The Bragg solar X-ray spectrometer SolpeX

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ABSTRACT

Detection of polarization and spectra measurement of X-ray solar flare emission are indispensable in improving our understanding of the processes releasing energy of these most energetic phenomena in the solar system. We shall present some details of the construction of SolpeX – an innovative Bragg soft X-ray flare polarimeter and spectrometer. The instrument is a part of KORTES – Russian instrument complex to be mounted aboard the science module to be attached to the International Space Station (2017/2018).

The SolpeX will be composed of three individual measuring units: the soft X-ray polarimeter with 1-2% linear polarization detection threshold, a fast-rotating flat crystal X-ray spectrometer with a very high time resolution (0.1 s) and a simple pin-hole soft X-ray imager-spectrometer with a moderate spatial (~20 arcsec), spectral (0.5 keV) and high time resolution (0.1 s). Having a fast rotating unit to be served with power, telemetry and "intelligence" poses a challenge for the designer. Some of the solutions to this will be provided and described.

Keywords: X-ray polarimetry, X-ray spectrometer, ISS

1. INTRODUCTION

SolpeX (Solar Polarimeter in X-rays) is an instrument designed and now under construction at the Solar Physics Division of Space Research Centre, Polish Academy of Sciences, in Wrocław, Poland. It will be mounted within the KORTES (Fig. 1) - Russian instrument complex to be delivered by a cargo transfer and mounted by astronaut aboard *Nauka* module (also known as a Multipurpose Laboratory Module) to be attached to the International Space Station (2017/2018). It is developed with main intention to measure X-ray polarization in the soft range, expected as a result of electrons and protons anisotropic beams interaction with ambient dense plasma of solar atmosphere during the solar flare, in form of non-thermal Bremsstrahlung. This kind of observations leads to better understanding of the Sun's magnetic field having its origin in reconnection process.

Besides polarimeter, two additional units are included within SolpeX, making together complementary solar soft X-ray flux measurement system:

- B-POL (Bragg Polarimeter) - the soft X-ray polarimeter with 1-2% linear polarization detection limit,
- RDS - fast-rotating drum X-ray spectrometer with very high time resolution (0.1s),
- PHI - a simple pin-hole soft X-ray imager-spectrometer with moderate spatial (~20arcsec), spectral (0.5 keV) and high time resolution.[1]

Designing device consisting of several complementary but independent units is a challenge, which electronic aspect is presented in this paper.

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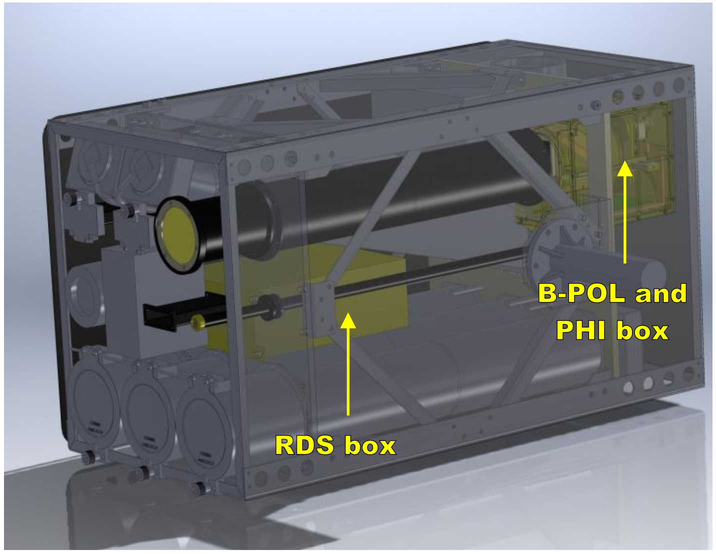

Figure 1. SolpeX' units built-in KORTES complex

2. OPERATION THEORY

Studying the nature of X-ray sources is crucial to understanding the processes of conversion of the magnetic energy into other forms of energy. The measurements to be made by SolpeX are expected to be of unprecedented quality in terms of sensitivity to detect the soft-X- ray polarization of solar emission emanating from active regions and flares in particular. Simultaneous measurements of the polarization degree and the other characteristics (e.g. evolution of the spectra) constitute the last, rather unexplored area of solar X-ray spectroscopy providing substantial diagnostic potential. The polarized emission is generally expected to originate in various types of highly anisotropic emission sources. Among them are for instance magnetically confined beams of accelerated non-thermal particles interacting with denser plasma layers. These types of scenarios are predicted by so-called standard flare models. To obtain simultaneous measurements of soft X-ray polarization, spectral and spatial evolution the SolpeX unit will consist three separate measuring instruments:

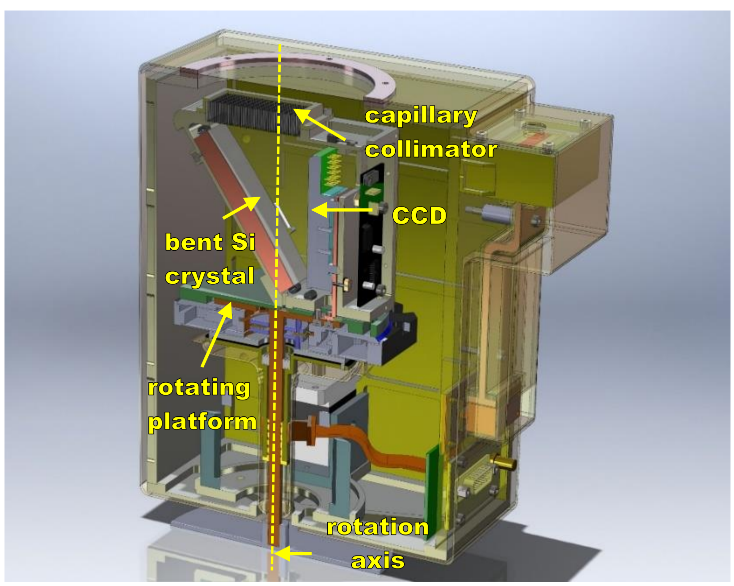

Figure 2. B-POL unit cross-section with the key functional elements marked.

B-POL

The soft X-ray polarimeter. This instrument will consist of a rotating (~one revolution per second) polarization detection unit equipped with the Si 111 bent crystal spectrometer measuring the spectra in the vicinity of the Brewster's angle of ~45°. The unit is to be associated with the co-rotating CCD detector (1024x256 pixels). This polarization measurement concept has no precedence and we expect that will reach 1-2% linear polarization detection limit. (Fig. 2)

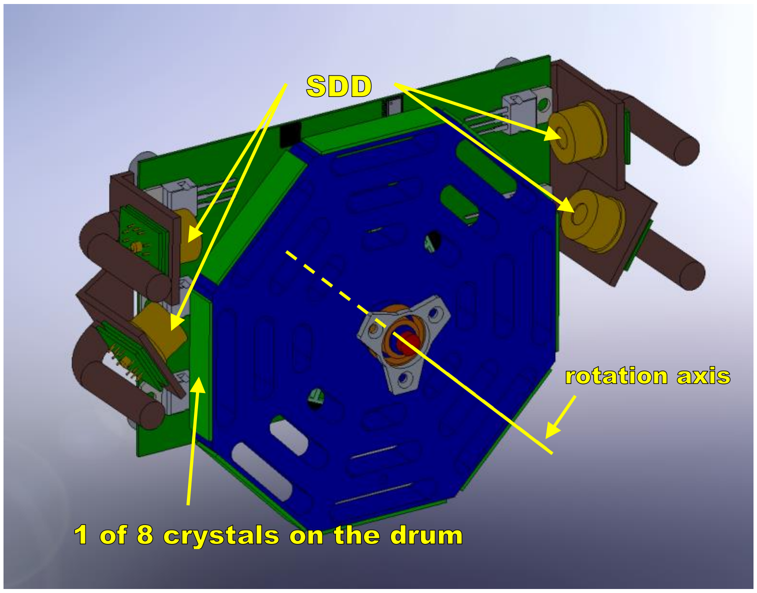

Figure 3. Main part of RDS: crystals and detectors positions.

RDS

The rotating drum X-ray spectrometer is a completely new concept for very high time resolution (0.1s) measurements of flare spectra, in particular the Doppler shifts of spectral lines in absolute terms. A fast rotating drum is equipped with two (or three) pairs of identical crystals mounted in the Dopplerometer configuration [2]. Bragg-reflected photons illuminate a new-generation silicone drift detectors (SDD) which are characterized by a very fast response (~1 μs). By monitoring the photon arrival times, the momentary respective crystal incidence angles can easily be determined and converted to corresponding incoming photon wavelengths (energies). The spectral histogram is to be built as the time progress, with the time resolution depending of the source intensity. (Fig. 3)

PHI

To localize solar fares or other sources in the instrument coordinate system simple pin-hole camera will be used. This unit will also be able to measure individual lightcurves and moderate spectra for individual separate sources. Focal length of the imager is about 60cm and the image will be produced on CCD detector. Additionally the diameter of the pin-hole can be adjusted, depending on the activity of the source. [3]

3. ELECTRONIC HARDWARE DESIGN

Electronic hardware in SolpeX is divided into two separated units due to theirs physical location in KORTES (Fig. 4). Both are based on low power, flash-based (more tolerant to radiation effects) Microsemi ProASIC3L family FPGA chips, but main control unit is in the B-POL/PHI segment, where version with Cortex-M1 microprocessor enabled is applied. It is 32-bit architecture ARM core designed specifically for implementation in FPGAs. As a 'heart' of instrument, this is the central commands and data transfer node connected to KORTES on-board computer over SpaceWire interface. All data from the instrument will be immediately transmitted outside, temporarily stored in KORTES and then passed to the ISS memory mass storage.

Significant part of electronic system is destined to allow components motion raised from their principles of operation. The most important moving systems are:

1) B-POL pointing system: in the PHI's FPGA algorithm to find central position of the brightest point on the Sun's disk will be implemented. This information will be passed to B-POL pointing system, where its rotation axis will be locked by the calculated adjustment of stepper motor linear actuators.

2) B-POL rotations: 1 rps is provided with Physik Instrumente M-660 precision piezo rotation stage with integrated incremental encoder, which gives up to 4 µrad resolution.

3) RDS rotations: Brushless DC (BLDC) electric motor with 18 coils and 3 Hall sensors will be mounted to move the drum. Additionally Frequency Generator (FG) trace under the motor magnet will be used together with sine wave drive to achieve the lowest possible rotational speed jitter and minimize torque ripple, which could have an impact on measurement (first tests give an optimistic results).

In all above cases high accuracy contactless magnetic position sensors manufactured by austriamicrosystems will operate to bring feedback information about the movement.

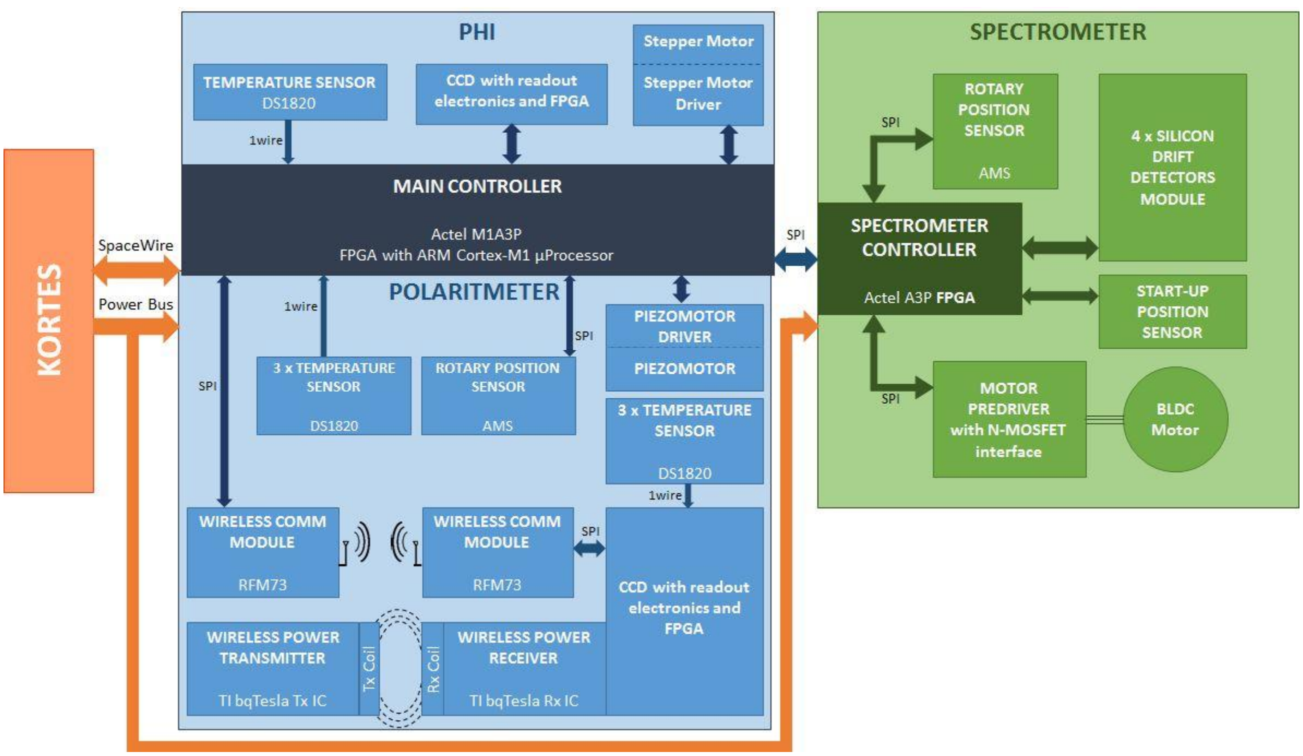

Figure 4. General block diagram of SolpeX electronics

DETECTORS

Two CCD sensors are selected for the instrument:

- e2v back illuminated CCD261-84 - 2048 x 4096 pixels of 15 µm size – for the B-POL,
- e2v back illuminated CCD3011 – 256 x 1024 pixels of 26 µm size – for the PHI.

For both of them Correlated Double Sampling (CDS) technique is used. Output signal is sampled twice during one pixel period – for the reference and for the data level. The subtraction result of these two values is desired information. This approach reduces the fixed pattern noise and dark noise significantly. Separate FPGA chips will be used for detectors as a core for readout systems.

In the RDS as a sensors four Silicon Drift Detectors (SDD) are chosen: 3 x Ketek VITUS H50 with 12.5 µm Beryllium window and Amptek SDD with 250 nm Aluminum coated 90 nm Silicon Nitride window for low energy range coverage. To all of them Amptek A250 Charge Sensitive Preamplifier will be utilized as state-of-the-art integrated circuit. Further signal processing will be performed also on the FPGA, one for all SDD's. Its flexibility will be used to achieve required high time resolution by adjusted shaping amplifier and multichannel analyzer.

ROTATIG ELECTRONICS IN B-POL

Due to the fact that the key elements of B-POL electronics are mounted on continually rotating element providing capability for wireless powering and data exchange is particularly important.

For data transmission RFM73 module is chosen, which is a Gaussian Frequency Shift Keying (GFSK) transceiver (Time Division Duplex (TDD) utilized) working on 1 MHz channel in 2400 - 2483.5 MHz band. Its compact size (12.8mm x 16.8 mm together with PCB antenna) with ability to data throughput up to 2 Mbps in burst mode with less than 0.1W power consumption makes it suitable to operate on rotating element of B-POL [RFM73-DS] as a relatively short distance wireless data interface. Auto re-transmission and auto acknowledge features embedded into internal packet processing unit provide reliable link controlled with SPI from the polarimeter main FPGA chip.

Supplying power to the rotating section is also kind of a challenge, especially when it is desirable during the moments of lack of rotary motion. This goal is reached with inductively coupled, flat and round coils. AC current in permanently mounted coil (Tx) generates a magnetic field, which induces a voltage in the spinning (Rx) one. Required up to 5W power transmission efficiency depends on coupling factor, which is achieved by matching coil size and appropriate alignment (vertical, lateral and angular). Another key factor is flexible ferrite material applied as effective shielding, which avoids eddy current in other instrument parts and also improves coupling. Both sites are controlled with modern Texas Instruments bqTesla integrated circuits.

Low output power level and the instrument and the space station metallic housing prevent interference with any RF sensitive experiments and the Station on-board Wi-Fi (the same frequency band), but propagation characteristics can be affected by the presence of power coils and other parts of construction inside the unit - Figure 5. This solution will be investigated using prepared full polarimeter mechanical model.

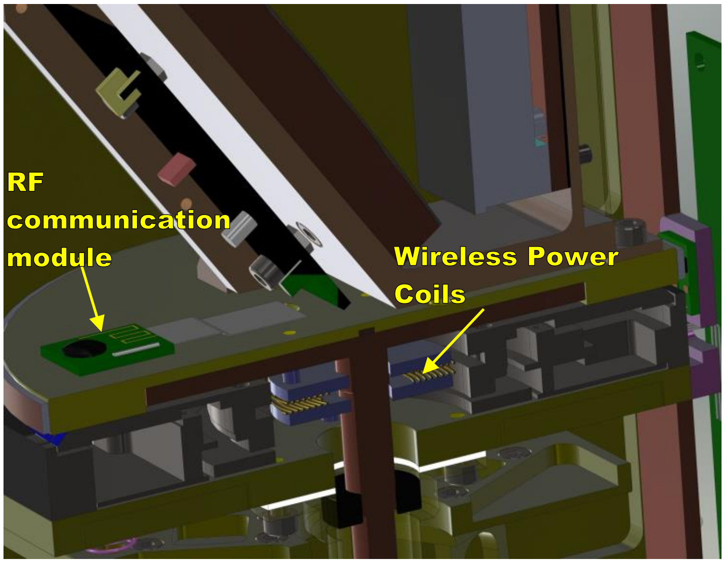

Figure 5. Wireless power transmission coils and RF data transmission modules locations in B-POL unit.

4. CONCLUSIONS

The SolpeX spectrometer will work on the ISS as a part of Russian KORTES instrument. Its three unique units: B-POL (Bragg polarimeter), RDS (crystals rotating spectrometer) and PHI (simple pin hole imager) will provide opportunity to better understand the physics of solar flares by reliable measurements of soft X-ray flare spectra, its polarization and evolution.

Three separate subsystems in combination with moving/rotating elements inside poses a challenge for developers. Presented solutions will be evaluated and in case of success operation adapted to the future instruments, where similar principles will be applied.

ACKNOWLEDGEMENT

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REFERENCES

[1] Stęślicki, M., et al., „Soft x-ray solar polarimeter-spectrometer," Proc. SPIE 9441, (2014)
[2] Sylwester, J., et al., "X-ray Flare Spectra from the DIOGENESS Spectrometer and its concept applied to ChemiX on the Interhelioprobe spacecraft," Solar Physics, 290, 2, (2015)
[3] Sylwester, J., et al., "SolpeX: the soft X-ray flare polarimeter–spectrometer for ISS," Proc. IAU Symposium, 305, submitted