CONTACLESS LOW RESOLUTION ANGULAR SENSOR

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ABSTRACT

Nowadays, low resolution angular sensors mounted on SADMs and APMs are more often potentiometers. Information is supplied through a voltage proportional to the measured angle. Because of its design, such device includes rubbing contacts and has a dead zone for which no voltage is transferred.

In order to remedy to these imperfections, CODECHAMP and CNES develop a contactless low resolution angular sensor, including an electric redundancy. This type of encoder can be easily integrated into various telecommunication platforms.

The final encoder output can be:

- a whole analog ramp over 360°;
- or whole analog ramp over 180° with a position identification signal over half revolution ;
- or a digital information.

It will have an accuracy of +/- 0.5% and a resolution from 10 to 12bits. The power supply voltage will be 5V±5% and the consumption will not exceed 30mA.

First, the principle of electro-optical signals modulated by a polarimetric device was selected. A first breadboard has confirmed the encoder feasibility.

Second, the concept was adapted to the wavelength of the infrared LEDs and a digital calculation was chosen for the signal processing. A second breadboard including the representative electro-optical components was used as baseline for the assessment of accuracy beginning of life and of sensitivity to the thermal and radiation environments.

Third, an on-going research including an electro-optical model of the sensor will allow to manufacture specific photoreceptors and ASIC. After this, a validation engineering model will be performed.

The works carried out in the frame of this project have led to a registration of CODECHAMP-CNES invention patent on May 2010. The achievement of this project will be a potentiometer type sensor without dead zone and particularly robust to geometrical defaults.

1. BACKGROUND

In space applications, especially solar array drive mechanism (SADM) and antenna pointing mechanism (APM), potentiometers are widely used as angular sensors providing coarse analog information.
Due to the dead zone between the supplying pins, a single turn rotary potentiometer can't produce a signal over full 360°. Moreover it includes a brush or a rubbing contact which is subject to wear and generates parasitic torque and debris.
The low resolution angular sensor currently developed by CODECHAMP and CNES is designed to overcome these disadvantages and replace potentiometers in space applications without any modification of the platform.
By selecting the optoelectronic solution among the several technologies which can be used to achieve the design of the encoder, CODECHAMP capitalizes on its know-how in this field.

2. SPECIFICATIONS

The contactless low resolution encoder is low cost coarse angular sensor of simple design which includes a full electrical redundancy and has an improved lifetime compared to potentiometers.

2.1. Technical specifications

- Worst case, end of life (EOL) accuracy: ±0.5% that is to say ±1.8°
- Resolution: 10 to 12 bits that is to say a step from 0.09° to 0.35°
- Output: Analog ramp voltage, sine-cosine voltages or digital
- Supply voltage: 5V±5%
- Consumption: below 30mA

2.2. Analog output configuration

The output of the encoder meets the two main standards used on space platforms to represent an angular position over 360° by a voltage:

- a full analog ramp over 360° (Fig. 1)

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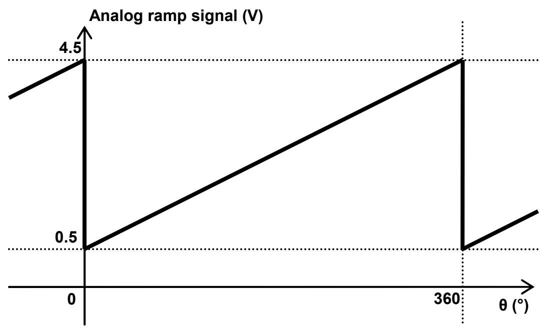

Figure 1. Output for a full analog ramp over 360°

- a full analog ramp over 180° associated with a switch signal (Fig. 2)

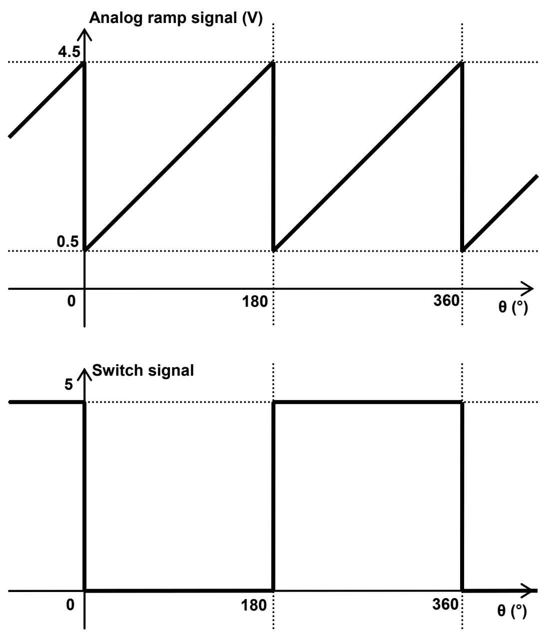

Figure2. Output for a full analog ramp over 180° associated with a switch signal

3. WORKING PRINCIPLE

The encoding technology relies on polarimetry:

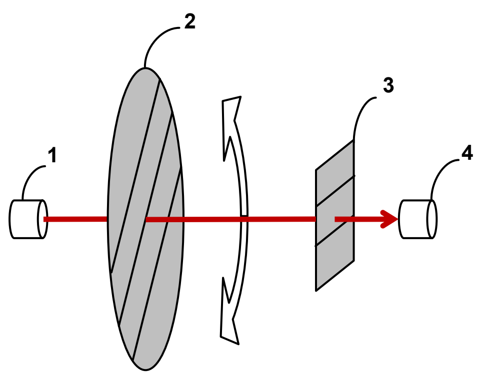

Figure 3. Modulation of illumination by two polarizers

As shown in Fig. 3, the incident unpolarized light coming from the emitter (1) goes successively through a moving polarizer (2) integral with the rotor, and a fixed polarizer (3) integral with the stator and ends it path on a photoreceptor (4) which converts it into an electrical current (photocurrent).

The photoreceptor's illumination is modulated by the angle between the axes of the two polarizers according to Malus' law:

$$I = I_0 \cdot \cos^2 \theta \qquad (1)$$

According to Eq. 1 the photoreceptor illumination is a 180° period sinusoidal function of angle between rotor and stator.

3.1. Constitution of the encoder

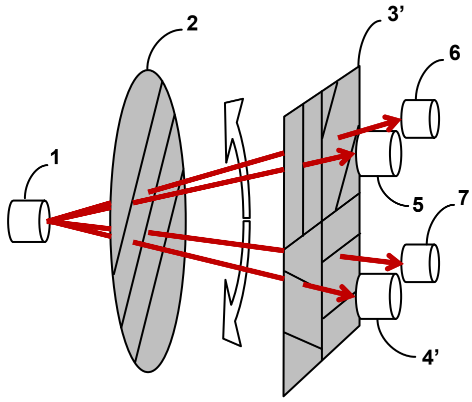

Figure 4. Signal generation principle

By a similar principle (Fig 5) a multi-sectored polarizer (3') with an angular shift of 45° between two adjacent sectors associated with a multi-channel photoreceptor 4' to 7) creates a system of four photocurrents in phase-quadrature.

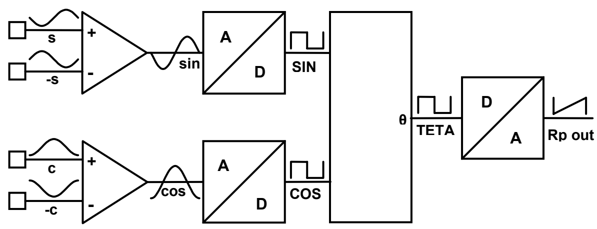

Figure 5. Signal shaping and processing

A differential amplification converts it into two reference sine and cosine voltages. The output angle is calculated from the two previous signals by digital processing and the output voltage is obtained by a digital to analog conversion.

4. ASSESSMENT

The concept of a polarimetric angle encoder is evaluated through the plan presented in Fig. 6.

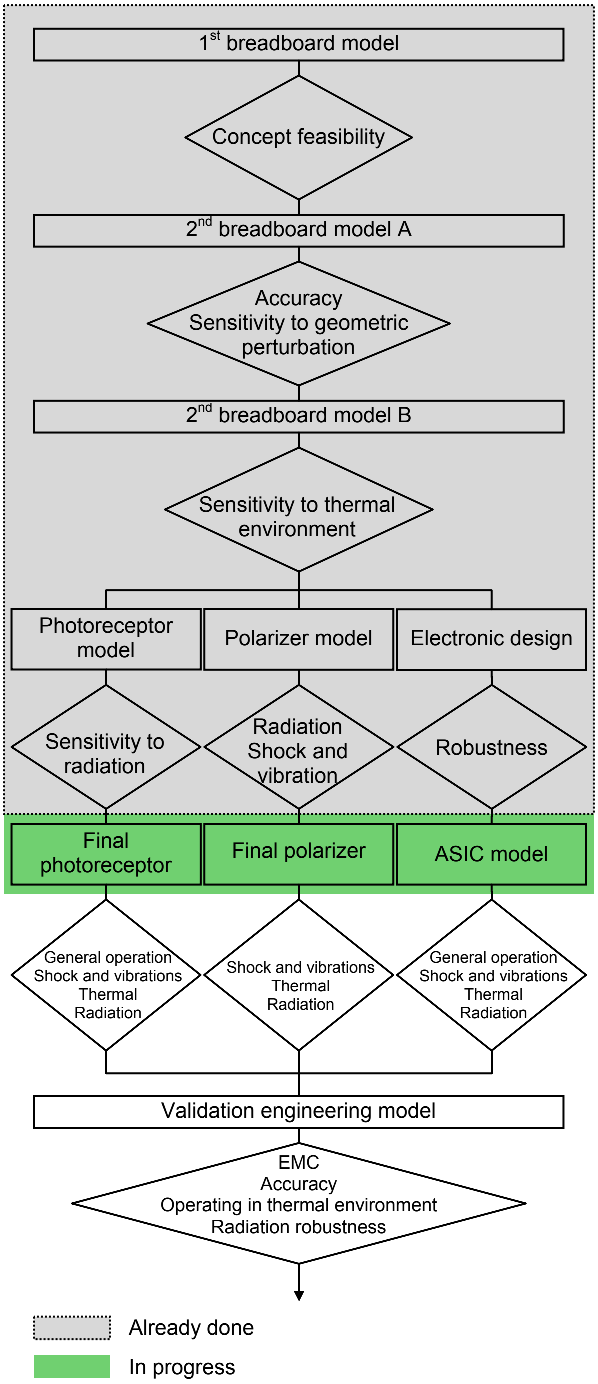

Figure 6. Assessment plan

4.1. Feasibility

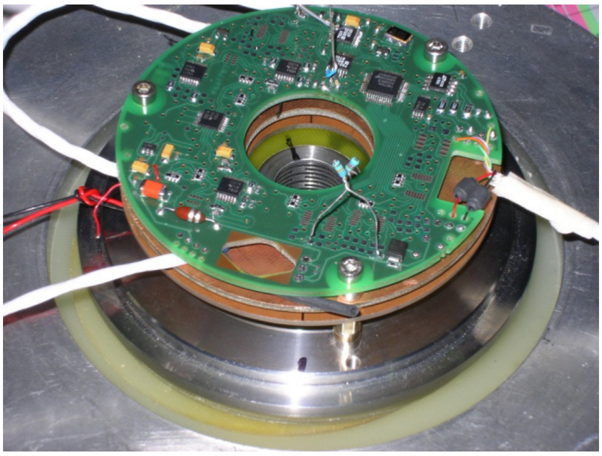

Figure 7. First breadboard model

The feasibility of an angle encoder based on the digital treatment of analog electric signals generated by a system of polarizers has been established by basic simulations and verified on the fist breadboard model (Fig. 7).

4.2. Accuracy and robustness to geometrical defects

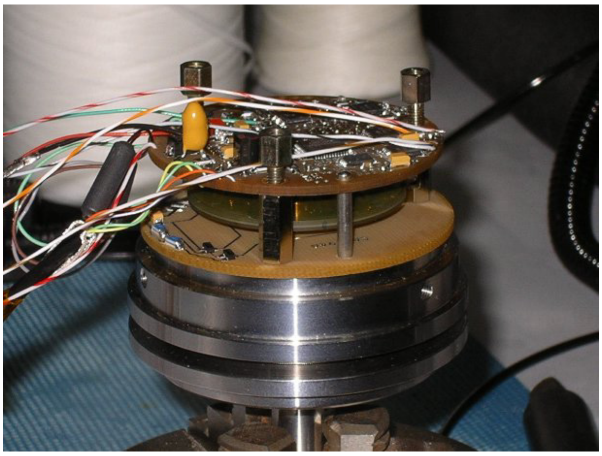

Figure 8. Second breadboard model, sub-version A

The beginning of life (BOL) accuracy and the effects of geometrical defects have been assessed on the version A of the 2nd breadboard model (Fig. 8) which works with near-infrared emitters and is adapted to geometrical test.

The nominal accuracy is ±0.6°, that is to say ±0.17%

No significant alteration of accuracy is noticed for:

- an air gap (distance between the rotating and the fixed polarizer) decreased by 2mm
- a 2mm mechanical eccentricity of the rotating polarizer

A 5° tilt of the rotating polarizer induced a slight increase in the peak to peak error.

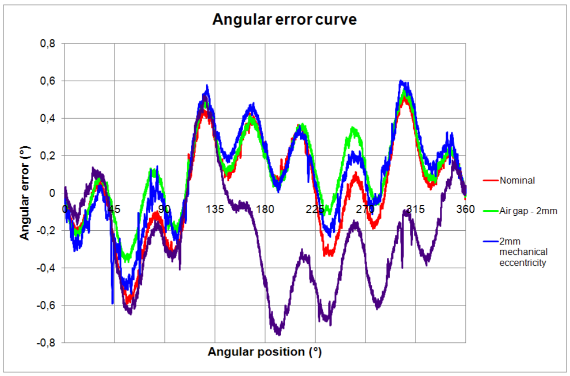

Figure 9. Geometrical defects effect on encoder's accuracy

This step of the assessment (Fig. 9) shows that the BOL accuracy fits with the EOL requirement, and highlights the robustness of the polarimetric encoder to geometrical defects.

4.3. Operation and accuracy in thermal environment

Figure 10. Second breadboard model, sub-version B

The sensitivity to environmental perturbation have been assessed on the version B of the 2nd breadboard model (Fig. 10) including photodiodes whose behavior in thermal environment is representative of the final encoder.

Fig. 11 shows the evolution of the peak to peak error during thermal cycling which slightly affects the precision of the encoder.

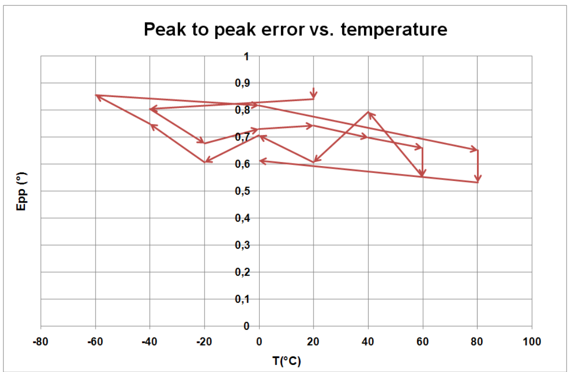

Figure 11. Evolution of encoder's accuracy during thermal cycling

Thermal cycling doesn't affect the operation of the encoder and has only little impact on its accuracy.

4.4. Radiation

The evaluations of radiation effect on polarizing elements and on photoreceptors have been conducted separately.

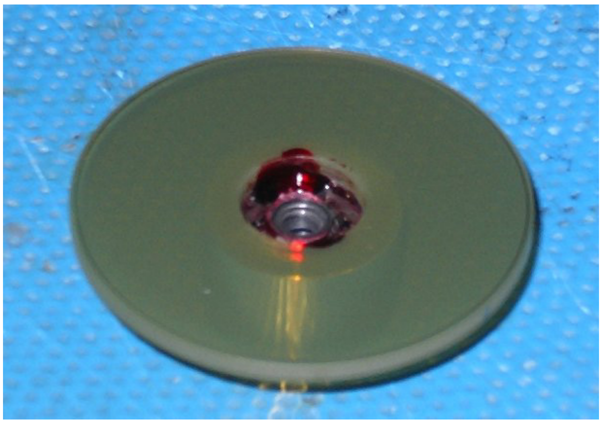

Figure 12. Rotating polarizer on its holder

Optical characteristics (transmittance and contrast) of a polarizing element representative of the final encoder (Fig. 12) were measured before and after irradiating it with ionizing dose (100krad) and proton flux (1.4×10^{11} protons/cm^2 at 100MeV).

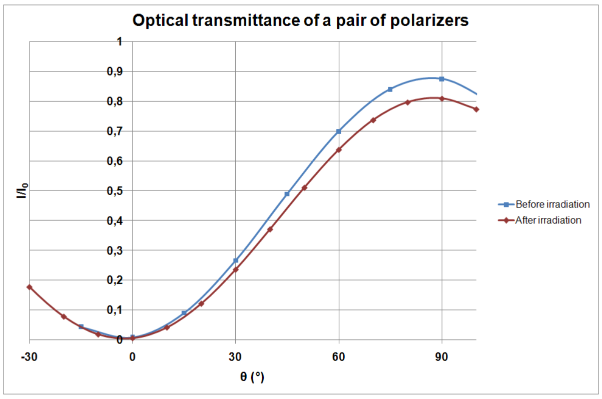

Figure 13. Optical transmittance measurements before and after irradiation

Fig. 13 shows there's virtually no change in transmittance and contrast after an ionizing dose and displacement damage much higher than those at which the encoder would actually be exposed.

The photoreceptor's responsivity drifts in a radiation environment have been measured on representative photodiode samples.

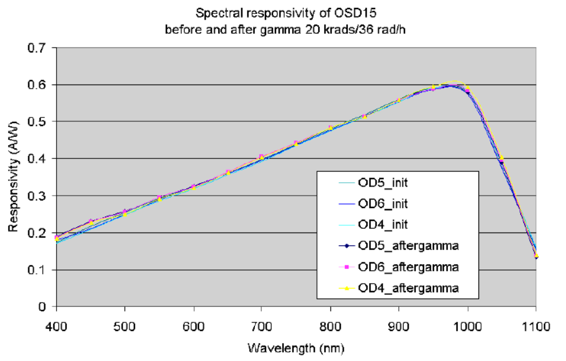

Figure 14. Photodiode sensitivity drift due to ionizing dose

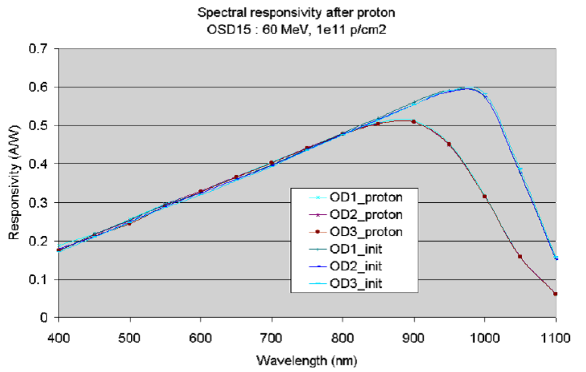

Figure 15. Photodiode sensitivity drift due to displacement damage

Fig. 14 and Fig. 15 shows there is virtually no sensitivity drift after mission-representative ionizing dose and displacement damage.

4.5. Electric design robustness

A PSPICE model of the encoder has been set up to determine the relationship between electrical imperfections (photodiode and amplifier) and encoder error.

A worst case simulation of the encoder (Fig. 16) shows an EOL accuracy of ±0.465% which is compliant with the technical specifications.

5. FUTURE PROSPECTS

The work carried out in the frame of this project led to a registration of CODECHAMP-CNES invention patent on May 2010, an application for an extension to Europe was registered on May 2011.

The assessment of the electric part and the realization of an engineering model are in progress.

6. CONCLUSION

The feasibility of a low resolution polarimetric encoder for space application is confirmed by the assessment conducted by CODECHAMP and CNES.

The results obtained in this project highlight the great robustness of the polarimetric concept to geometrical defects, and establish the robustness of the electric design and the optical components' good behavior.

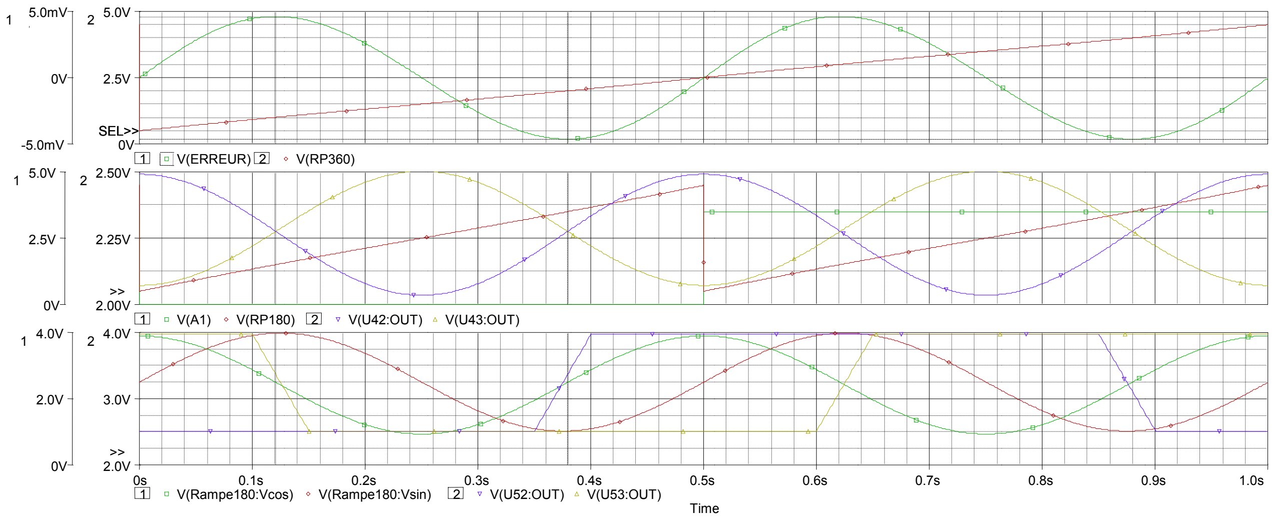

Figure 16. Error and signals from the PSPICE simulation