Polish contribution to the ATHENA Wide Field Imager

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ATHENA is a second *Large-class* mission selected by ESA in Cosmic Vision plan, with a launch foreseen in 2028. Polish scientists and engineers participate in the design and construction of the Wide Field Imager (WFI) – one of two instruments onboard of the ATHENA mission. We are responsible for the Filter Wheel Assembly (FWA) with its controller and the Power Distribution Unit (PDU). FWA is an opto-mechanical system for filter changing situated in front of the sensor, and in addition used for calibration of the whole instrument. PDU will be used to distribute power into the given instrument components. We present the preliminary design of both satellite components, which are discussed with WFI consortium.

1 Introduction

The ATHENA mission is a new generation X-ray telescope for detection of photons of energies between 0.1-12 keV with a fixed 12 m focal length (Nandra et al., 2013). It will consists of a single mirror module based on ESA's Silicon Pore Optics (SPO) technology (Willingale et al., 2013). ATHENA will have two focal plane detectors: X-ray Integral Field Unit (X-IFU, Barret et al., 2016), and Wide Field Imager (WFI, Rau et al., 2016). This paper is devoted to the second detector – an array of Si-based active pixel sensors (ASP) with fast readout of the order of 10 μs as well as a count rate capability sufficient to deal with the brightest X-ray sources in the sky. Thanks to WFI high sensitivity we will detect objects with redshifts up to ~ 2. In addition this detector is going to have a large field of view, which is crucial to study galaxy clusters.

Main science goals of the ATHENA mission are to search: interaction of galaxy clusters with intergalactic gas including the warm hot intergalactic medium (WHIM) and the distribution of the hot phase of the cosmic web, the feedback in cluster of galaxies and AGN feedback (including our Milky Way), direct monitoring of hot, ionized outflows (Różańska et al., 2016), and close environment of supermassive black holes. ATHENA will also observe many closer objects as: the Solar system, exoplanets, end-points of stellar evolution and supernova remnants.

In this paper we present contribution of Polish scientists and engineers to the design and construction of the two WFI components. We are involved in building the Filter Wheel Assembly (FWA) with its controller, and the Power Distribution Unit (PDU).

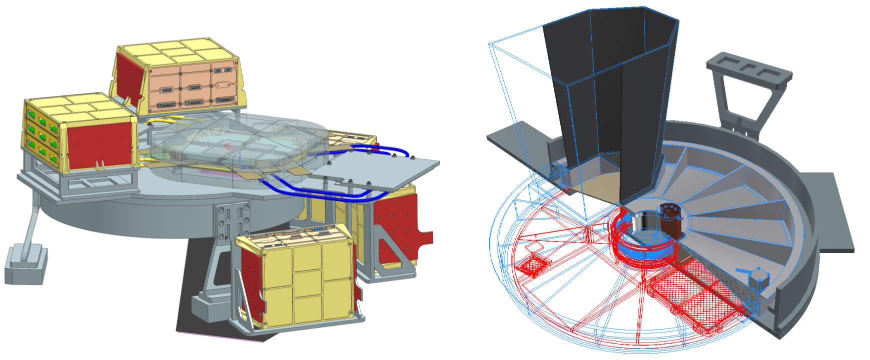

Fig. 1: Left – an overview of the WFI instrument. Right – the WFI Filter Wheel Assembly as critical part of WFI structure.

2 Filter Wheel Assembly for WFI

The filter wheel assembly (FWA) is a system which allows to change the spectral filters and to use a calibration source. Such subsystem will provide four positions, i.e. open aperture, optical blocking filter, closed position and calibration source position. The FWA will modulate the signal according to requirements and will allow to calibrate the detector. Since the camera has an extremely large detector with an aperture of $160 \times 160\,\mathrm{mm}^2$ and an additional small detector for fast measurements with an aperture of $15 \times 15\,\mathrm{mm}^2$, the aforementioned features have to be doubled. The four positions necessary for each one of two detectors (large array detector and fast detector) can be partly combined. Current WFI FWA design provides seven operational modes, which fulfill these requirements (see Fig. 1 for illustration).

2.1 WFI FWA design trade-offs, mass saving and reliability issues.

The launch environment becomes critical with respect to high loads in case of dynamic coupling if the frequencies cannot be moved far enough away from the eigenfrequencies of the instrument structure. These vibration loads are main design drivers for FWA structure and its mechanism components – bearings, stepper motor and gear. Due to the large size of the WFI FWA (wheel diameter $\sim 600\,\mathrm{mm}$) mass saving is a major issue. In order to reduce the inertia of rotating components and to provide necessary stiffness of such a large wheel, large diameter bearings mounted on hollow shaft are used. The aluminum housing and integrated front stray-light baffle shall serve as proton shield for detector. Also, parts of the WFI FWA housing would be a structural frame for the whole instrument, which increases the complexity of the design. Whole mechanism has total weight about 44 kg.

Mechanisms designed for space have to provide high reliability in vacuum and low gravity environment. The WFI FWA mechanism is designed to work for 10 years in the L2 Sun-Earth point. In order to provide uninterrupted work for this time period, design efforts were focused on using highly reliable, well known components designed for usage in Space environment. The risk of mechanism failure is reduced by introducing redundancy, like stepper motor with redundant wiring. Also the single-point of failure parts are avoided in places when it is possible: at the closed-

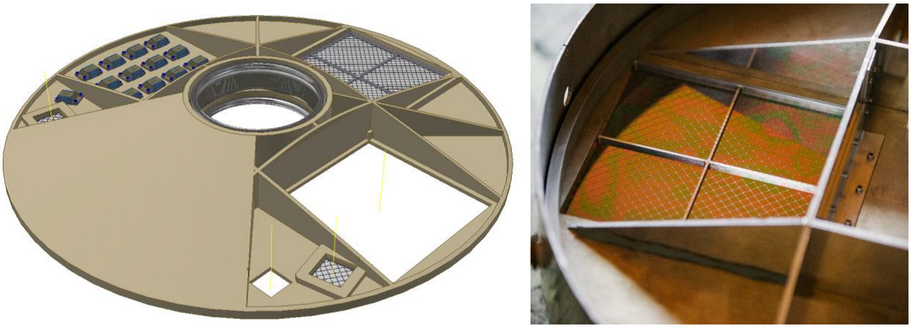

Fig. 2: Left – the Filter Wheel, which would provide all necessary operational modes. Right – optical blocking filter specimen mounted inside WFI FWA engineering model.

position the FWA would serve as *door* during lunch, providing necessary protection against possible contamination or direct acoustic waves.

2.2 WFI Filter protection from mechanical loads.

The optical blocking filters of WFI are extremely thin. Large detector array requires $170 \times 170\,\mathrm{mm}^2$ filter with thickness of $\sim 180\,\mathrm{nm}$ (Fig. 2 left panel). Such filter is vulnerable for mechanical loads and it may be damaged during the launch of ATHENA mission. The FWA has to provide necessary protection to the filters from vibration and acoustic loads. In addition, the complexity of the camera head causes that a vacuum chamber as the filter wheel housing shall be avoided. First analysis, simulations and tests indicate that the FWA can be in atmosphere during launch with localized protection of the filter, mainly with respect to acoustic load. Also, abandoning vacuum is desired due to mass savings, described in previous section.

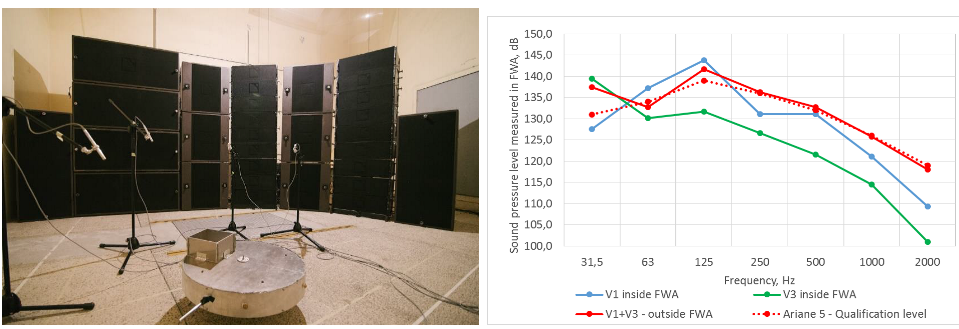

Fig. 3: Left – test stand for acoustic tests of WFI FWA. Right – results from high SPL tests using two design configurations (blue and green), and with SPL generated by Ariane 5 rocket (red).

To prove that not-using the vacuum chamber is possible, acoustic test campaign in an-echoic chamber was performed, in which several design variants of WFI FWA were tested. The most promising design configurations was later tested in the reverberation chamber, in which the filter specimen was exposed to high Sound Pressure

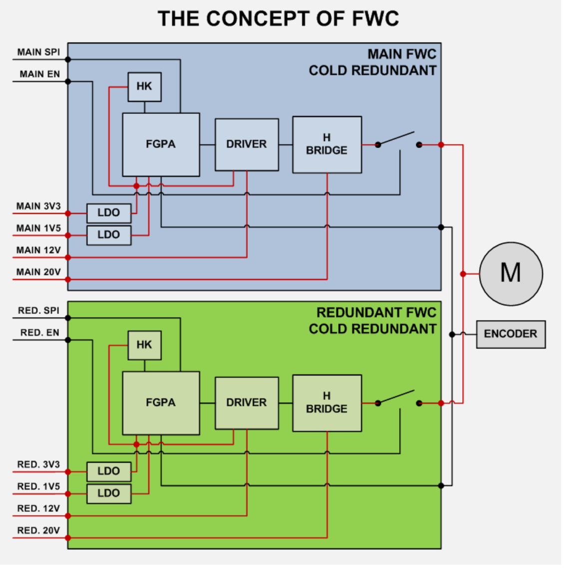

Fig. 4: Preliminary concept of the FWC for ATHENA WFI instrument

Level, according to Ariane 5 rocket Qualification Levels. The results of our tests and simulations (Fig. 3) have shown directions of changes in design of FWA, which – in principal – may be described as reducing the volume of air in which the acoustic waves can propagate. One of design variant is reducing the SPL, while another is amplifying few of bands spectrum.

2.3 Filter Wheel Controller for WFI FWA

The Filter Wheel Controller (FWC) is an electronic subsystem used to move and control the FWA of the WFI Instrument. The subsystem is connected with Instrument Control Unit (ICU), Power Distribution Unit (PDU), Motor and Encoder. The FWC is implemented as Main and Redundant blocks and shall work in cold redundancy scheme. Preliminary concept of FWC is presented if Fig. 4.

The FWC has one interface with ICU to transmit commands and data. The baseline for this interface is to use SPI (Serial Peripheral Interface). The ICU controls also an output switch via a dedicated signal. The FWC interface with PDU provides four voltages: 1V5, 3V3, 12V and 20V. The 1V5 and 3V3 lines may not have to be precisely stabilized as local LDOs (Low Drop Out regulators) can be implemented on FWC. Furthermore, the 12V and 20V lines go to Driver and H-bridge, therefore they don't need to be precisely stabilized as well (Fig. 4).

The FWC board consists from RTSX32SU FPGA (Field-Programmable Gate Array) that will serve as a local controller that steers the motor through a driver. The control of the motor is done via state machine implemented in the FPGA. The FPGA implements SPI controller and simple state machine that reads out the basic House-Keeping (HK) information like for example: motor temperature, voltages and currents on power lines. A separate state machine in the FPGA reads-out the Encoder as well. The FPGA is followed by a driver and H-bridge. The H-bridge is

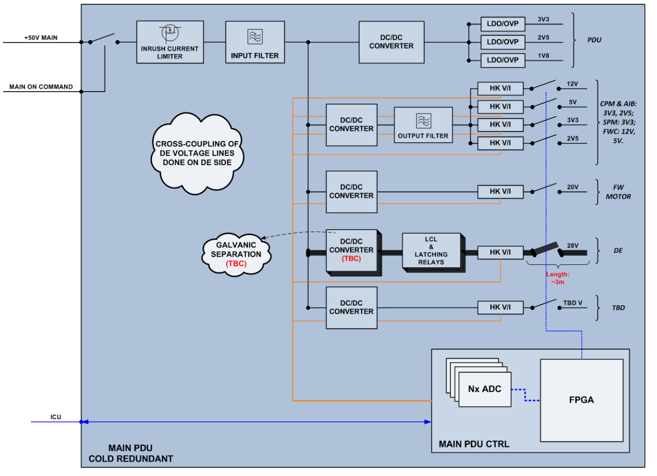

Fig. 5: Preliminary concept of the PDU for Athena WFI instrument

shown as a separate block to indicate that the finally selected motor might require bigger power that has to be dissipated or dealt with. At the end of the FWC board an output switch is located. The switch is controlled directly via ICU. The switch is used to decide whether main or redundant FWC shall be used to control the motor.

3 Power Distribution Unit for WFI

The Power Distribution unit (PDU) is a system for power distribution among all other WFI instrument subsystems. Total amount of distributed power is around 750W. The PDU is connected with spacecraft via power interface, ICU, FWC, Analog Interface Board (AIB), Detectors Electronics (DE), Science Processing Module (SPM) and other WFI subsystems if needed. The PDU is implemented as Main and Redundant blocks and shall work in cold redundancy scheme.

The PDU has two interfaces with spacecraft: Main and Redundant. It is assumed that the spacecraft power bus will use 50V as a nominal voltage. The spacecraft provides also a command signal to enable or disable the input switch. It is not decided yet, whether a status signal of input switch shall be returned to spacecraft. After the input switch the PDU implements Inrush Current Limiter, followed by Input Filer. The PDU main power bus is located after the Input Filter. Following DC/DC (Direct-Current to Direct-Current) converters are connected in parallel to the PDU main power bus: i) one converter for local supply of PDU electronics; ii) one (or more) multiple output DC/DC converter that provides the power (several voltage lines) to ICU, SPM, AIB and FWC (electronics only); iii) one DC/DC converter that provides the power for filter wheel motor; iv) five DC/DC converters that provide the power for all DE; v) one or more DC/DC converters that can provide the power for other subsystems according to requirements.

The converter that supplies the PDU electronics is followed by a set of LDOs. The LDOs assure well stabilized voltages for the local electronics and serve as overvoltage protection. The converter for ICU, SPM, AIB and FWC is followed by output filtering circuitry. The converters for DE may be followed by LCL protections if needed.

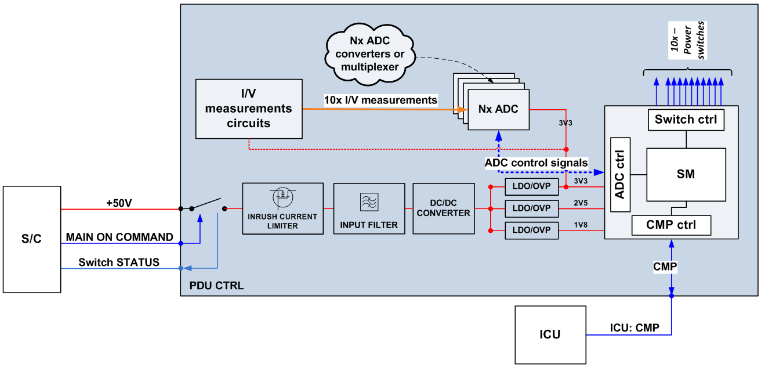

Fig. 6: Preliminary concept of the PDU Controller for ATHENA WFI instrument.

Each of the output power lines (except of those that supply PDU local electronics) contain its own output switch. Each output switch can be controlled independently from other switches. The default state of each switch is off. A command to enable or disable a given switch goes from ICU to PDU local controller. The PDU controller then sends a proper signal to switch on or off a given switch. Each of the output power line includes a HK measurement circuitry. At the moment it is assumed that the both voltage and current are measured on each output line. The HK is digitized by PDU controller and sent to ICU as digital values.

The PDU controller consists from small FPGA. The preliminary concept is presented in Fig. 6. The FPGA implements a set of state machines that i) control the output switches; ii) control a set of ADCs (Analog-to-Digital Converter) used for HK measurements; iii) control the communication with ICU and iv) control and manage the i), ii) and iii) state machines to work in proper and required way.

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