $-3V \rightarrow +3V$ ) of

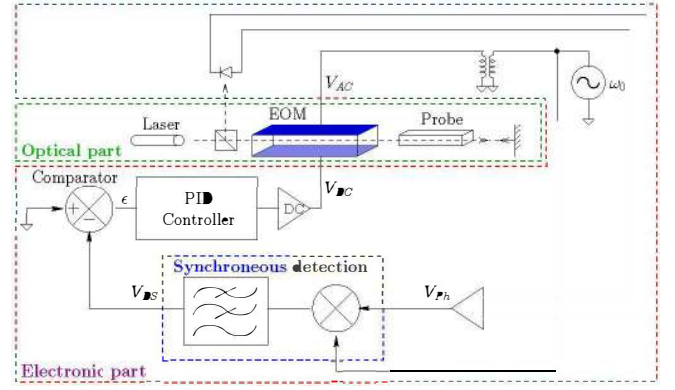


FIG. 4: Sensor with the feedback loop and the PID Controller

the PWM oscillator. The optical signal is converted to a voltage signal by a photodiode and a transconductance amplifier. Detection is made by a multiplier and a low-pass filter.

The input of the comparator is set to zero which is the  $\omega_0$  amplitude. This value is adjusted with a spectrum analyser because of the very small amplitude of fundamental  $\omega_0$ . The electronic loop controls the system at this value.

#### IV. RESULTS

The system was studied in open loop in order to calculate controller's parameters according to the Strejc-Naslin method. Furthermore, we have evaluated the dynamical performances in both open-loop and close-loop configurations. Figure 5 shows the response of the system submitted to a disturbance (simulated by a step voltage added after the PID controller). We can deduce from this

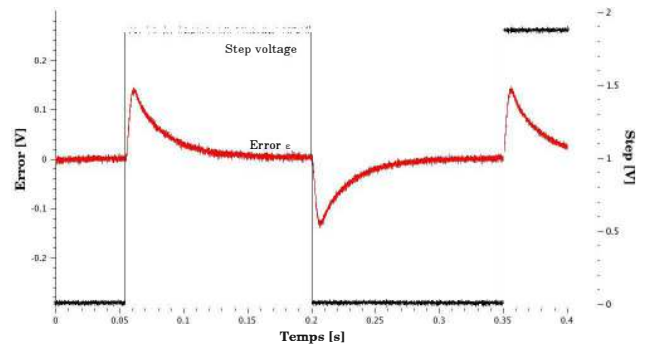


FIG. 5: Error signal when the system is submitted to a disturbance.

figure that the response time is 50ms while it was 100ms in the close-loop configuration. This quite long time is

mainly due to the PWM based amplifier. The error signal shows us that the PID controller fully compensates the disturbance.

As an application, we show on figure 6, the sensitivity of the sensor (output voltage versus temperature). The slope of this curve gives the sensitivity which is  $0.91^{\circ}\text{C}/\text{V}$ .

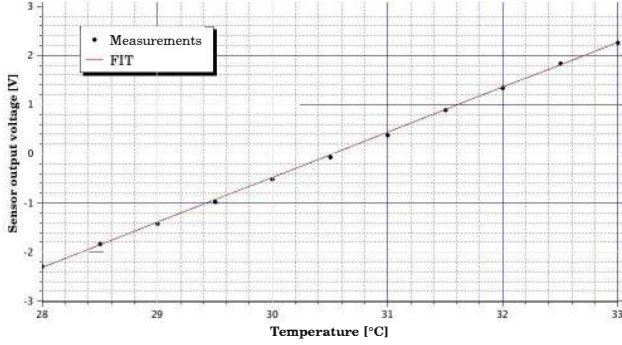


FIG. 6: Sensor sensitivity for temperature measurements

## V. CONCLUSION

We introduced an electro-optic sensor with a new architecture, based on Sénarmont setup and controlled in order to hold the same operating point. For temperature measurements, the sensor has a sensitivity of  $0.91^{\circ}\text{C}/\text{V}$ . The response time is closed to 50ms. This sensor can be easily adapted for others parameters such as electrical field or strain measurements. It's fully insensitive to EMC and to the laser variations.

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